Analysen zur Glyphosatanwendung im Ackerbau –
Ertragseffekte, Anwendungsmuster und Bestimmungsfaktoren

Dissertation
zur Erlangung des Doktorgrades
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Armin Wiese
geboren in Eckernförde

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1. Referent: Herr Professor Dr. Ludwig Theuvsen
2. Korreferent: Herr Dr. Horst-Henning Steinmann

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Kapitel 1

Einleitung
1.1 Analysen zur Glyphosatanwendung im Ackerbau – Ertragseffekte, Anwendungsmuster und Bestimmungsfaktoren


Mit diesen Zahlen rückte der Wirkstoff Glyphosat in Deutschland, aber auch in der gesamten EU in den Mittelpunkt kontroverser Diskussionen, die sowohl die Frage betreffen, ob Glyphosat noch zulassungsfähig ist als auch in welchem Ausmaß eine Anwendung in Zukunft stattfinden sollte. Folgende Punkte stehen dabei im Vordergrund:

- Da die toxikologische Wirkung von Glyphosat auf Menschen kontrovers diskutiert wird, ist unklar, ob der Einsatz von Glyphosat in den EU-Staaten auch künftig erlaubt bleibt.
- Anwendungseinschränkungen sollen zukünftig in Erwägung gezogen werden, um das Ausmaß der Anwendung zu reduzieren (EC, 2018).

Diesen Forderungen werden Befürchtungen zu drastischen Auswirkungen bei einem Verbot von Glyphosat entgegengesetzt, die sich vor allem auf wirtschaftliche Einbußen beziehen. Analysen zur ökonomischen Bedeutung von Glyphosat zufolge könnte die EU bei einem Verbot von Glyphosat infolge von Ertragsverlusten von einem Nettoexport...
teur von Getreide zu einem Nettoimporteur werden bzw. es sind Deckungsbeitragsverluste je nach Kultur in Höhe von 40–70 % zu erwarten (Schmitz & Garvert, 2012; Fairclough et al., 2017). Andere Studien gehen jedoch von möglicherweise sehr geringen Ertragsverlusten aus (Steinmann et al., 2012; Böcker et al., 2017).

Für eine wissenschaftlich fundierte Diskussion über den zukünftigen Umgang mit Glyphosatherbiziden bestehen trotz breiter Diskussion noch erhebliche Wissenslücken. So fehlen Daten für ökonomische Analysen, Folgenabschätzungen für den Fall eines Glyphosatverbots, aber auch zur Ableitung von Best-Management-Praktiken (Schulte & Theuvsen, 2015). Für diese Analysen sind Daten erforderlich, aus denen Anwendungsmuster und Bestimmungsfaktoren ermittelt werden können, sowie Daten zur Ertragswirkung von Glyphosat (siehe Abb. 1).


Ein Schwerpunkt der vorliegenden Dissertation ist die Erweiterung der bereits vorhandenen Erkenntnisse zum Glyphosateinsatz auf Basis einer Datenerhebung von landwirt-

Abbildung 1. Beitrag dieser Dissertation zur Analyse von Glyphosatanwendungen im Ackerbau


1.2 Kapitelübersicht


Tabelle 1. Übersicht der Kapitel 2–6: Analysegegenstände und verwendete Methoden

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<th>Methoden</th>
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<td>Kapitel 3</td>
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<tr>
<td>Nicht-, Wenig- und Vielanwender</td>
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<tr>
<td>Kapitel 4</td>
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<tr>
<td>Vorsaat- und Stoppelbehandlung in Nord-, Süd- und Ostdeutschland</td>
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<td>Kapitel 5</td>
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<tr>
<td>Weltweite Glyphosatstudien und Glyphosat-Ertragsstudien im Nicht-GVO-Anbau</td>
<td>Bibliometrische Literaturrecherche- und Abstract-basierte Auswertung</td>
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In Kapitel 3 werden mithilfe einer Clusteranalyse Betriebstypen hinsichtlich der Glyphosat-Behandlungsflächenanteile beschrieben. Die Variablen im Datensatz wurden zunächst einer Faktorenanalyse unterzogen und dienten dann als Input-Variblen für die

In Kapitel 4 werden die Umfrageteilnehmer drei Gruppen zugeordnet: Nichtanwender (Betriebe, die im zurückliegenden Jahr kein Glyphosat eingesetzt haben), Weniganwender (Betriebe mit einer Anwendungsfläche unterhalb des Medians aller Anwendungen; das entspricht einer Anwendungsfläche von < 20 % der Ackerfläche (AF) im Betrieb); und Vielanwender (Betriebe mit einer Anwendungsfläche oberhalb des Medians aller Anwendungen; > 20 % der AF im Betrieb). Mittelwertvergleiche dienen dazu, diese Anwendergruppen hinsichtlich von ackerbaulichen und herbologischen Variablen sowie persönlichen Einschätzungen und Einstellungen auf signifikante Unterschiede hin zu untersuchen. Mittelwertvergleiche zwischen den Gruppen erfolgten mittels t-Test, Mann-Whitney-U-Test und Chi-Quadrat-Test.


1.3 Literatur


Interactions of glyphosate use with farm characteristics and cropping patterns in Central Europe

Armin Wiese, Michael Schulte, Ludwig Theuvsen & Horst-Henning Steinmann
2.1 Abstract

Background

Although glyphosate is the most widely used herbicide in the European Union, little is known about the patterns of its usage in arable farming. Therefore, a nation-wide survey of 2,026 German farmers was analyzed to obtain further knowledge about glyphosate applications in conventional European arable farming. Given its broad range of agri-environmental and farm type conditions, Germany can be regarded as a suitable study region to represent Central European farming. The growing season 2013/14 was set as a reference.

Results

Farmers that participated in the survey employ diverse patterns of glyphosate use. While 23% stated that they did not use glyphosate in the season in question, others applied glyphosate to their total arable area. However, most applications occurred on specific parts of the farm. Application patterns of oilseed rape, winter wheat, maize and sugar beet were studied in detail and U-shaped distributions of glyphosate use intensity were observed. The effects of farm type and management practices on glyphosate use patterns were mixed in the various crops.

Conclusion

Motivation for glyphosate use differs widely within the farming community. Agricultural researchers, extension services and policy makers are recommended to mitigate vulnerabilities associated with glyphosate use, such as routine spraying and practices that increase selection pressure for the evolution of glyphosate-resistant weeds.

Keywords: farm survey; glyphosate; inflated beta regression; post-harvest application; pre-sowing application; soil cultivation; weed management


2.2 Introduction

Usage of the herbicide active ingredient, glyphosate, has increased rapidly since the introduction of glyphosate-resistant crops in 1996, such that it is now the most widely used herbicide worldwide.\(^1\) However, also in European arable farming where glyphosate resistant crops have not been adopted in common agricultural practices, glyphosate has the largest share of the herbicide market. For example, in Germany, market sales data indicate a >500% increase in glyphosate usage from the early 1990s to the present, and it has been estimated that the annual application area corresponds to 30-40% of the total arable area.\(^2,3\) Similarly, survey data for the United Kingdom (UK) revealed an increase of 130% in the use of glyphosate between 1998 and 2014, and a total crop application area of 30% in 2014,\(^4,5\) while glyphosate sales in Finland tripled from 1996 to 2006\(^6\) and increased by 314% from 1992 to 2004 in Switzerland.\(^7\) Although, there are no such studies that include all of Europe, data associated with individual European countries indicate high glyphosate usage across the continent.

This extensive application of glyphosate in conventional cropping systems is associated with several factors. Firstly, when practicing reduced tillage, which increased to 26% of the arable area within the European Union (EU) in 2010,\(^8\) growers tend to increase herbicide application to minimize weed infestation. Off-season applications of glyphosate are especially favored as they effectively control a broad spectrum of annual and perennial weeds.\(^9-11\) Furthermore, glyphosate applications are used in management practices in place of mechanical cultivation approaches, such as removal of cover- and volunteer crops.\(^3,7,12\) The use of glyphosate for residue management gained in popularity due to the reduced cost of glyphosate products once its patent expired in the 1990s.\(^13-15\) While survey data from Germany and France indicate a major reliance of glyphosate applications after harvest and prior to seeding, glyphosate use in the United Kingdom involves a relatively high proportion of pre-harvest applications with an estimated annual application area of up to 40% in wheat and 75% in oilseed rape, respectively.\(^3,16,17\) Collectively, these studies indicate that glyphosate usage is firmly established in European arable farming systems.

However, this strong dependence on glyphosate has led to public and scientific debate about whether the widespread use of a single herbicide is sustainable with respect to
areas of public interest, such as human health, ecosystem services and agricultural system stability.\textsuperscript{18} While human and eco-toxicological effects of glyphosate have been extensively studied, little is known about actual application patterns of glyphosate in European arable farming. Such information would allow a more effective analysis of factors that are influenced by pesticides, such as farming system economies and landscape effects, and would be of great value for a rationale European pesticide policy.\textsuperscript{19} Furthermore, preventing the evolution of weed populations that are resistant to glyphosate requires knowledge of cropping and application practices. Recent surveys revealed glyphosate resistance in biotypes of five weed species in Europe,\textsuperscript{20} which suggests that there is an urgent need to manage preventively the selection pressure on European weed populations.

The first studies of glyphosate usage in European arable farms were based on observations or surveys with low sample sizes.\textsuperscript{2,16,17} For the UK, quite detailed usage data for glyphosate are available. However, glyphosate use data could generally not be provided for different applications.\textsuperscript{15} Furthermore, knowledge is lacking about the extent of glyphosate usage on farms to determine the proportions of those that have high, low or no preference for the herbicide. Moreover, the relationship between glyphosate usage, characteristics of farm types and farming practices is required to better understand the factors that influence glyphosate use. To date, only a few studies have used an analytical approach to address such questions. Andert et al.\textsuperscript{12} surveyed 60 farms in Northern Germany and found that glyphosate use is mainly influenced by tillage, farm type, farm size and workforce. The authors also observed a regional gradient when it was shown that explanatory variables of glyphosate usage in smaller farms in the western regions differed from larger farms in the eastern regions.\textsuperscript{12} Due to diverse structures in farm size and agri-environmental conditions, Germany spans a range of geographic and climatic conditions across Western- and Eastern-Central Europe, and so represents a suitable study region to encompass diversity within Central European farming systems.

In this current study, we assessed the use of glyphosate on specific crops on German farms in 2013/2014 and the results are discussed in the context of farming systems and the motivation for glyphosate usage within the farming community.
2.3 Data and Analysis

2.3.1 Study design

We developed a questionnaire-based survey to elicit details about glyphosate use and its interactions with cropping patterns in German arable farming. The conception as well as the final version of the questionnaire were discussed and pretested with a group of experts and eight respondents. The survey was conducted from November 2014 to January 2015 and was targeted only to conventional farms. The questionnaire (see supplementary material) could be answered by mail or online. The web address of the survey was published in several regional and transregional farming magazines. Email lists of official plant protection agencies of the German federal states, farm consultancy services and farmers’ associations were also used to advertise the survey. For the postal responses, 1,000 questionnaires were sent to farms known to participate in young farmer education, based on information provided by the chambers of agriculture of the respective federal states. A total of 8,023 farmers either clicked on a survey link or received a questionnaire in the mail. After data cleaning and plausibility considerations, a convenience sample of 2,026 farms was used for further analysis. As shown in Figure 1, collectively the respondents covered the whole of Germany. The lower number of respondents from eastern areas can be explained by a lower density of farming operations, reflecting larger farm sizes in this region.

The survey contained 38 questionnaire constructs regarding operational aspects of the farm and details of glyphosate use, as well as subject-specific and personal opinions. The participants were asked to treat the growing season 2013/2014 as a reference. On average, the respondents were 47 years old and 79% were full-time farmers. The largest share of participants managed cash crop farms (49%), while another large share (26.8%) managed livestock farms. Of the respondents, 21.5% were not specialized in a particular branch of farming and a small percentage (2.7%) either managed permanent crop farms or other farming operations. The average farm size of our sample was 279.4 ha (median: 95 ha) and on average, 31.8% of the arable area was ploughed, which contrasts with the national average farm size (58.6 ha)\(^2\) and the nation-wide plough-cultivated arable land (61%).\(^2\) However, although the sample used in this study contains above-average farms in terms of hectarage and use of reduced tillage operations, we considered the data to be
valuable for further analysis since we included both professional and future-oriented farms.

![Survey data](image)

**Figure 1.** Distribution of German farms that participated in the survey. The diameter of the symbols corresponds to the total number of participants in each county. The insert map shows the geographical location of the main map.

### 2.3.2 Glyphosate use

Pesticide use is typically analyzed based on the amount of active ingredient per hectare alone, or in combination with the treated area. However, in the case of glyphosate, the amount per hectare is generally defined for specific uses such as pre-harvest, post-harvest and pre-sowing. Since we were less interested in dosages, but rather in specifying allocation of glyphosate to fields and agronomic situations, we focused on farm ra-
ther than on field data. Therefore, the survey participants were asked for the hectare per crop treated with glyphosate in the uses mentioned above.

Uses of glyphosate were categorized as follows: pre-sowing (period beginning about three weeks before sowing of the main crop), pre-harvest (desiccation) and post-harvest (period beginning directly after threshing crops have been harvested, with the overall post-harvest period lasting until about three weeks before the next crop is sown). For a better agronomic understanding, we attributed post-harvest applications to the preceding crop, since stubble applications are usually planned on the basis of residue management.

On average, farmers used glyphosate based herbicides predominantly post-harvest (22.2% of arable area; Table 1). Almost 13% of the arable area received glyphosate before sowing, while glyphosate was rarely used before harvest (2.2%).

**Table 1.** Crop area for the EU and Germany in 2013 for important crops (proportion of total arable area, rel.) as well as glyphosate use in Germany (proportion of crop area treated with glyphosate, rel.) (n=2,026, growing season 2013/2014)

<table>
<thead>
<tr>
<th>Crop</th>
<th>EU (rel.)</th>
<th>Germany (rel.)</th>
<th>Glyphosate uses in Germany*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-sowing</td>
<td>Post-harvest</td>
<td>Pre-Harvest</td>
</tr>
<tr>
<td>Winter wheat</td>
<td>0.21</td>
<td>0.26</td>
<td>0.13 0.22 0.02</td>
</tr>
<tr>
<td>Maize</td>
<td>0.15</td>
<td>0.21</td>
<td>0.11 0.18 0.02</td>
</tr>
<tr>
<td>Oilseed rape</td>
<td>0.06</td>
<td>0.12</td>
<td>0.09 0.61 0.02</td>
</tr>
<tr>
<td>Winter barley</td>
<td>0.05</td>
<td>0.10</td>
<td>0.10 0.16 0.07</td>
</tr>
<tr>
<td>Legumes</td>
<td>0.04**</td>
<td>0.02</td>
<td>0.15 0.10 0.02</td>
</tr>
<tr>
<td>Winter rye</td>
<td>0.03</td>
<td>0.07</td>
<td>0.04 0.13 0.04</td>
</tr>
<tr>
<td>Sugar beet</td>
<td>0.02</td>
<td>0.03</td>
<td>0.47 0.01*** -</td>
</tr>
</tbody>
</table>

* Own data. ** EU-Crop area for legumes in 2013 not available, value refers to 2014. *** Post-harvest uses of glyphosate after sugar beet and maize are uncommon and so in this case the information provided by the farmers might be erroneous.
2.3.3 Variables

For an in-depth analysis of glyphosate applications we used nine predictor variables (Table 2) related to whole farm management, which are expressed on four different scales. The variable “Cash crop” depends on the key economic activity being the production of cash crops or not and so has a binary response. The variable “Farm size” corresponds to the land available for arable farming. We also used three variables that assess the use of different management practices on the whole arable land. Questions were also asked with pre-formulated statements, with the possibility of answering on a five-point Likert scale from -2 (completely disagree) to 2 (completely agree). These variables were used as proxies to describe farmers’ attitudes towards organization of farm work, the use of cover crops, situation of soil erosion, and herbicide resistance. The latter proxy was designed to gain insights into motivations for using glyphosate as a tool to reduce selection pressure on weed populations resulting from the use of other herbicides, rather than assumptions or proven occurrences of resistant weed populations. Farmers have hardly any precise data regarding the status of resistance in their fields.

Table 2. Predictor variables in the analysis

<table>
<thead>
<tr>
<th>Variable</th>
<th>Descriptions</th>
<th>Range</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cash crop</td>
<td>Dummy variable defined as unity if farm is a Cash crop farm and zero if otherwise</td>
<td>(0-1)</td>
<td>0.49</td>
</tr>
<tr>
<td>Farm size</td>
<td>Arable land (ha)</td>
<td>(0.6-3810)</td>
<td>258.1</td>
</tr>
<tr>
<td>Plough</td>
<td>Share of ploughed area on total arable land (rel.)</td>
<td>(0-1)</td>
<td>0.32</td>
</tr>
<tr>
<td>Winter crop</td>
<td>Share of arable area allocated to winter crops (rel.)</td>
<td>(0-1)</td>
<td>0.72</td>
</tr>
<tr>
<td>Crop share</td>
<td>Share of arable area allocated to a crop (rel.)*</td>
<td>(0-1)</td>
<td>-</td>
</tr>
<tr>
<td>Working time</td>
<td>&quot;Rising costs for labor and machinery lead to higher use of glyphosate on my farm&quot;***</td>
<td>(-2…+2)</td>
<td>-0.65</td>
</tr>
<tr>
<td>Cover crop</td>
<td>&quot;The cultivation and removal of cover crops is facilitated by glyphosate&quot; **</td>
<td>(-2…+2)</td>
<td>-0.25</td>
</tr>
<tr>
<td>Erosion</td>
<td>&quot;The sensitivity of the soil to erosion affects the method of farming&quot; **</td>
<td>(-2…+2)</td>
<td>-0.14</td>
</tr>
<tr>
<td>Resistance</td>
<td>&quot;I apply glyphosate to avoid herbicide resistance in arable farming&quot; **</td>
<td>(-2…+2)</td>
<td>0.01</td>
</tr>
</tbody>
</table>

*Refers to the crop under analysis. E.g. in the case of oilseed rape: the share of oilseed rape within the crop portfolio. **Five-point Likert scale from -2 = completely disagree to 2 = completely agree. Relative values are projected onto total arable land.

Using these predictor variables, we analyzed data related to glyphosate applications on four crops of major importance, in terms of land use and economy. Winter wheat, win-
ter oilseed rape and maize are the crops with the highest acreage in European and German arable farming (Table 1). Maize is cultivated in Germany most notably as whole crop silage, grain maize and as a substrate for the production of biogas. In our analysis we did not make a distinction between these uses as they are not associated with differing cropping practices. Sugar beet was also chosen as a spring crop as while the area in which it is cultivated is relatively moderate, it is highly profitable and vulnerable to weeds and so is typically subject to intensive weed control operations. Table 3 shows the mean values of the selected predictor variables regarding growers of the single crops.

Table 3. Mean values of the predictor variables regarding the selected crops

<table>
<thead>
<tr>
<th></th>
<th>Oilseed rape (n=1,142)</th>
<th>Winter wheat (n=1,684)</th>
<th>Sugar beet (n=571)</th>
<th>Maize (n=1,193)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cash crop</td>
<td>0.60</td>
<td>0.52</td>
<td>0.71</td>
<td>0.37</td>
</tr>
<tr>
<td>Plough (rel.)</td>
<td>0.29</td>
<td>0.31</td>
<td>0.27</td>
<td>0.32</td>
</tr>
<tr>
<td>Farm size (ha)</td>
<td>371</td>
<td>280</td>
<td>392</td>
<td>284</td>
</tr>
<tr>
<td>Working time*</td>
<td>-0.56</td>
<td>-0.66</td>
<td>-0.62</td>
<td>-0.70</td>
</tr>
<tr>
<td>Winter crop (rel.)</td>
<td>0.76</td>
<td>0.73</td>
<td>0.72</td>
<td>0.67</td>
</tr>
<tr>
<td>Crop share (rel.)**</td>
<td>0.21</td>
<td>0.34</td>
<td>0.07</td>
<td>0.20</td>
</tr>
<tr>
<td>Cover Crop*</td>
<td>-0.14</td>
<td>-0.21</td>
<td>0.16</td>
<td>-0.15</td>
</tr>
<tr>
<td>Erosion*</td>
<td>-0.09</td>
<td>-0.1</td>
<td>0.08</td>
<td>-0.03</td>
</tr>
<tr>
<td>Resistance*</td>
<td>0.21</td>
<td>0.04</td>
<td>0.11</td>
<td>-0.07</td>
</tr>
</tbody>
</table>

*Five-point Likert scale from -2 = completely disagree to 2 = completely agree. Statements see in Tab. 2. **Refers to the crop under analysis. E.g. in case of oilseed rape: the share of oilseed rape within the crop portfolio. Relative values are projected onto total arable land.

2.3.4 Statistical analysis

Glyphosate usage related to crop specific applications and for the total arable area treated with glyphosate were first visualized using histogram plots (Fig. 3). The latter analysis corresponded to the sum of the farm specific single applications to glyphosate application areas. However, some farmers did not provide sufficient information regarding all applications and so for this analysis the number of full data-sets was reduced from the original 2,026 to 1,726.
To investigate the relationship between the predictor variables and crop specific glyphosate applications, we chose a regression model that met the unique characteristics of the respective glyphosate use variables. The frequency distributions of these variables are U-shaped, such that structural zeros and ones are abundant. A ‘0’ indicates that a farmer did not use glyphosate in the reference period, whereas a farmer with a value of ‘1’ used glyphosate over the entire crop area. Intermediate values characterize farmers that employed field- or site- specific use of glyphosate. The use of an ordinary least squares regression (OLS) is not appropriate for these variables. Due to the bounded property and non-normality of fractional variables, the underlying assumptions of an OLS are violated. For modeling proportions, recent statistics literature recommends a beta regression, a Tobit model or a fractional logit model. However, these models have limitations: the beta regression does not include the extreme values (0 and 1). Transforming these values to fall into the considered range between 0 and 1 could solve this problem, as suggested by Smithson and Verkuilen. Nevertheless, if 0s and 1s exist well beyond the continuous proportion of the distribution, a truncation would add mass at the tail ends of the distribution, as well as skewing the central measures.

Tobit and fractional logit models allow for values at the end of the range, but one-part models ignore important information associated with U-shaped variables. Confirming this, Ramalho et al. purported doubt about constant effects of predictor variables on fractional response variables since the peak values are likely to represent distinct processes. Therefore, Ospina and Ferrari presented a model that was termed a zero-and-one inflated beta regression; an extension of the beta regression already mentioned. This model can be defined as a mixture of a continuous beta distribution for the range $0<y<1$ and a Bernoulli distribution, giving non-negative probabilities to 0 and 1. Figure 2 illustrates the concept of this model. The beta regression is represented by the $\mu$-parameter. Part of the beta regression is also the variance parameter $\sigma$ (for fixed $\mu$, the larger the value of $\sigma$, the smaller the variance of $y$; not shown in Figure 2). The intermediate part is discriminated from the endpoints (0 and 1) by means of the $\nu$- and $\tau$ –parameter, which are related to the probability of having a value of zero and one, respectively, and not a value between zero and one.
Zero-and-one inflated beta regressions have recently been used in research studies in a number of different scientific fields.\textsuperscript{34,35} The analysis was carried out with generalized additive models of location scale and shape (GAMLSS) using R software and the packages ‘gamlss’ as well as ‘gamlss.dist’ for different distributions as the beta inflated.\textsuperscript{36-38} In general, we followed the rule of thumb for logistic regressions (\(\nu\)- and \(\tau\)- parameter) of having at least 10 events per predictor variable to avoid biases of the regression coefficients.\textsuperscript{39} Vittinghoff and McChulloch\textsuperscript{40} introduced a relaxation of this rule, arguing that biases are uncommon even with 5 events per variable. To enhance the expressiveness of the analysis, we used a number of predictors that can satisfactorily explain glyphosate usage, while keeping potential biases to a low level. We made use of this relaxation of the rule of thumb for exactly three equations that still have \(\sim\)6 events per variable (winter wheat \(\tau\) equation; Section 3.2) and \(\sim\)9 events per variable (sugar beet \(\tau\)- and \(\nu\)- equation; Section 3.2). Due to a low number of observations for the beta-part within the frequency distribution of glyphosate use in sugar beet, we reduced the numbers of predictors for this regression from nine to eight.

Since this model is non-linear, a usual \(R^2\) value is not applicable. We therefore applied the Nagelkerke Pseudo-\(R^2\) measure.\textsuperscript{41} The value it typically produces is considered to be higher than an equivalent \(R^2\) value for linear models. A likelihood ratio test was performed to determine whether the model differed significantly from the null model that

\textbf{Figure 2.} Explanation of the essential equations of the zero-and-one-inflated beta regression with respect to a typical glyphosate frequency distribution. \(p_0\) and \(p_1\) are the probabilities of \(y=0\) and \(y=1\), respectively. \(\mu\) is the expected value of \(Y\) given \(0<Y<1\). (Source: Authors’ illustration)
comprised only the intercept. No problems were identified with multicollinearity: the variance inflation factors (VIFs) were analyzed using an OLS with the respective dependent and independent variables (max VIF maize= 2.5; oilseed rape = 1.5; winter wheat = 1.5; sugar beet = 1.4). Due to missing values of the predictor variables, we omitted the following numbers of observations for each crop: 14 (oilseed rape), 23 (winter wheat), 4 (sugar beet) and 19 (maize).

2.4 Results

2.4.1 Descriptive results

2.4.1.1 Frequency distribution of overall glyphosate use

Figure 3 shows the overall distribution pattern of glyphosate application area, derived from adding up all the farm-specific values (Fig. 3). We identified 23% of farmers as non-users of glyphosate and the distribution was positively skewed. The tail of the distribution exceeded 1; meaning that to some extent glyphosate was applied on the whole arable area and some fields also received a double application in a given year.

![Figure 3](image)

*Figure 3. Proportion of overall arable area treated with glyphosate (rel.) (sum of pre-/post-harvest, and pre-sowing uses, n=1726, growing season 2013/2014)*
2.4.1.2 Frequency distributions of crop specific glyphosate use

Usage patterns differed between crops and types of uses (Figure 4). All frequency distributions were characterized by three glyphosate-user groups: a high number of non-users ranged from 51-92%, depending on the crop. A proportion of farmers with a specific use level between 0-100% were considered to be site- or field- specific users. Some farmers applied glyphosate to 100% of the respective crop and these were considered to be intensive users.

Frequency distributions with masses of observations of both 0 and 1 were apparent for the post-harvest applications after oilseed rape and pre-sowing applications before sugar beet. In our data set, 30.9% and 32.4% of all oilseed rape and sugar beet growers, respectively, used glyphosate on 100% of their respective cropping area, while 12.2% of the maize farmers were intensive users. The proportions of specific and intensive users related to pre-sowing applications of oilseed rape were nearly equal, whereas for both winter wheat applications (pre-sowing and post-harvest) there were more specific users than intensive-users.

Within the group of specific users, variations were seen in the proportion of the crop area on which glyphosate was applied. For the pre-sowing application with sugar beet, the specific users tended to spray higher percentages of their area, whereas for post-harvest use with winter wheat the specific users were predominantly allocated to the left boundary of the distribution. For the other uses, specific use patterns were almost evenly distributed.
Figure 4. Frequency distributions of six glyphosate uses. Axis breaks between 0.13 and 0.25. (share of non-users, share of specific users, share of intensive users): (a) pre-sowing sugar beet (0.56, 0.12, 0.32), (b) pre-sowing maize (0.69, 0.19, 0.12), (c) pre-sowing winter wheat (0.86, 0.11, 0.05), (d) post-harvest winter wheat (0.74, 0.23, 0.03), (e) pre-sowing oilseed rape (0.92, 0.04, 0.04), (f) post-harvest oilseed rape (0.51, 0.19, 0.31)
2.4.2 Regression analysis

The data associated with four glyphosate uses were subjected to a regression analysis. The mean values of the predictor variables regarding the user-groups are shown in Table 4 and regression coefficients of the four parts of the regressions in Table 5. We observed that the tested variables had substantially different effects on the single application patterns.

**Table 4.1 Mean values of the predictor variables for user-groups: (a) Non-users, (b) specific users, (c) intensive users**

<table>
<thead>
<tr>
<th>User-group</th>
<th>Oilseed rape</th>
<th>Winter wheat</th>
</tr>
</thead>
<tbody>
<tr>
<td>n=</td>
<td>577</td>
<td>1,253</td>
</tr>
<tr>
<td>Cash crop</td>
<td>0.55</td>
<td>0.48</td>
</tr>
<tr>
<td>Plough (rel.)</td>
<td>0.33</td>
<td>0.38</td>
</tr>
<tr>
<td>Farm size (ha)</td>
<td>218</td>
<td>246</td>
</tr>
<tr>
<td>Working time*</td>
<td>-0.71</td>
<td>-0.67</td>
</tr>
<tr>
<td>Winter crop (rel.)</td>
<td>0.76</td>
<td>0.73</td>
</tr>
<tr>
<td>Crop share (rel.)**</td>
<td>0.21</td>
<td>0.31</td>
</tr>
<tr>
<td>Cover Crop*</td>
<td>-0.39</td>
<td>-0.26</td>
</tr>
<tr>
<td>Erosion*</td>
<td>-0.26</td>
<td>-0.12</td>
</tr>
<tr>
<td>Resistance*</td>
<td>-0.08</td>
<td>-0.05</td>
</tr>
</tbody>
</table>

*Five-point Likert scale from -2 = completely disagree to 2 = completely agree. Statements see in Tab. 2. **Refers to the crop under analysis. E.g. in case of oilseed rape: the share of oilseed rape within the crop portfolio. Relative values are projected onto total arable land.

2.4.2.1 Post-harvest applications in oilseed rape

The estimated coefficients for farm size were significant for the equations for ν, μ and τ. Nevertheless, the effects of the variables were not constant over the entire range of the dependent variables. The ν-equation showed that increasing farm size correlates with a higher probability of a farm having a glyphosate use between zero and one rather than a value of zero (non-use of glyphosate). The effect on the continuous part was positive (μ-equation). Thus, specific glyphosate usage increased with increasing farm size. In con-
contrast, the τ-equation indicated, larger farms were more associated with specific than with intensive use of glyphosate. The proportion of ploughed land on a farm was not significant in any of the equations. The ν-equation also showed that specific users, rather than non-users, were linked to resistance issues and the demand for saving working time. Furthermore, operation of a cash crop farm was significantly correlated with glyphosate use on the total area of oilseed rape after harvest rather than operating at a specific use level. The amount of oilseed rape in the farm’s crop portfolio had little influence on post-harvest applications of glyphosate.

Table 4.2. Mean values of the predictor variables for user-groups: (a) Non-users, (b) specific users, (c) intensive users

<table>
<thead>
<tr>
<th>User-group</th>
<th>Pre-sowing</th>
<th></th>
<th>Maize</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sugar beet</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>b</td>
<td>c</td>
<td></td>
<td></td>
</tr>
<tr>
<td>n=</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cash crop</td>
<td>0.64</td>
<td>0.88</td>
<td>0.78</td>
<td>0.37</td>
</tr>
<tr>
<td>Plough (rel.)</td>
<td>0.29</td>
<td>0.23</td>
<td>0.23</td>
<td>0.38</td>
</tr>
<tr>
<td>Farm size (ha)</td>
<td>452</td>
<td>272</td>
<td>334</td>
<td>283</td>
</tr>
<tr>
<td>Working time*</td>
<td>-0.68</td>
<td>-0.58</td>
<td>-0.52</td>
<td>-0.75</td>
</tr>
<tr>
<td>Winter crop (rel.)</td>
<td>0.74</td>
<td>0.64</td>
<td>0.71</td>
<td>0.69</td>
</tr>
<tr>
<td>Crop share (rel.)**</td>
<td>0.05</td>
<td>0.13</td>
<td>0.09</td>
<td>0.18</td>
</tr>
<tr>
<td>Cover Crop*</td>
<td>-0.4</td>
<td>0.41</td>
<td>1.02</td>
<td>-0.53</td>
</tr>
<tr>
<td>Erosion*</td>
<td>-0.21</td>
<td>0.1</td>
<td>0.58</td>
<td>-0.15</td>
</tr>
<tr>
<td>Resistance*</td>
<td>-0.14</td>
<td>0.29</td>
<td>0.48</td>
<td>-0.24</td>
</tr>
</tbody>
</table>

*Five-point Likert scale from -2 = completely disagree to 2 = completely agree. Statements see in Tab. 2. **Refers to the crop under analysis. E.g. in case of oilseed rape: the share of oilseed rape within the crop portfolio. Relative values are projected onto total arable land.

2.4.2.2 Post-harvest applications in winter wheat

Different patterns were evident for post-harvest use of glyphosate after winter wheat. The resistance variable was significant in the ν as well as in the μ-equation. The overall intention of a farmer to prevent herbicide resistance by using glyphosate corresponded with increased glyphosate use after harvesting winter wheat. An increase in farm size was associated with specific use of glyphosate rather than non-use, but did not correlate
with the specific use intensity of glyphosate (µ-equation). The share of ploughing had a significant influence in two equations: the specific use intensity was slightly greater on farms with less ploughing, and intensive use was also more likely on farms with a lower level of ploughing. The effect of the amount of winter wheat in the whole crop portfolio relating to glyphosate use was mixed. A higher share of winter wheat was associated with a greater likelihood of specific glyphosate use (ν- and τ-equation). Moreover, specific glyphosate use was decreased in farms with higher shares of winter wheat.

2.4.2.3 Pre-sowing applications in sugar beet

Glyphosate use before the cultivation of sugar beet was strongly linked to management of residue from the preceding cover crops. For this variable the v- and the τ-equation both had significant estimators. The likelihood of specific rather than non-use of glyphosate before sugar beet sowing was significantly decreased in cases when there were higher proportions of winter crops in the crop portfolio, while the likelihood of glyphosate use over the total sugar beet area was significantly increased. The share of ploughing variable was not strongly linked to pre-sowing glyphosate use in sugar beet, while the cash crop variable had significant influence in both in the v- and the τ-equation with a minus sign, indicating that cash crop farmers are more likely to be specific glyphosate users than non- or intensive users.

2.4.2.4 Pre-sowing applications in maize

Similar to pre-sowing applications in sugar beet, glyphosate usage with maize increased significantly with increases in the cover crop variable (v- and µ-equation). Furthermore, all maize equations indicated that significant increases in glyphosate use were associated with a lower share of ploughing on a farm level. Cash crop farmers had a greater likelihood of non-use of glyphosate than specific use and were more likely to use glyphosate on the whole maize area, rather than specifically. Moreover, a larger farm size significantly correlated with glyphosate use at a specific use level rather than operating on the total maize area.
### Table 5. Parameter coefficients from the zero-and-one inflated beta models

<table>
<thead>
<tr>
<th></th>
<th>Post-harvest</th>
<th>Pre-sowing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Oilseed rape</td>
<td>Winter wheat</td>
</tr>
<tr>
<td>Zero inflation equation (ν)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cash crop</td>
<td>0.197</td>
<td>-0.337 **</td>
</tr>
<tr>
<td>Plough</td>
<td>-0.218</td>
<td>0.184</td>
</tr>
<tr>
<td>Farm size</td>
<td>-1.303 ***</td>
<td>-0.591 ***</td>
</tr>
<tr>
<td>Save working time</td>
<td>-0.218 **</td>
<td>-0.003</td>
</tr>
<tr>
<td>Winter crop</td>
<td>-0.904</td>
<td>2.666 ***</td>
</tr>
<tr>
<td>Crop share</td>
<td>-1.194</td>
<td>-4.014 ***</td>
</tr>
<tr>
<td>Cover crop</td>
<td>-0.021</td>
<td>0.066</td>
</tr>
<tr>
<td>Erosion</td>
<td>-0.043</td>
<td>-0.037</td>
</tr>
<tr>
<td>Resistance</td>
<td>-0.140 **</td>
<td>-0.153 ***</td>
</tr>
<tr>
<td>Mean equation (µ)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cash crop</td>
<td>-0.029</td>
<td>0.148</td>
</tr>
<tr>
<td>Plough</td>
<td>-0.214</td>
<td>-0.291 *</td>
</tr>
<tr>
<td>Farm size</td>
<td>0.489 ***</td>
<td>-0.026</td>
</tr>
<tr>
<td>Save working time</td>
<td>0.043</td>
<td>-0.014</td>
</tr>
<tr>
<td>Winter crop</td>
<td>1.333 *</td>
<td>0.424</td>
</tr>
<tr>
<td>Crop share</td>
<td>-2.214 *</td>
<td>-2.368 ***</td>
</tr>
<tr>
<td>Cover crop</td>
<td>0.056</td>
<td>-0.060</td>
</tr>
<tr>
<td>Erosion</td>
<td>0.008</td>
<td>0.079 *</td>
</tr>
<tr>
<td>Resistance</td>
<td>-0.001</td>
<td>0.141 ***</td>
</tr>
<tr>
<td>Variance equation (σ)</td>
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<td></td>
</tr>
<tr>
<td>Cash Crop</td>
<td>-0.006</td>
<td>0.061</td>
</tr>
<tr>
<td>Plough</td>
<td>-0.132</td>
<td>-0.197</td>
</tr>
<tr>
<td>Farm size</td>
<td>0.036</td>
<td>-0.016</td>
</tr>
<tr>
<td>Save working time</td>
<td>0.089</td>
<td>-0.091 *</td>
</tr>
<tr>
<td>Winter crop</td>
<td>0.964</td>
<td>0.323</td>
</tr>
<tr>
<td>Crop share</td>
<td>0.222</td>
<td>-0.564</td>
</tr>
<tr>
<td>Cover crop</td>
<td>0.028</td>
<td>-0.061</td>
</tr>
<tr>
<td>Erosion</td>
<td>-0.064</td>
<td>0.092 **</td>
</tr>
<tr>
<td>Resistance</td>
<td>-0.057</td>
<td>0.074 *</td>
</tr>
<tr>
<td>One inflation equation (τ)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cash crop</td>
<td>0.699 ***</td>
<td>0.541</td>
</tr>
<tr>
<td>Plough</td>
<td>-0.410</td>
<td>-1.390 ***</td>
</tr>
<tr>
<td>Farm size</td>
<td>-0.459 ***</td>
<td>-0.297</td>
</tr>
<tr>
<td>Save working time</td>
<td>-0.007</td>
<td>0.019</td>
</tr>
<tr>
<td>Winter crop</td>
<td>-1.079</td>
<td>0.814</td>
</tr>
<tr>
<td>Crop share</td>
<td>-0.593</td>
<td>-5.710 ***</td>
</tr>
<tr>
<td>Cover crop</td>
<td>0.124 *</td>
<td>0.096</td>
</tr>
<tr>
<td>Erosion</td>
<td>0.096</td>
<td>-0.170</td>
</tr>
<tr>
<td>Resistance</td>
<td>0.066</td>
<td>-0.074</td>
</tr>
<tr>
<td>Likelihood ratio test</td>
<td>233.921 ***</td>
<td>231.924 ***</td>
</tr>
<tr>
<td>AIC</td>
<td>2132.955</td>
<td>1912.148</td>
</tr>
<tr>
<td>Observations</td>
<td>1,128</td>
<td>1,661</td>
</tr>
<tr>
<td>Nagelkerke R²</td>
<td>0.22</td>
<td>0.18</td>
</tr>
</tbody>
</table>

*** Significant at 1% level. ** Significant at 5% level. * Significant at 10% level. AIC= Akaike Information Criterion. The coefficients are presented in log form for the equations for ν and τ and in logit form for the equations for µ and σ. We note that the variables are expressed on four different scales and were not standardized, since standardization would result in misleading values. To minimize issues of the positive-skewed distribution of the variable “Farm size”, a logarithmic transformation was conducted.
2.5 Discussion

The study concentrated on conventional farmers, so none of the patterns could be attributed to organic farming. Within the group of conventional farmers, patterns of glyphosate use were highly diverse, reflecting different farming practices, as discussed later, but differences in use might also be attributed to personal attitudes towards glyphosate usage. Our survey included questions regarding those personal attitudes. As a result, many farmers stated the urgent necessity of having glyphosate, whereas others raised concerns over the recent intensive reliance on its use.42 The farmers’ community seems to have extremely mixed opinions about intensive glyphosate use.

2.5.1 Patterns of glyphosate use

The nature of the glyphosate use variables (i.e. the numbers of observations at zero and one) led us to use zero-and-one-inflated beta regression models. This statistical approach allowed us to distinguish between farmers with zero or overall glyphosate use, from those with an intermediate use level. The majority of the predictors are not constant over the entire range of the dependent variables. We therefore consider that the chosen model offers an optimal view of the glyphosate use variables.

Glyphosate use patterns have been reported to differ widely between countries, regions and different uses,2,3,43 and in this study we found evidence that they also vary substantially between crops and farms. Although a high proportion of farmers operate without glyphosate in a given year, many use glyphosate on a high proportion of their arable area. We also identified farms with an application area up to twice as large as their farm size: the farmers at these locations clearly rely heavily on glyphosate and probably tend towards routine applications.

While selective herbicides are rarely applied site- or field- specifically, patterns of glyphosate use are different. Since we did not have access to field specific data, it remains uncertain whether a specific user applied glyphosate to specific sites or fields. However, a large proportion of applications after winter wheat are used within a range of >0-10% of arable farm area. This may be seen as evidence for site-specific use of glyphosate, but also for use on only a few of the farm’s fields. Nevertheless, quite a
large proportion of maize, sugar beet and oilseed rape growers were identified as intensive users, with a 100% use level.

2.5.2 Tillage regime

Most European arable farmers rely on ploughing as the major soil cultivation technique, but reduced tillage has gained growing importance. Reduced tillage is implemented in various ways, with some farmers relying entirely on non-inversion tillage. Often, farmers operate both ploughing and reduced tillage on their farms, depending on the site and other conditions, such as weather or specific crop needs. The variable “share of ploughed area per farm” was therefore used as a proxy to describe the overall soil cultivation management system on a farm level more easily. The variable “erosion”, which was extracted from a qualitative question, gave only poor explanatory gain for the models, and it is not clear whether prevention of erosion is the major driver for reduced tillage, or whether the motivation for reduced tillage is primarily to reduce labor costs and fuel.

The share of ploughing is inversely related to the share of reduced tillage with cultivators or rotary hoes. Direct seeding does not play a role in the study region. Although this share does not provide information about the use of the plough on specific fields related to the selected crops, we observed a trend of a higher glyphosate use on farms with a higher share of reduced tillage. Studies indicate that all herbicide use, not just that of glyphosate, is more intensive on farms with reduced tillage. A larger amount of herbicides is necessary to control increasing weed pressure. Perennial weeds in particular cause severe problems in reduced tillage systems and are controlled with glyphosate. Additionally, a previously reported cluster analysis, based on the data presented here, showed that farm clusters with a focus on reduced tillage have higher shares of glyphosate use in total. Nevertheless, in terms of the selected crop specific applications, the effect of the plough variable varied substantially.

The regression analysis results indicate that post-harvest applications after oilseed rape are not significantly greater due to a reduced intensity of soil cultivation at the farm level. Other aspects seem to be more related to the use intensity. In many cases glyphosate is used for nutrient management. Oilseed rape residues include large amounts of nitrogen, and the uptake of nitrogen in the fall by the follow-on winter wheat is small.
Holding back or substituting tillage for glyphosate applications after the harvest reduces nitrogen leaching. However, our results suggest that single farm characteristics are associated with further increase in glyphosate use. For example, farms with “Cash crop” as a key economic activity are more likely to practice intensive glyphosate use. One explanation for this is that cash crop farms usually have higher work peaks in the summer/autumn and so may rely more on glyphosate than on tillage for stubble management due to time constraints. It seems that time saving stubble cleaning motivates farmers to intensify glyphosate use after oilseed rape harvest, rather than practicing reduced tillage or solving severe weed problems.

For pre-sowing uses, our study indicates that glyphosate use before maize is strongly connected with reduced tillage, while glyphosate use before seeding of sugar beet does not show a strong link to the intensity of ploughing on a farm level. Andert et al. reported that in Northern Germany, herbicide use intensity in common sugar-beet rotations is even higher on fields with ploughing regimes than within reduced tillage regimes. Accordingly, we suggest that some previously proposed relationships between herbicide, and likewise glyphosate, use and tillage regimes for sugar beet production in Europe may need to be revised.

2.5.3 Farm size

We previously reported that, on average, users of glyphosate have larger farms than non-users. This current study provides information about the effect of farm size on glyphosate use. The results of post-harvest regression models of oilseed rape and winter wheat cultivation showed that glyphosate usage is significantly increased in larger farms. Similar to other European countries, the average farm size in Germany has increased in recent decades and this has been accompanied by a decrease in the number of farm workers per hectare. It is therefore likely that labor shortages have promoted more extensive use of glyphosate particularly in post-harvest situations.

2.5.4 Cover crops

Next to reduced tillage, management of cover crops is thought to be a major driver for glyphosate use. For environmental reasons, such as preventing nutrient leaching and soil erosion, European farmers are required to grow cover crops during the winter if the
soil would otherwise be left bare.\textsuperscript{50,51} The so-called “greening” of the Common European Agricultural Policy also requires minimum standards in crop diversity and off-crop habitats,\textsuperscript{51} and farmers appreciate that cover crops fulfill these requirements. Theoretically, dense cover crop stands can suppress weed growth and so serve to reduce herbicide use.\textsuperscript{52} However, growing periods for cover crops under Central European conditions are often short, and this strategy might not be sufficient.\textsuperscript{53} Established in late summer, cover crops usually die during winter, but a mild winter may allow some residual plants to persist. In the case of non-inversion systems, several cultivation passes would then be necessary to allow the establishment of a successful spring crop, whereas this can be avoided by one application of glyphosate. We found evidence of a strong link between motivation to remove cover crops and glyphosate use intensity before planting for both maize and sugar beet. Growers of sugar beet reported a particularly high preference for using glyphosate, as they tend to seed in early spring and there is little time to carry out tillage. In contrast, the establishment of maize occurs two to four weeks later in the season and so growers may have more time to incorporate cover crops mechanically. This might explain the higher proportion of intensive users (100% of the area) for the pre-sowing applications of glyphosate for sugar beet compared to maize.

2.5.5 Weeds and herbicide resistance

The main targets of glyphosate are annual and perennial weeds. However, Wiese et al.\textsuperscript{42} assumed that the reason for glyphosate use was less for controlling perennials than for managing weeds, which were less susceptible to commonly used selective herbicides. Our current analysis indicates an association between use intensity of post-harvest applications of glyphosate and the variable “herbicide resistance”. This proxy was introduced to understand the awareness of farmers of the need for resistance management. While glyphosate resistance in weed populations in glyphosate-resistant crops is an inherent problem,\textsuperscript{54} the situation in Europe is different. Due to a decrease in the efficacy of selective herbicides, glyphosate is used in pre-sowing situations to combat herbicide resistant weed populations such as \textit{Alopecurus myosuroides} and \textit{Apera spica-venti}.\textsuperscript{2} Indeed, farmers have been advised by extension services to use glyphosate to maintain high levels of weed control efficacy at the population level.\textsuperscript{55} Although, glyphosate use helps to diversify resistance management for other herbicides, the selection pressure
conferred by the heavy use of glyphosate can eventually result in evolution of glyphosate-resistant weeds. After several glyphosate resistant weeds were found in European perennial cropping systems, the first glyphosate resistant weeds in European annual cropping systems were observed in central Italian wheat-based cropping systems in 2012. Glyphosate should therefore not be regarded as the single management tool and requires careful management to prevent European weed communities from evolving resistance to it.

2.6 Conclusions

The results presented here indicate that arable farmers use glyphosate under widely varying conditions and with a range of motivations. Application intensity is governed by individual farm characteristics. Some users of glyphosate treat only a small proportion of their arable land or have completely abandoned its use, while other farmers embed glyphosate strongly into their crop production management. The findings of our analysis may influence practical applications, agronomic research and policy formulations. The farming community and extension services are recommended to carefully consider the risks associated with intensive glyphosate use, such as routine spraying and practices that might enhance the selection pressure for glyphosate-resistant weeds. The experiences of non-users, or less-intensive glyphosate users, may help in the establishment of farming practices that optimize glyphosate deployment. This analysis may also help agricultural researchers, and particularly agricultural economists, understand associated strengths and weaknesses of current farming systems. Economists generally calculate pesticide economics regardless of farmers’ behavior. However, we saw evidence of farmers not following generally the same patterns of glyphosate use. It remains unclear whether non-users unwittingly sacrifice farm income by not using glyphosate, or whether they deliberately adopt non-glyphosate systems for non-economic reasons. From a policy perspective, it is clear that restrictions in glyphosate use, such as a ban or a strong reduction, would affect farmers in different ways, as intensive users would be forced to modify their practices more profoundly than specific users or non-users.
Acknowledgements

This study was funded by the Federal Ministry of Food and Agriculture (BMEL) based on a decision of the Parliament of the Federal Republic of Germany via the Federal Office for Agriculture and Food (BLE) under the Innovation Support Programme. We would like to thank the farmers who participated in our survey, as well as all the magazines and organizations that disseminated our questionnaires.

2.7 References


Kapitel 3

Anwendungen von Glyphosat im deutschen Ackerbau – Betriebliche Aspekte

Armin Wiese, Michael Schulte, Ludwig Theuvsen & Horst-Henning Steinmann
3.1 Zusammenfassung


**Stichwörter:** Betriebsstrukturen, Herbizide, Stoppelanwendung, Vorsaatanwendung

**Abstract**

Glyphosate is the most frequently used herbicide active ingredient in Germany. Studies regarding its usage in non-GMO arable farming are still rare even though it plays an important role in several agronomic situations. Therefore, we conducted a comprehensive survey, which was carried out among conventional German farms in Winter 2014/2015. Based on the results of this survey we analyzed via cluster analysis how types of farms differ in terms of glyphosate usage. An illustration of seven clusters allows deep insights into arable farm structures. The farm types can be distinguished re-
Regarding their tillage system and similar to this differentiation also concerning their intensity of glyphosate application. Furthermore, it becomes obvious that farm clusters with a higher level of glyphosate usage are characterized by a lower number of labourers per hectare, more arable land and/or enhanced cover cropping. Moreover, groups of farmers who rely more on glyphosate are more likely to state that they need glyphosate for herbicide resistance management. Farmers’ assessments of the economic importance of glyphosate usage vary depending on the type of farm. By means of the farm clusters, the most important situations of glyphosate usage can be further analyzed economically and scenarios for impact assessments can be made.

**Keywords:** Farm structures, herbicides, pre-sowing application, stubble application

### 3.2 Einleitung


Entgegen der intensiven, wenn auch kontrovers diskutierten Forschung zu toxikologischen Fragestellungen, ist die agronomische Bedeutung des Wirkstoffes im europäischen Ackerbau nach wie vor wenig erforscht. Für eine genauere Bewertung des Glyphosateinsatzes im deutschen Ackerbau gibt es keine ausreichenden wissenschaftlichen Grundlagen (Schulte & Theuven, 2015; Steinmann, 2013).

ist darum der Frage nachgegangen worden, inwiefern sich Betriebstypen hinsichtlich der Anwendung von Glyphosat unterscheiden.

### 3.3 Material und Methoden


Die Teilnehmer der Befragung bewirtschaften größtenteils Ackerbaubetriebe (49 %), während sich 21,5 % als Gemischtbetriebe, 17 % als Veredlungsbetriebe, 9,8 % als Milchviehbetriebe, 0,9 % als Dauerkulturbetriebe und 1,8 % als Sonstige bezeichnen. Das Durchschnittsalter der Teilnehmer beträgt 47 Jahre und 79,1 % der befragten Betriebe werden im Haupterwerb bewirtschaftet. Die durchschnittliche landwirtschaftliche Nutzfläche (LNF) aller teilnehmenden Betriebe beträgt 279,4 Hektar (ha) (Median: 95 ha), der Anteil der gepflügten Ackerfläche 31,8 %. Somit ist die durchschnittliche Betriebsgröße in dieser Umfrage höher und der „Pfluganteil“ niedriger als im Bundesdurchschnitt (Statistisches Bundesamt, 2011; Statistisches Bundesamt, 2014). Aufgrund der Besonderheiten der Datengewinnung handelt es sich zwar nicht um eine repräsentative Erhebung, wohl aber um ein sogenanntes Convenience Sample (FOWLER, 2002)
und damit um eine für sozioökonomische Studien geeignete Datenquelle. Ein Bestandteil des analytischen Teils dieser Auswertung sind acht elementare Betriebsstrukturmerkmale. Tabelle 1 listet diese Variablen mit den entsprechenden Mittelwerten auf.

**Tab. 1** Variablen der analytischen Auswertung mit Mittelwerten (n = 2026).

<table>
<thead>
<tr>
<th>Merkmal</th>
<th>Mittelwert</th>
<th>Merkmal</th>
<th>Mittelwert</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anteil gepflügter Fläche (%)</td>
<td>31,8</td>
<td>Anteil Zwischenfruchtanbau auf AF (%)</td>
<td>10,7</td>
</tr>
<tr>
<td>Ak (Arbeitskraft) je 100 ha (LNF)</td>
<td>0,9*</td>
<td>Anteil Sommerfruchtanbau auf AF (%)</td>
<td>25,6</td>
</tr>
<tr>
<td>Ackerfläche (AF) in ha</td>
<td>258,1</td>
<td>Shannon-Index</td>
<td>1,46</td>
</tr>
<tr>
<td>Ackerzahl</td>
<td>47,5</td>
<td>Complexity-Index</td>
<td>0,92</td>
</tr>
</tbody>
</table>

*umgerechnet von 110,8 ha (LNF) / Ak


Einige Fragen – insbesondere zu den Fruchtfolgen – wurden nicht vollständig ausgefüllt oder waren nicht auswertbar, woraufhin sich der Datensatz für den analytischen Teil der Auswertung auf 1628 Betriebe reduziert. Die Variablen im Datensatz wurden zunächst einer Faktorenanalyse unterzogen und dienten der Cluster-Analyse dann als Input-variablen. Da im vorliegenden Datensatz miteinander korrelierende Variablen vorlagen, konnte mit der Faktorenanalyse eine Gleichgewichtung erreicht werden. Im selben Zuge

3.4 Ergebnisse

Die Anwendungsmengen der jeweiligen Glyphosat-Anwendungsbereiche werden in der Tabelle 2 dargestellt. Die Stoppelbehandlung ist die bedeutendste Anwendung und wurde im Anbaujahr 2013/2014 auf 22,2 % der gesamten ackerbaulich genutzten Fläche appliziert, gefolgt von der Vorsaatanwendung (12,7 %). Die Vorernteanwendung hat die geringste Bedeutung und wird nur auf 2,2 % der Ackerfläche angewendet. Hochrechnungen auf Kulturflächen ergeben ebenfalls deutliche Unterschiede (Tab. 3). Während Winterweizen, Mais, Leguminosen und Wintergerste auf ca. einem Drittel der Fläche mit Glyphosat behandelt werden, liegt der Anteil behandelter Fläche bei Winterraps (71,5 %) und Zuckerrüben (48,4 %) wesentlich höher.

Tab. 2 Durchschnittliche behandelte Ackerfläche der drei verschiedenen Glyphosatanwendungen (% der Ackerfläche im Mittel der Betriebe, n = 2026, 2013/2014).

<table>
<thead>
<tr>
<th>Anwendung</th>
<th>beh. AF (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stoppel</td>
<td>22,2</td>
</tr>
<tr>
<td>Vorsaat</td>
<td>12,7</td>
</tr>
<tr>
<td>Vorernte</td>
<td>2,2</td>
</tr>
<tr>
<td>ges. beh. Ackerfläche</td>
<td>37,1</td>
</tr>
</tbody>
</table>
Tab. 3 Durchschnittliche behandelte Fläche wichtiger Ackerbaukulturen (% der Kulturfläche im Mittel der Betriebe, n = 2026, 2013/2014).

<table>
<thead>
<tr>
<th>Feldfrucht</th>
<th>beh. Fläche (%)</th>
<th>Feldfrucht</th>
<th>beh. Fläche (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winterraps</td>
<td>71,5</td>
<td>Winterweizen</td>
<td>30,9</td>
</tr>
<tr>
<td>Zuckerrübe</td>
<td>48,4</td>
<td>Mais</td>
<td>27,0</td>
</tr>
<tr>
<td>Wintergerste</td>
<td>32,9</td>
<td>Leguminosen</td>
<td>26,4</td>
</tr>
</tbody>
</table>

Tabelle 4 fasst die Ergebnisse der Faktoren- und der Clusteranalyse zusammen. Im Rahmen der Faktorenanalyse sind vier Faktoren mit Eigenwerten >1 extrahiert worden, wobei nur Variablen mit Faktorladungen von mindestens 0,4 berücksichtigt wurden. Der erste Faktor beschreibt den Anbau von Zwischenfrüchten und Frühjahrskulturen. Der zweite Faktor setzt sich aus den miteinander korrelierenden Variablen Arbeitskräftebesatz, Pfluganteil und dem Anteil der Stoppel- und Vorsaatverwendung von Glyphosat auf der betrieblichen Ackerfläche zusammen. Faktor 3 beinhaltet die Variablen der Fruchtarten- und Fruchtfolgevielfältigkeit, während der vierte Faktor die Rahmenbedingungen unter denen der Betrieb wirtschaftet beschreibt (Ackerfläche und Bodengüte). Der Anteil der mit Glyphosat als Vorernteanwendung behandelten Ackerfläche konnte im Rahmen der Faktorenanalyse keine ausreichend hohe Faktorladung erreichen und ist deswegen aus der Analyse ausgeschlossen worden. Im Nachgang der Analyse werden die Cluster-Mittelwerte dieser Variable aufgeführt. Die Faktoren erklären insgesamt 62,59 % der Varianz aller berücksichtigten Variablen und eine Diskriminanzanalyse bestätigte eine Klassifizierungsgenauigkeit der im Folgenden beschriebenen Clusteranalyse von 90,5 %.


3.5 Diskussion

allein von diesen Faktoren abzuleiten. Betriebe mit einer höheren Glyphosat-Anwendungsintensität lassen sich zusätzlich durch einen niedrigeren Ak-Besatz oder einem verstärkten Zwischenfruchtanbau charakterisieren (vgl. SCHULTE et al., in prep.).

Tab. 4 Ergebnisse der Faktorenanalyse und Charakterisierung der Betriebscluster mit Mittelwertwerten (n = 1615).

<table>
<thead>
<tr>
<th>Charakterisierung der Betriebe</th>
<th>Cluster A</th>
<th>Cluster B</th>
<th>Cluster C</th>
<th>Cluster D</th>
<th>Cluster E</th>
<th>Cluster F</th>
<th>Cluster G</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Kleine Betriebe&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;Pfluglastige Betriebe mit einseitigen Fruchtfolgen&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;Pfluglastige Betriebe mit diversen Fruchtfolgen&quot;</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>&quot;Betriebe mit sommerungs-&quot;lastigen Fruchtfolgen&quot;</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;Großbetriebe&quot;</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;Mulchsaatbetriebe auf Gunststandorten&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;Rationalisierte Betriebe&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

N= Anzahl der Betriebe 300 393 251 160 116 230 165

Faktor 1
ZW*** (FL=0,853) 28,9 5,7 20,9 42,6 7,9 21,7 5,4
SO*** (FL=0,809) 48,7 14,7 37,1 52,8 24,1 32,1 12,9

Faktor 2
PF*** (FL=0,724) 79,7 62,8 58,4 30,6 30,1 27,3 14,6
VS*** (FL=0,711) 3,4 4,7 4,9 34,3 6,8 20,5 29,8
AK*** (FL=0,524) 2,5 1,5 1,7 1,6 0,9 1,3 0,7
ST *** (FL=0,522) 6,7 9,6 6,5 13,3 30,6 8,1 34,8

Faktor 3
CI*** (FL=0,824) 0,59 0,62 1,2 0,83 1,05 1,08 0,77
SI*** (FL=0,793) 1,1 1,19 1,56 1,15 1,66 1,27 1,18

Faktor 4
AZ*** (FL=0,827) 37,8 55,4 46,2 44,3 40,4 67,8 52,1
HA*** (FL=0,478) 67,7 113,7 156,1 121 1600,7 161,3 405

Cluster beschreibende Variablen
VE 1 1,4 1 1,7 2,5 1,3 2
Erosion1*** -0,25 -0,46 -0,12 0,27 0,28 0,19 0,02
Resistenz2*** -0,5 -0,1 -0,31 0,19 0,46 0,1 0,89
Erfolg1*** 0,37 0,22 0,25 -0,36 -0,64 -0,06 -0,72

Faktor 1 = (ZW/SO) Anteil mit Zwischenfrüchten bzw. Sommerfrüchten kultivierte Ackerfläche (%)
Faktor 2 = (VS) Vorsaatbehandlung (%), (PF) Pfluganteil (%), (AK) Ak je 100 ha - umgerechnet von ha/Ak -, (ST) Stoppelbehandlung (%)
Faktor 3 = (CI) Complexity-Index, (SI) Shannon-Index
Faktor 4 = (AZ) Ackerzahl, (HA) Ackerfläche in Hektar
VE= Vorernteanwendung
Erosion= "Die Erosionsanfälligkeit des Bodens beeinflusst die Form der Bewirtschaftung"
Resistenz= "Ich wende Glyphosat gezielt an, um Resistenzene im Ackerbau zu vermeiden"
Erfolg= "Auch ohne Glyphosat werde ich die bisherigen betriebswirtschaftlichen Ergebnisse erzielen"

Auch die Rahmenbedingungen, innerhalb der die verschiedenen Arten der Glyphosatbehandlungen angewendet werden, unterscheiden sich erheblich. Die Vorsaatannahme wird häufig flankierend zur Kultivierung von Sommerungen durchgeführt, welche eher auf den mittelgroßen Mulchsaatbetrieben (Cluster D und F) in dieser Studie rele-

Eine Auswirkung der Anbauvielfältigkeit auf die Intensität der Glyphosate-Anwendungen ist nicht abzuleiten. So weisen auf der einen Seite die Cluster mit einem geringeren Glyphosateinsatz (Cluster A und B) und auf der anderen Seite Cluster mit dem intensivsten Glyphosateinsatz (Cluster D und G) geringere Anbauvielfältigkeitsindizes auf. Gleichwohl fällt auf, dass der Cluster „Großbetriebe“ eine höhere Anbauvielfalt aufweist, was aus pflanzenbaulicher Sicht positiv zu bewerten ist. Kleine Betriebe verfügen, entgegen dem Klischee, nicht per se über diversere Fruchtfolgen. Möglicherweise ist in diesen Gruppen die Nebenerwerbsquote hoch, was zu vereinfachter Betriebsstruktur führen kann.

Der intensivste Glyphosateinsatz ist auf den „Rationalisierten Betrieben“ (auf ca. 67 % der AF) zu verzeichnen. Ein Mittelwert von ca. 15 % gepflügter Fläche weist darauf hin, dass der Pflug auf diesen Betrieben kaum noch angewendet wird oder schon komplett durch Mulchsaattechnik ersetzt worden ist. Gleichzeitig besteht auf diesen Betrieben ein Bedarf danach, Glyphosat einzusetzen um Resistenzschutz vorzubeugen. Dies weist auf bereits vermutete Herbizid-Minderwirkungen hin (WIESE et al., 2016). Diese Betriebe erwarten bei einem Glyphosateverzicht ernste wirtschaftliche Konsequenzen. Es steht die Frage zur Diskussion, ob vor allem die Einstellung des Betriebsleiters, die Betriebsgröße oder ein Fachkräftemangel in der deutschen Landwirtschaft für das Management auf diesem Betriebstyp bestimmend sind (vgl. SCHULTE et al., in prep.).

Im Vergleich mit einer ersten Erhebung zum Glyphosateinsatz im Winter 2010/2011 (STEINMANN et al., 2012) ist der Gesamtanwendungsumfang nahezu unverändert geblieben. Die Vorernteanwendung ist nach wie vor eine Spezialmaßnahme. Durch Anwendungseinschränkungen sowie Beratungsempfehlungen konnte die Einsatzmenge auf

3.5 Danksagung


3.6 Literatur


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Kapitel 4

Anwendungen von Glyphosat im deutschen Ackerbau –
Herbologische und ackerbauliche Aspekte

Armin Wiese, Michael Schulte, Ludwig Theuvsen & Horst-Henning Steinmann
4.1 Zusammenfassung


**Stichwörter:** Bodenbearbeitung, Herbizidanwendung, perennierende Unkräuter, Resistenzmanagement

**Abstract**

Data on glyphosate use, personal attitudes and farm characteristics were collected in a Germany-wide inventory from 2026 farms. About 1700 farms could be analyzed in detail. Categories of glyphosate users were split into: non-users, low proportion users and high proportion users. The latter apply glyphosate on \( \geq 20\% \) of their arable land are characterized by a high amount of non-inversion tillage, low labor effort and above-average farm size. Perennial weeds play a less important role for glyphosate use than managing weed populations that are regarded as less susceptible to regular herbicides. Non-users and users of glyphosate differ in their attitude towards the benefits of glyphosate and the amount of glyphosate use in agriculture.

**Keywords:** Herbicide application, perennial weeds, resistance management, soil cultivation
4.3 Einleitung


4.4 Material und Methoden

Grundlage für die Auswertungen war die bereits von WIESE et al. (2016) im Detail vorgestellte Befragung. Im Winter 2014/2015 wurden deutschlandweit mit Hilfe internetbasiertener wie auch per Post versandter Fragebögen Angaben von 2026 Landwirten erhoben. Aufgrund der Besonderheiten der Datengewinnung handelt es sich zwar nicht um eine repräsentative Erhebung, wohl aber als sogenanntes Convenience Sample um eine
für sozioökonomische Studien geeignete Datenquelle. Im Anschreiben der Befragung waren gezielt konventionell wirtschaftende Betriebe angesprochen worden.


4.5 Ergebnisse

Betriebe, die Glyphosat gar nicht (a), in geringem Umfang (b) oder auf ≥ 20% der Ackerfläche anwenden (c), unterscheiden sich hinsichtlich wesentlicher Kriterien. Die Nichtanwender sind durch kleinere, relativ arbeitsintensive Betriebe mit hohem Pfluganteil gekennzeichnet (Tab. 1). Die Fruchtarten- und Fruchtfolgediversität ist in diesen Betrieben jedoch niedriger als in den Betrieben mit höherem Glyphosateinsatz.

<table>
<thead>
<tr>
<th>Kategorie</th>
<th>Betriebsgröße [ha AF] n=1726</th>
<th>Pfluganteil [%] n=1724</th>
<th>Ak-Besatz [/100 ha] n=1718</th>
<th>Fruchtwechsel (0 … 2,26) (0 … 1,91) n=1657</th>
<th>Shannon-Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nichtanwender (a)</td>
<td>78,56</td>
<td>68,93</td>
<td>2,09</td>
<td>0,74</td>
<td>1,14</td>
</tr>
<tr>
<td>Anwender &lt; Median (b)</td>
<td>214,46</td>
<td>60,00</td>
<td>1,50</td>
<td>0,84</td>
<td>1,32</td>
</tr>
<tr>
<td>Anwender ≥ Median (c)</td>
<td>354,50</td>
<td>37,21</td>
<td>1,15</td>
<td>0,87</td>
<td>1,28</td>
</tr>
<tr>
<td>Test auf Unterschiede</td>
<td>*</td>
<td>*</td>
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</tr>
<tr>
<td>ab</td>
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<td>0,000</td>
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<td>bc</td>
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<td>0,000</td>
<td>0,000</td>
<td>0,141</td>
<td>0,024</td>
</tr>
</tbody>
</table>

Die Anwender von Glyphosat nehmen in größerer Anzahl an Agrarumweltprogrammen teil als die Nichtanwender (Tab. 2). Betriebe mit überproportionalem Glyphosateinsatz schätzen ihren Bodenzustand als verbessert gegenüber früheren Jahren ein, beobachten aber in höherem Maße bodenbürtige Krankheiten.

Weniganwender sehen bei Vorhandensein einer besseren Technik zur Wurzelunkrautbekämpfung eher Einsparpotenzial von Glyphosat als Vielanwender (Tab. 3). Weiterhin

Tab. 2 Betriebliche Rahmenbedingungen der Anwendergruppen: Kennziffern zu Agrarumweltpolitik und Boden. *: Chi–Quadrat-Test; **: Mann-Whitney-U-Test.

<table>
<thead>
<tr>
<th>Kategorie Teilnahme Agrarumweltprogramme</th>
<th>Bodenzustand ist besser geworden</th>
<th>Vorkommen bodenbürtiger Krankheiten</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Agrarumweltprogramme</td>
<td>-2 ... +2</td>
</tr>
<tr>
<td>Nichtanwender (a)</td>
<td>0,37</td>
<td>0,72</td>
</tr>
<tr>
<td>Anwender &lt; Median (b)</td>
<td>0,47</td>
<td>0,78</td>
</tr>
<tr>
<td>Anwender &gt; Median (c)</td>
<td>0,49</td>
<td>0,88</td>
</tr>
<tr>
<td>Test auf Unterschiede</td>
<td>*</td>
<td>**</td>
</tr>
<tr>
<td>ab</td>
<td>0,004</td>
<td>0,227</td>
</tr>
<tr>
<td>ac</td>
<td>0,000</td>
<td>0,000</td>
</tr>
<tr>
<td>bc</td>
<td>0,561</td>
<td>0,015</td>
</tr>
</tbody>
</table>

Tab. 3 Herbologische Einschätzungen: Nachlassende Wirkung bei Herbiziden (generell), Vorkommen von Spätverunkrautung und Leitunkräutern sowie Einsparpotenzial von Glyphosat zur Wurzelunkrautbekämpfung. *: Chi-Quadrat-Test; **: Mann-Whitney-U-Test.

| Kategorie Nachlassende Wirkung Spätverunkrautung Leitunkraut Windhalm Leitunkraut Ackerfuchsschwanz Leitunkraut Perennierend Glyphosat und Wurzelunkrautbekämpfung |
|----------------------------------|----------------------------------|--------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| | (-2...+2) | (-2...+2) | (0 ... 1) | (0 ... 1) | (0 ... 1) | (0 ... 1) | (-2 ... +2) |
| Nichtanwender (a) | -0,87 | -0,68 | 0,12 | 0,27 | 0,15 | -0,14 |
| Anwender < Median (b) | -0,64 | -0,46 | 0,14 | 0,31 | 0,09 | 0,2 |
| Anwender > Median (c) | -0,36 | -0,27 | 0,18 | 0,33 | 0,1 | -0,09 |
| Test auf Unterschiede | ** | ** | * | * | * | ** |
| ab | 0,000 | 0,000 | 0,539 | 0,223 | 0,010 | 0,000 |
| ac | 0,000 | 0,000 | 0,013 | 0,051 | 0,005 | 0,447 |
| bc | 0,000 | 0,000 | 0,053 | 0,516 | 0,829 | 0,000 |

\[1\text{Wenn es eine bessere Technik zur Wurzelunkrautbekämpfung gäbe, könnte ich weniger Glyphosat einsetzen}^{*}\]

**Tab. 4** Persönliche Einstellungen zu Glyphosat, zum Einsatz von Glyphosat und zur betrieblichen Abhängigkeit von der Verfügbarkeit von Glyphosat; Antworten zu vorformulierten Statements (in „...“).**:

<table>
<thead>
<tr>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(-2 ... +2)</td>
<td>(-2 ... +2)</td>
<td>(-2 ... +2)</td>
<td>(-2 ... +2)</td>
<td>(-2 ... +2)</td>
</tr>
<tr>
<td>Nichte- anwender (a)</td>
<td>0,19</td>
<td>0,81</td>
<td>0,48</td>
<td>0,81</td>
<td>0,88</td>
</tr>
<tr>
<td>Anwender &lt; Median (b)</td>
<td>-0,47</td>
<td>0,13</td>
<td>-0,05</td>
<td>0,38</td>
<td>0,42</td>
</tr>
<tr>
<td>Anwender &gt; Median (c)</td>
<td>-0,65</td>
<td>-0,27</td>
<td>-0,22</td>
<td>0,03</td>
<td>-0,44</td>
</tr>
<tr>
<td>Test auf Unterschiede</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>ab</td>
<td>0,000</td>
<td>0,000</td>
<td>0,000</td>
<td>0,000</td>
<td>0,000</td>
</tr>
<tr>
<td>ac</td>
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<td>0,003</td>
<td>0,000</td>
<td>0,000</td>
<td>0,000</td>
<td>0,000</td>
</tr>
</tbody>
</table>

4.6 Diskussion

Glyphosat wird von Landwirtschaftsbetrieben sehr unterschiedlich wahrgenommen und eingesetzt. Die hier gewählte Unterteilung der Anwendergruppen gibt notgedrungen nur ein grobes Raster wieder. Die Auswertungen von SCHULTE et al. (in prep.) sowie WIESE et al. (2016) zeigen, dass Rahmenbedingungen und Motivation des Einsatzes von Glyphosat durchaus vielschichtig sein, bzw. motiviert sein können. Somit ist der Glyphosateinsatz im Normalfall ein Resultat verschiedener einflussnehmender Faktoren; in manchen Fällen aber vermutlich auch eine feste Rahmengröße im Betrieb. In diesem Zusammenhang ist der Hinweis wichtig, dass die Einordnung der Betriebe in die Katego-


Bei der Auswertung von Strukturmodellen zum Glyphosateinsatz auf regionaler Ebene (SCHULTE et al., in prep.) ist vor allem die Arbeitserhöhung als signifikante Einflussgröße bei der Glyphosatanwendung identifiziert worden, während die Betriebsgröße nicht so deutlich hervortrat.


Der Glyphosatabsatz in Deutschland wird von den Vielanwendern dominiert, da sie die größeren Behandlungsflächenanteile auf größeren Betrieben realisieren. Beratungs- und Managementkonzepte müssen somit vor allem auf diese Nutzer abgestimmt werden.

4.7 Danksagung

4.8 Literatur


BVL – Bundesamt für Verbraucherschutz und Lebensmittelsicherheit, versch. Jahrgänge: Absatz an Pflanzenschutzmitteln in der Bundesrepublik Deutschland.


Glyphosate use of German farmers: A structural equation model

Michael Schulte, Armin Wiese, Ludwig Theuvsen & Horst-Henning Steinmann
5.1 Abstract

Glyphosate is the world’s most widely used active herbicide ingredient and is classified as a non-selective herbicide. Although many studies have focused on the role of glyphosate in GMO production, only a few have investigated its use in non-GMO European agriculture. This study seeks to help fill this gap through a region-specific analysis of German arable farming using the non-parametric partial least squares (PLS) method. The authors conducted a survey of German farmers between November 2014 and January 2015 and developed their own research model, taking an innovative research approach. The results show that a high reliance on non-inversion tillage increase glyphosate use. Moreover, in addition to the primary objective of weed control, farmers commonly report using glyphosate as part of a management strategy to reduce water erosion and resistance against selective herbicides and to save time. Furthermore, political changes such as the European Union’s Common Agricultural Policy (CAP) reform of 2014 may affect glyphosate use in future.

5.2 Introduction

Glyphosate is the most used active substance in nonselective herbicides worldwide (Duke & Powles, 2008). Among other reasons, growth in glyphosate use stems from the increasing cultivation of genetically modified organisms (GMOs) that are resistant to this herbicide, an increase in the practice of reduced tillage (Gehring et al., 2012a) and a rise in the rotation of related winter crops (Schwarz & Pallutt, 2014). When cultivating GMOs, multiple applications of glyphosate for weed control are common, while in Germany and other widely GMO-free countries, one can distinguish between stubble application, pre-sowing application and pre-harvest application (Dickeduisberg et al., 2012). Outside the agricultural sector, glyphosate is applied in horticulture and private gardens as well as by public and private institutions such as railway companies (German Parliament, 2011). In Germany, the consumption of glyphosate is about 5,000 tons (t) per year, or about 30–40% of total herbicide sales (Federal Office of Consumer Protection and Food Safety, various years). Although the environmental hazard risk level caused by glyphosate, as compared to other herbicides, is relatively low (Duke & Powles, 2008; Giesy et al., 2000), in recent years glyphosate has become a controversial subject in the European Union (EU). In particular non-governmental or-
ganizations (NGOs), such as environmental groups and other critical stakeholders, suspect glyphosate of having a negative influence on biodiversity by causing irreversible damage to the environment and human health (IARC, 2015). German public authorities classify it as safe in its current field of application (Federal Institute for Risk Assessment, 2014) and the European Commission has authorized its use until the end of 2017. Until then, further insights into its effects on human health are expected (by the European Chemicals Agency, among others) to ensure a comprehensive assessment (European Commission, 2016).

The use of glyphosate in European farming has frequently been the topic of scientific studies but there are very few research studies from the perspective of agricultural economics (SCHULTE & THEUVSEN, 2015). Most existing studies on the economics of glyphosate use address the cultivation of GMOs and have only limited application to European arable farming systems. Hence, very little is known about why and how European farmers use glyphosate. COOK et al. (2010), STEINMANN et al. (2012) Schmitz & Garvert (2012) and SCHULTE et al. (2016) analyzed the herbicide's scope of application in order to identify glyphosate's economic value. KEHLENBECK et al. (2015) carried out an impact assessment of a potential ban on glyphosate in Germany. WIESE et al. (2017) analyzed individual fields of application patterns at a nationwide level in Germany characterizing the influence of the cultivation program on the amount of glyphosate usage. What is still missing in agro-economic research is an in-depth analysis into which factors influence farmers' level of glyphosate use. Due to this lack of research, the objective of this paper is to examine farm-specific application patterns of glyphosate and farmers’ attitudes towards its use. In addition, the effect of farm characteristics like machinery, tillage strategy and topographic location will be analysed. This paper will therefore represent a rare study into examining glyphosate usage in non-GMO cultivation from an economic viewpoint.

For the study, we evaluated the farm-specific data of 2,026 German farmers who participated in a survey into their use of glyphosate between November 2014 and January 2015. The innovative region-specific evaluation of the sample (Northwest, East and South) reflects differing farm structures in Germany (German Farmers’ Association, 2014) and helps in identifying glyphosate application patterns. The results can be considered representative for European agriculture (non-GMO production); what is more,
Germany is one of the most productive areas in arable farming so the results can be used for ongoing policy consultation.

After a short descriptive analysis of the sample and presentation of the scope of application, we will analyse each region’s data using the partial least squares (PLS) method. The PLS method is a combination of path, principal component and regression analyses that tests the interrelationship of latent constructs in a single step and is particularly suitable for the present study. To the best of our knowledge, this is one of the first studies to analyse the application of glyphosate in European agriculture with a causal-analytic and model-based approach.

The paper is structured as follows: Section 2 includes a brief overview of the current literature about the use of glyphosate in European arable farming from an agronomic and economic perspective. Section 3 describes the newly developed theoretical framework with regard to the research model. A design of the survey and a sample description follow in section 4. Then, section 5 presents descriptive findings (5.1) and the results of the structural equation model (5.2 and 5.3) as well as comparing the three models (5.4). The paper ends with a discussion of the results and some concluding remarks.

5.3 Literature Review

Numerous studies have focused on various aspects of glyphosate use in international agriculture with GMO production (Moschini et al., 2000; Gianessi, 2008) or on the possibility of leaching (Cederlund et al., 2017). A review of relevant European literature shows that only a limited number of studies exist that focus on glyphosate use in the fields of plant protection monitoring (cf. PAPA, 2016) and agricultural economics (cf. Schulte & Theuvsen, 2015). Cook et al. (2010), for example, surveyed British farmers with regard to the application of glyphosate. The share of the pre-sowing treatment in wheat varied between 23% and 85% of the total area and in rapeseed between 19% and 75% of the area. They found that pre-harvest treatment of wheat is carried out on only 8% to 25% of the area, while the proportion in rapeseed production varied between 64% and 75%. The prohibition of glyphosate would lead to significant economic losses as a result of lower yields, especially as pre-harvest treatment cannot be fully replaced by other measures. In pre-harvest situations glyphosate could be substituted by
the active ingredient Diquat but the latter is more likely to dry out the crop too fast and also makes the pods less rubbery so they may shatter.

STEINMANN et al. (2012) surveyed German farmers to analyse their application behaviour. The authors showed that glyphosate is used on about 39% of arable land in Germany; 23.1% of the area, glyphosate is applied for stubble treatment, 7.0%, for pre-seeding treatment and on only 3.8%, for desiccation. Unlike in the UK, Steinmann et al. (2012) saw the greatest benefits lay with machinery and labour savings that do not have any direct influence on yields. If the use of glyphosate were restricted, the selection of tillage would change towards more intensive soil preparation. The use of mechanical tillage would rise by a factor of 1.6 and the share of ploughed land would increase from 38.1% to 71.4%.

SCHMITZ & GARVERT (2012) conducted 14 expert interviews with cultivation advisers and official consultants, evaluating the application of glyphosate. Reduced tillage is one of the major drivers of the application of glyphosate (see STEINMANN et al., 2012). Without glyphosate, estimated yield losses that could not be avoided through the application of other crop protection or tillage practices stood at up to 10%. Depending on the region, another consequence would be the reduction of the gross margin per hectare by 3–36%; this range is similar to that noted by SCHULTE et al. (2016), who identified decreases in the gross margins of between 6% and 39% depending on the crop rotation and the current method of tillage (ploughing/reduced tillage) on the farm. However, in these studies glyphosate yield effects are contradictory because SCHMITZ and GARVERT (2012) observed a drop in cereal and rapeseed production in the European Union (EU) between 4.3% and 7.1% and, as a result, a welfare loss of about US$1.4 billion while Schulte et al. (2016) saw only minor yield effects.

WYNN et al. (2014) found that banning glyphosate would lead to higher food prices, changes in land use, higher greenhouse gas emissions and other environmental impacts including reduction in soil biodiversity. Their study also predicted socio-economic disadvantages for farmers due to increased need for human labour. This could lead to more work-related accidents or to the recruitment of additional staff, which would in turn require additional staff management.

KEHLENBECK et al. (2015) studied the potential consequences if farmers’ use of glyphosate were to be restricted. Their results were based on current literature as well as on
PAPA’s (2016) statistical elevation analysis of the application of plant protection products in practice, which demonstrated that substituting additional tillage for glyphosate application was not more expensive as long as only one additional tillage pass was necessary. However, banning glyphosate, including its pre-harvest application for crop desiccation, would be both more difficult and more cost intensive.

The results of the studies show that the economic implications of glyphosate use vary widely. This might be caused by the different locations of the studies and methodological discrepancies, for instance, surveys versus expert interviews. While some application areas are referred as a “luxury application” (STEINMANN, 2013), glyphosate seems to be very difficult to replace for pre-harvest application in cereals and rapeseed which are not harvestable. All in all, existing studies provide an incomplete picture of farmers’ application behaviour. What is missing is an in depth study of various management practices and other determinants that might influence the amount of glyphosate applied. Quantitative analyses with a higher number of participants are therefore urgently required. In particular, the relationship between tillage and the application of glyphosate should be focused on (cf. LAUKKANEN & NAUGES, 2011; Schneider, 2009; SCHWARZ, 2013). In the present study, German farmers have been surveyed in order to determine causal relationships between farm organization and the selection of tillage as well as the application of glyphosate.

5.4 Research model

In our research model, we take into account several constructs (factors) that could have an influence on the application of glyphosate. As no theory for the use of glyphosate is available; the research model has been derived from several studies in the field of agronomy and agricultural economics. As we know from earlier research (Chapter 2), desiccation is not of major importance in German agriculture. Moreover, the recent regulations for glyphosate products by the Federal Office of Consumer Protection and Food Safety (2014) allow desiccation in Germany only in cases of late weed infestation and second growth resulting from unpredictable incidents (e.g., weather) or cultivation problems. Desiccation is therefore regarded as a special treatment and is not widely used. Pre-harvest treatment can also be substituted, at least in rapeseed, with Diquat, but it is less effective (COOK et al., 2010) and far less environmentally compatible than
glyphosate (ARENDT-PETER & TAUCHNITZ, 1990). In our model, we therefore only focus on the most common treatments— **stubble** and **pre-sowing application**—as the dependent variables on the right side of the model:

- **Stubble application**: Stubble application begins directly after threshing crops have been harvested, and the overall period of application lasts about three weeks before the next crop is sown. The main purpose of this treatment is to combat volunteer cereals and perennial weeds after the main crop has been harvested. The construct reflects the proportion of treated area for this field of application.

- **Pre-sowing application**: The pre-sowing application period begins about three weeks before the main culture is sown and is used for seedbed preparation. It is used especially in mulch-seeding systems in order to create a weed-free seedbed and ideal conditions for growing the main crop. The application is specifically used if there is a strong infestation with blackgrass (false seedbed technique).

The third construct on the right side of the research model represents both a dependent and, at the same time, an explanatory construct, namely **ploughing**. Earlier studies indicate that the type of tillage has a significant influence on the amount of glyphosate used (see section 2; NAIL et al., 2007; SCHMITZ & GARVERT, 2012; SCHWARZ & PALLUTT, 2014; FREIER et al., 2015) and, for this reason, it is a core construct for understanding the application of glyphosate. This construct reflects the share of ploughed land on each farm surveyed. Arable farm land that is not ploughed is managed through the use of reduced tillage, direct seeding or strip-drill technique. The construct also reflects farmers’ attitudes towards intensive tillage.

The constructs on the left are the independent constructs that are presumed to influence tillage as well as glyphosate usage. Theoretical constructs based on preliminary considerations are illustrated in Figure 1.
• **Reduction of working time:** In recent decades, advances in technology have led to an increase in minimum tillage (BRUNOTTE et al., 2001; SCHNEIDER, 2008) and a stronger focus on agronomic and environmental effects, such as water availability and erosion (KRUG, 2013). By reducing tillage, it is possible to save machinery as well as working time while increasing the use of non-selective herbicides like glyphosate (STEINMANN et al., 2012). Glyphosate is also applied at workload peaks (SCHULTE et al., 2016a), so its use reduces the fluctuations in existing working peaks. With this in mind, we developed a factor that might influence the share of plough and glyphosate use. More specifically, it addresses the question whether the farmers’ desire to save man hours influences how much glyphosate is used.

• **Farm size:** German agricultural enterprises are characterised by changing farm equipment. Taking into consideration the size of arable and total farmland, we measure whether farm size has any influence on choice of tillage or on glyphosate treatment. OSEI et al. (2012), for instance, have shown that reduced tillage provides economic benefits, especially for small farms, which might have a direct effect on glyphosate use.

• **Risk of erosion:** Germany is characterized by highly variable topography and soils. Many terrains, hilly and sandy areas for example, are subject to land degradation
through erosion. Erosion occurs through soil detachment and soil transport. About 17% of the total area is threatened by water and wind erosion (Schmitz et al., 2015). To counteract erosion, it is important for farmers to adapt their tillage so making the soil more favourable for plant growth (Klute, 1982) as well as protecting the ground against environmental degradation. Our model examines two aspects of this issue: the extent to which erosion represents a challenge for farmers and whether, or to what extent, water erosion is particularly challenging. Referring to Koeller et al. (2014), it can be assumed that a higher risk of erosion increases the practicality of mulch seeding and thus requires a greater use of glyphosate.

- **Herbicide resistance:** International research institutes and cultivation advisors have been warning about increasing herbicide resistance in arable farming (Gehring, 2009). A growing number of glyphosate-resistant biotypes have been evolving in GMO-cultivation for quite some time now. Furthermore, in European non-GMO arable farming, glyphosate-resistant weeds have also been observed (Heap, 2016). Due to the low—compared to GMO production—usage interval in European farming, no sharp increase in resistance to glyphosate is expected. In Europe, glyphosate is only one of a number of herbicide resistance management options (Gehring et al., 2012; Kehlenbeck et al., 2015). Particularly in areas with high portions of winter cereals in the crop rotation, pre-sowing treatment with glyphosate provides an effective defence against blackgrass (*Alopecurus myosuroides*) and silky bentgrass (*Apera spica-venti*), which often show resistance to other common classes of herbicide active ingredients (ACCase- and ALS inhibitors). Hence, pre-sowing application is a very effective option for herbicidal removal of these weeds (Moss, 2013). The statements in our questionnaire address this issue and assess whether farmers rely on glyphosate reducing the growing resistance to selective herbicides.

- **Critical perspective on glyphosate:** As mentioned in the introduction to this paper, glyphosate has been the target of public criticism in recent years. In addition to numerous studies about its negative impact on biodiversity, more recent analyses have detected glyphosate in groundwater and in human urine (Federal Institute for Risk Assessment, 2013). Using this construct, we test whether farmers’ perceptions of public criticism have any influence on their application of the substance. Similar to Boulding (1961), we analyse in depth how the image of a product affects its use.
• **Cover crops:** There are numerous reasons to grow cover crops, such as the formation of humus, nitrogen formation and protection against erosion. However, changes in the European Union’s Common Agricultural Policy (CAP) and the introduction of ‘greening’ may affect that cultivation. The distribution of cover crops in a region varies considerably (Werner et al., 2014; Roeder et al., 2016) and depends decisively on crop rotation design. At the same time, it has become obvious in recent years that the elimination of cover crops is especially difficult and expensive when they do not freeze in mild winters. This construct measures the extent to which growing cover crops is linked to tillage and glyphosate use.

Taking into account Germany’s highly diverse agricultural structures (German Farmers’ Association, 2014), its fluctuating climate (German Meteorological Service, 2015) and expert assessment, we divided Germany into three regions, each encompassing several states. As no farmers from Berlin, Bremen or Hamburg (which comprise mainly metropolitan areas) participated in the survey, only 13 of the 16 German states were examined. The final breakdown is depicted in Figure 2.

*Figure 2. Region-specific subdivision of Germany*

- **Northwest:** Lower Saxony, North Rhine–Westphalia, Schleswig-Holstein (n = 661)
- **East:** Brandenburg, Mecklenburg–West Pomerania, Saxony, Saxony-Anhalt, Thuringia (n = 328)
• **South**: Baden-Wuerttemberg, Bavaria, Hesse, Saarland, Rhineland Palatinate (n = 1037)

## 5.5 Research design and sample description

The data we analysed were gathered through a survey of German farmers conducted between November 2014 and January 2015 using a standardized questionnaire. Although the data were collected from participants throughout the country, the sample does not fully comply with all the criteria of representativeness; therefore, it must be considered a convenience sample (FOWLER, 2002).

To draw attention to the survey, several channels were used. Based on lists provided by German companies that provide vocational training in agriculture, one thousand hard-copy surveys were sent to farmers. A press release was also published in all relevant agricultural periodicals (*Top Agrar*, *DLG Mitteilungen*, *DLZ-Magazin*, *Agrarzeitung*, *Landwirtschaft ohne Pflug*, *Allgaeuer Bauernblatt* etc.). Several of these periodicals placed a direct link to the survey on their internet homepages. The German Farmers’ Association and plant protection agencies in several federal states also alerted their farmers to the data collection. In all, 8,023 farmers received a written questionnaire or clicked on one of the online links, and 2,026 usable questionnaires were completed for the analysis—a return rate of 25.3%.

In order to prevent the risk of common method bias (cf. SOEHNCHEN, 2009), various scales (Likert scales, percentages, nominal scales, etc.) were used to rank statements and attributes. However, five-point Likert scales from -2 to 2 were the predominant means used (cf. WEIJTERS et al., 2010). Questions were constructed based on a literature review and expert discussions and pre-tested on eight respondents. The pre-testers rated the quality of the survey, examining all relevant aspects of the topic, and provided feedback on the validity of the measured variables based on the research model presented above. The survey contained various questions about individual farm parameters, such as farm size, crop rotation, number of workers and available machinery, as well as the types and extent of tillage and glyphosate application. Questions also addressed economic savings through glyphosate application. In addition, farmers responded to statements concerning soil erosion, herbicide resistance, attitude toward glyphosate use and their intention to apply glyphosate in future.
Data analysis was conducted using the statistics programmes IBM SPSS Statistics 22 and Smart PLS Version 3 (RINGLE et al., 2015). The non-parametric partial least squares method (PLS) has become a popular multivariate method for complex models and explorative studies containing novel models. PLS is a composite methodology for structural equation modelling and tests the interrelationship between the latent constructs in a single step. It is especially useful for studies that focus on predicting key driver constructs rather than testing clear hypotheses (cf. SHMUELI, 2010; GOODHUE et al., 2013; HAIR et al., 2017). PLS is not subject to any restrictions in regard to covariance between indicators of the same construct. In comparison to the ordinary least square method, PLS has significantly fewer difficulties with multicollinearity (HAENLEIN & KAPLAN, 2004) and with the illustration of factors' partial and total effects. In our analysis, the items were defined by different scales. The variation ranged from indices reflecting the shares of glyphosate and plough use as well as the growing circumference of cover crops. All constructs illustrating the attitude of farmers were ranked on five-point Likert scales (BACKHAUS et al., 2008).

5.6 Descriptive results and verification of the measurement model

5.6.1 Descriptive results

The mean age of the respondents was 47 years, 97.2% were male, and 79.1% work full-time on their farms. The rest work part-time. The study comprises several farm types: 49% cash-crop farms, 21.5% mixed farms, 17% finishing farms (pigs or poultry), 9.8% animal feed production farms, 0.9% permanent-crop farms and 1.8% other. On average, 3.8 full-time workers, 1.8 part-time workers and 4.9 seasonal farm workers are employed on the farms. The average soil score\(^1\) is 49.3 in the Northwest, 46.1 in the East and 50.5 in the South. Compared to the official German average farm size, our sample comprises larger-than-average farms in all three study areas. The mean farm size, median farm size and official mean farm size according to the German Farmers’ Association (2014) are shown in Table 1.

\(^1\) The soil score is an index describing the quality of farmland. The range of possible values is from 1 (worst) to 120 (very good).
Table 1. Mean and median farm size

<table>
<thead>
<tr>
<th></th>
<th>Northwest (ha)</th>
<th>East (ha)</th>
<th>South (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean farm size</td>
<td>173.33</td>
<td>1121.58</td>
<td>91.69</td>
</tr>
<tr>
<td>Median</td>
<td>100</td>
<td>800</td>
<td>65</td>
</tr>
</tbody>
</table>

(ha = hectare; German Farmers’ Association, 2014, n (Northwest) = 648, n (East) = 312, n (South) = 1,034)

The median is considerably lower, indicating that both small businesses and some very big farms participated. Arable land data are shown in Table 2.

Table 2. Farm size and glyphosate application in the three regions

<table>
<thead>
<tr>
<th></th>
<th>Northwest (ha)</th>
<th>East (ha)</th>
<th>South (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arable land</td>
<td>164.7</td>
<td>1031.5</td>
<td>83.3</td>
</tr>
<tr>
<td>Pre-harvest application (percent of users)</td>
<td>12.5</td>
<td>33.3</td>
<td>8</td>
</tr>
<tr>
<td>Pre-harvest application (percent of arable area)</td>
<td>2.1</td>
<td>2.8</td>
<td>1.2</td>
</tr>
<tr>
<td>Stubble application (percent of users)</td>
<td>53.8</td>
<td>80.1</td>
<td>53.1</td>
</tr>
<tr>
<td>Stubble application (percent of arable area)</td>
<td>13.5</td>
<td>28</td>
<td>13.9</td>
</tr>
<tr>
<td>Pre-sowing application (percent of users)</td>
<td>56.9</td>
<td>54.9</td>
<td>43.5</td>
</tr>
<tr>
<td>Pre-sowing application (percent of arable area)</td>
<td>18</td>
<td>10.5</td>
<td>14.7</td>
</tr>
</tbody>
</table>

(a = average)

The area of arable farming is much smaller than the total area because several respondents also farm grassland. In terms of tillage, significant differences between the three regions become obvious. Farmers in the Northwest (41.8%) and the South (38.1%) plough considerably higher shares of their land than farmers in the East (26.3%). The remaining portion of tillage is done by mulch seeding and a small share by direct seeding and strip tillage. The average of ploughing for all three regions amounts to 31.8%, which is much lower than the national average (cf. Schmitz et al., 2015). Cover crops are grown in the Northwest (14.6%) and the South (18.3%), while the share in the East is only 7.4%. Furthermore, 62.5% of all farmers participate in voluntary (e.g., game pasture, lark stripes) or monetary (flower strips, field margins) agro-environmental measures. To apply crop protection products, various techniques are used: 44.5% of the farmers use parallel tracking systems, 32% automatic boom section control of the field sprayer and 64.6% injection computers for exact spreading. The average amount of arable land, the proportion of farmers using glyphosate in the respective field of application and the proportion of cultivated land treated with glyphosate are shown in Table 2.
In general, the fiscal year 2013/2014 can be classified as an average year in terms of glyphosate use. Only 10.9% of the respondents indicated that they sprayed more glyphosate than usual; 23% of the farmers reported that they did not use pre-harvest, stubble or pre-sowing application of glyphosate in 2013/2014; 15% did not use Glyphosate at all in the year 2013/2014. However, glyphosate application patterns reveal several differences between the farm managers surveyed. Although the average share of desiccated area is low across all regions, there are clear differences between the farmers’ behaviours. While glyphosate is rarely applied for pre-harvest treatment by farmers in the Northwest (12.5%) and the South (8%), 33.3% of the farmers in the eastern part of Germany practice pre-harvest application of glyphosate. Although stubble application in the Northwest and the South are roughly the same—both in terms of overall application and of treated area—a clear deviating value exists in the eastern region, where 80.1% of the farmers surveyed use glyphosate after harvest on 28.0% of the total arable area—an acreage twice as large as in the other regions. Even with regard to pre-sowing application the eastern region assumes a special role. While only 10.5% of arable farmland in the East is treated before sowing, a greater area undergoes pre-sowing application in the South (14.7%) and Northwest (18%). At the same time, the percentage of users is at the same level in Northwest (56.9%) and East (54.9%), whereas only 43.5% of farmers in the South apply glyphosate before sowing.

Regardless of region and application type, glyphosate use depends to a large extent on the crop being cultivated. Whilst the proportion of the treated area for winter barley (32.9%), winter wheat (30.9%), maize (27%) and legumes (26.4%) is similar, the highest percentages of treated area are found in the cultivation of sugar beet (48.4%) and winter rapeseed (71.5%). Glyphosate application is also common for the re-establishment of grassland, for the destruction of couch grass, in forestry, with permanent crops (e.g., Christmas trees) and in fruit and vegetable production.

5.6.2 Verification of the measurement model

A measurement model is used to assess the correlations between the various constructs and their respective observable variables, whereas a structural model explores the relationships between the constructs taken into account in the research model. Formally, PLS models comprised an inner and an outer linear equation collectively referred to as the structural equation model.
Table 3. Overview of the constructs with their factor loadings

<table>
<thead>
<tr>
<th>Constructs</th>
<th>Statements/Items</th>
<th>Region Northwest</th>
<th>Region East</th>
<th>Region South</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>FL</td>
<td>µ</td>
<td>SD</td>
</tr>
<tr>
<td>Reduction of working time</td>
<td>Rising costs for labour and machinery lead to higher use of glyphosate on my farm.</td>
<td>1.000</td>
<td>-0.638</td>
<td>0.991</td>
</tr>
<tr>
<td>Farm size</td>
<td>Arable land</td>
<td>0.968</td>
<td>164.737</td>
<td>294.058</td>
</tr>
<tr>
<td></td>
<td>Total area of agricultural land (grassland included)</td>
<td>0.939</td>
<td>173.326</td>
<td>294.459</td>
</tr>
<tr>
<td>Risk of erosion</td>
<td>Water erosion is a problem on my farm.</td>
<td>0.770</td>
<td>-0.766</td>
<td>1.042</td>
</tr>
<tr>
<td></td>
<td>The possibility of soil erosion affects the method of farming.</td>
<td>0.942</td>
<td>-0.326</td>
<td>1.319</td>
</tr>
<tr>
<td>Herbicide resistance</td>
<td>I apply glyphosate to avoid herbicide resistance in agriculture.</td>
<td>1.000</td>
<td>0.179</td>
<td>1.400</td>
</tr>
<tr>
<td>Critical perspective on glyphosate</td>
<td>Criticism in the media about the use of glyphosate in Germany is justified.</td>
<td>0.748</td>
<td>-0.482</td>
<td>1.016</td>
</tr>
<tr>
<td></td>
<td>Many glyphosate applications can be replaced easy by other measures.</td>
<td>0.873</td>
<td>0.012</td>
<td>0.999</td>
</tr>
<tr>
<td></td>
<td>Glyphosate is used too intensively in German agriculture.</td>
<td>0.804</td>
<td>-0.091</td>
<td>0.907</td>
</tr>
<tr>
<td>Cover crops</td>
<td>Share of area of cover crops (Index)</td>
<td>1.000</td>
<td>0.198</td>
<td>0.210</td>
</tr>
<tr>
<td>Ploughing</td>
<td>Share of ploughed area on farm (Index)</td>
<td>1.000</td>
<td>0.534</td>
<td>0.347</td>
</tr>
<tr>
<td>Stubble application</td>
<td>Share of area subjected to stubble application (Index)</td>
<td>1.000</td>
<td>0.113</td>
<td>0.162</td>
</tr>
<tr>
<td>Pre-sowing application</td>
<td>Share of area subjected to pre-sowing application (Index)</td>
<td>1.000</td>
<td>0.160</td>
<td>0.212</td>
</tr>
</tbody>
</table>

(µ = mean value per farm; SD = standard deviation; a = 5-point Likert scale from 2 = very modern to -2 = very outdated; b = 5-point Likert scale from 2 = very powerful to -2 = less powerful; c = ha; d = 5-point Likert scale from 2 = completely agree to -2 = completely disagree; e = 5-point Likert scale from 2 = much more successful to -2 = much less successful; f = authors’ calculation based on data from the survey (index))
The analysis was carried out in two steps. First, the quality of the measurement model was rated with respect to its reliability and validity (goodness of fit). All items with a factor loading of at least 0.7 were considered significant and retained in the measurement model (HAIR et al., 2012, 2012a; see Table 3). In our model, not every factor comprises more than one item. Nevertheless, we decided to consider these single item constructs (see Table 3; cf. DIAMANTOPOLULOS et al., 2012; HAIR et al., 2014; HENSELER et al., 2016; SARSTEDT et al., 2016) because they are of immense importance for our model. Doing so, however, requires a cautious interpretation of the results.

Second, we assessed the internal consistency of the constructs by calculating the composite reliabilities (CR); a value > 0.7 is considered reliable (FORNELL & LARCKER, 1981). Another indicator of internal consistency is Cronbach’s alpha (CRA), which indicates that a construct is reliable if the value is > 0.6 (NUNALLY, 1978). Discriminant validity is measured using the average variance extracted (AVE), which measures the proportion of variance accounted for by certain factors and should be > 0.5 (cf. DAVCIK, 2014; see Table 4).

Finally, the calculation of the heterotrait-monotrait ratio (HTMT) shows the ratio between the cross-trait correlations and the within-trait correlations of the constructs and should be < 0.9 (HENSELER et al., 2016; HAIR et al., 2017). The remaining variables fitted into their constructs well. As in other studies, such as HEYDER & THEUVSEN (2012) and KAYSER et al. (2014), despite some small shortfalls for a few criteria, most of the specified requirements for the goodness of a measurement model are fulfilled in our model. In summary, considering the region-specific evaluation and given the high complexity of the research topic, this result can be considered satisfactory. Furthermore, the results still offer new insights into this under-researched topic.
<table>
<thead>
<tr>
<th>Latent Variables</th>
<th>NOI</th>
<th>CRA</th>
<th>CR</th>
<th>AVE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Region Northwest</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduction of working time</td>
<td>1</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Farm size</td>
<td>2</td>
<td>0.898</td>
<td>0.953</td>
<td>0.909</td>
</tr>
<tr>
<td>Risk of erosion</td>
<td>2</td>
<td>0.676</td>
<td>0.850</td>
<td>0.740</td>
</tr>
<tr>
<td>Herbicide resistance</td>
<td>1</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Critical perspective on glyphosate</td>
<td>3</td>
<td>0.751</td>
<td>0.851</td>
<td>0.656</td>
</tr>
<tr>
<td>Cover crops</td>
<td>1</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Ploughing</td>
<td>1</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Stubble application</td>
<td>1</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Pre-sowing application</td>
<td>1</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td><strong>Region East</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduction of working time</td>
<td>1</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Farm size</td>
<td>2</td>
<td>0.982</td>
<td>0.992</td>
<td>0.983</td>
</tr>
<tr>
<td>Risk of erosion</td>
<td>2</td>
<td>0.704</td>
<td>0.870</td>
<td>0.770</td>
</tr>
<tr>
<td>Herbicide resistance</td>
<td>1</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Critical perspective on glyphosate</td>
<td>3</td>
<td>0.781</td>
<td>0.871</td>
<td>0.693</td>
</tr>
<tr>
<td>Cover crops</td>
<td>1</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Ploughing</td>
<td>1</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Stubble application</td>
<td>1</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Pre-sowing application</td>
<td>1</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td><strong>Region South</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduction of working time</td>
<td>1</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Farm size</td>
<td>2</td>
<td>0.995</td>
<td>0.998</td>
<td>0.997</td>
</tr>
<tr>
<td>Risk of erosion</td>
<td>2</td>
<td>0.730</td>
<td>0.879</td>
<td>0.785</td>
</tr>
<tr>
<td>Herbicide resistance</td>
<td>1</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Critical perspective on glyphosate</td>
<td>3</td>
<td>0.789</td>
<td>0.875</td>
<td>0.700</td>
</tr>
<tr>
<td>Cover crops</td>
<td>1</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Ploughing</td>
<td>1</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Stubble application</td>
<td>1</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Pre-sowing application</td>
<td>1</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
</tbody>
</table>

(NOI = number of items; CR = composite reliability; CRA = Cronbach’s alpha; AVE = average variance extracted from the construct)
5.6.3 Results of the Structural Equation Model

Estimating a structural equation model serves to test the relationships between latent constructs. The variance explained ($R^2$) measures the goodness of fit of a regression function to data acquired empirically and thus measures the relative importance of certain exogenous latent variables for a given endogenous latent variable (BACKHAUS et al., 2008). The stated path coefficients show the directions (+ or – symbol in front of the value) and strengths of the relationships of the various paths in the structural equation model. The significance of the path coefficients are obtained through bootstrapping. Our samples were set at 5,000 resamples, so that the $t$-test was performed with 5,000 degrees of freedom (df), which is approximately the same as a $t$-test with df $= \infty$ (JAHN, 2007).

In addition, the effect size $f^2$ is examined. The effect size shows how the $R^2$ of an endogenous variable changes when an exogenous latent variable is excluded from the calculation (COHEN, 1988; HENSELER et al., 2016). The predictive relevance of the (reflective) latent endogenous variable can be evaluated using the Stone-Geisser criterion ($Q^2$). The predictive relevance of our model can be assumed with values $\geq 0$ and also complies with current guidelines.

In the following paragraphs, we present the results of our statistical analyses. Because there has been no previous research and this is the first model-based examination of glyphosate use, the $R^2$ shows fluctuating values depending on the region and the constructs. Taking into account the complexity of the model (cf. HENSELER et al., 2016) as well as the multifaceted operational purposes for using glyphosate, the results can be assessed as satisfactory. In addition to direct effects, indirect effects via one or more mediating constructs can also contribute to the two application fields as well as to tillage. The sum of both the direct and the indirect relationships form the total effects on the endogenous variable (O’CASS, 2001; HENSELER et al., 2016; HAIR et al., 2017).

Region Northwest

Figure 3 presents the results of the structural equation model for Region Northwest. The chosen constructs explain 16.2% of the variance for ‘pre-sowing application’, but only 9.0% of the variance for ‘stubble application’. Furthermore, 17.2% of the variance for ‘ploughing’ can be explained by the independent variables.
For ploughing, the constructs ‘farm size’ (-0.130****), ‘risk of erosion’ (-0.258****) and ‘herbicide resistance’ (-0.136****) show meaningful negative influences, while a ‘critical perspective on glyphosate’ (0.138****) influences ‘ploughing’ positively. Five factors have a significant effect on the ‘stubble application’ of glyphosate. ‘Reduction of working time’ (0.104****), ‘risk of erosion’ (0.068*) and ‘herbicide resistance’ (0.128***) exert a positive influence on its application, whereas ‘ploughing’ (-0.091**) and ‘critical perspective on glyphosate’ (-0.085*) have a negative influence. With regard to ‘pre-sowing application’, the factors ‘herbicide resistance’ (0.093**) and ‘cover crops’ (0.173***) exert a positive influence, whereas having a ‘critical perspective on glyphosate’ (-0.176****) and ‘ploughing’ (-0.252****) both have negative effects.

**Figure 3.** Structural Equation Model: Region Northwest

![Structural Equation Model: Region Northwest](image)

(****significant at 0.001 level (2-tailed t-test – t > 3.29); ***significant at 0.01 level (2-tailed t-test – t > 2.58); **significant at 0.05 level (2-tailed t-test – t > 1.96); *significant at 0.1 level (2-tailed t-test – t > 1.64); only significant paths are shown)

**Region East**

The measurement model in Figure 4 shows the relationships between the various constructs for the subgroup in Region East. As can be seen, ‘pre-sowing application’ has an $R^2$ of 16.7%, ‘stubble application’ an $R^2$ of 18.6% and ‘ploughing’ an $R^2$ of 17.3%. ‘Risk of erosion’ (-0.086*) and ‘herbicide resistance’ (-0.226****) influence the factor...
‘ploughing’ in a negative manner, while a ‘critical perspective on glyphosate’ (0.236****) has a positive effect on ‘ploughing’. ‘Herbicide resistance’ (0.144**) has a positive influence on the ‘stubble application’, whereas ‘ploughing’ (-0.213****), a ‘critical perspective on glyphosate’ (-0.141**) and ‘cover crops’ (-0.137**) have a negative influence on ‘stubble application’. ‘Pre-sowing application’ is positively affected by ‘cover crops’ (0.159***), but is negatively influenced by a ‘critical perspective on glyphosate’ (-0.174***), ‘farm size’ (-0.136**) and ‘ploughing’ (-0.217****).

**Figure 4.** Structural Equation Model: Region East

![Structural Equation Model: Region East](image)

(*****significant at 0.001 level (2-tailed t-test – \( t > 3.29 \)); ***significant at 0.01 level (2-tailed t-test – \( t > 2.58 \)); **significant at 0.05 level (2-tailed t-test – \( t > 1.96 \)); *significant at 0.1 level (2-tailed t-test – \( t > 1.64 \); only significant paths are shown)

**Region South**

For the Region South subsample, the model including the path coefficients and their significances is shown in Figure 5. While the construct ‘ploughing’ has an \( R^2 \) of 13.4%, about 12.9% of the variance for ‘stubble application’ and 24.1% of the variation for ‘pre-sowing application’ can be explained through our model. A ‘critical perspective on glyphosate’ (0.123****) shows a positive influence on ploughing. The constructs ‘reduction of working time’ (-0.052*), ‘farm size’ (-0.251****), ‘risk of erosion’ (-0.094***) and
‘herbicide resistance’ (-0.070**) exert a negative effect on ‘ploughing’. ‘Stubble application’ is explained by ‘herbicide resistance’ (0.131****) positively, while ‘ploughing’ (-0.164****), a ‘critical perspective on glyphosate’ (-0.115****) and ‘cover crops’ (-0.147****) influence it negatively. ‘Pre-sowing application’ is negatively influenced by ‘ploughing’ (-0.136****) and a farmer’s ‘critical perspective on glyphosate’ (-0.103****), whereas ‘risk of erosion’ (0.104****), ‘herbicide resistance’ (0.181****) and the cultivation of ‘cover crops’ (0.085**) have positive effects.

Figure 5. Structural Equation Model: Region South

5.6.4 Comparison of the three models

In order to draw reliable conclusions concerning the various influences on the choice of tillage and of glyphosate use in the regions analysed, we compared the three peer groups. Questions remain as to whether significant differences that occur between the regions can be explained by the landscape or by farm-specific characteristics or whether any differences cannot be proven statistically. To this end, we employed a permutation test for multi-group analysis (Chin & Dibbern, 2010; Henseler et al., 2016). This approach considers measurement invariance between groups. The calculation consists of
three steps: a) configural invariance (e.g., same parameterization), b) compositional invariance (equal correlations of the composites) and c) the equality of the composite averages and variances (HENSELER et al., 2016a; HAIR et al., 2017). The three steps are interdependent, and one can only be satisfied if the previous step has been fulfilled.

Table 5. Compositional invariance assessment

<table>
<thead>
<tr>
<th>Construct</th>
<th>Northwest vs South</th>
<th>Northwest vs. East</th>
<th>East vs. South</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>c</td>
<td>5 percent quantile of c</td>
<td>c</td>
</tr>
<tr>
<td>Reduction of working time</td>
<td>1.000 1.000</td>
<td>1.000 1.000</td>
<td>1.000 1.000</td>
</tr>
<tr>
<td>Farm size</td>
<td>1.000 0.999</td>
<td>1.000 1.000</td>
<td>0.999 0.997</td>
</tr>
<tr>
<td>Risk of erosion</td>
<td>0.996 0.985</td>
<td>0.996 0.984</td>
<td>0.994 0.976</td>
</tr>
<tr>
<td>Herbicide resistance</td>
<td>1.000 1.000</td>
<td>1.000 1.000</td>
<td>1.000 1.000</td>
</tr>
<tr>
<td>Critical perspective on glyphosate</td>
<td>0.998 0.995</td>
<td>0.997 0.991</td>
<td>0.998 0.993</td>
</tr>
<tr>
<td>Cover crops</td>
<td>1.000 1.000</td>
<td>1.000 1.000</td>
<td>1.000 1.000</td>
</tr>
<tr>
<td>Ploughing</td>
<td>1.000 1.000</td>
<td>1.000 1.000</td>
<td>1.000 1.000</td>
</tr>
<tr>
<td>Stubble application</td>
<td>1.000 1.000</td>
<td>1.000 1.000</td>
<td>1.000 1.000</td>
</tr>
<tr>
<td>Pre-sowing application</td>
<td>1.000 1.000</td>
<td>1.000 1.000</td>
<td>1.000 1.000</td>
</tr>
</tbody>
</table>

(Due to the differing number of respondents in the three regions, random sampling was generated for the Northwest and the South in the last two comparisons; sample size for Northwest (661) vs. South (1037); Northwest (500) vs. East (328), East (328) vs. South (500); cf. HAIR et al., 2017)

In our case, step 2 was achieved (see Table 5), but step 3 did not yield satisfying values, which means that partial measurement invariance exists, thus enabling multi-group analysis (HENSELER et al., 2016a; SCHLAEGEL & SARSTEDT, 2016).

The results in Table 6 show the differences between the regions, which are only noticeable in seven path coefficients in the three groups, indicating that the differences between the regions are not very large. Interestingly, four significant differences occur for the construct 'erosion' and the dependent construct 'pre-sowing application'.
Table 6. Group specific differences in path coefficients between the regions

<table>
<thead>
<tr>
<th>Region</th>
<th>Path coefficients</th>
<th>Δ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northwest vs. East</td>
<td>Erosion → Ploughing</td>
<td>0.197b</td>
</tr>
<tr>
<td></td>
<td>Farm size → Pre-sowing application</td>
<td>-0.176b</td>
</tr>
<tr>
<td>Northwest vs. South</td>
<td>Erosion → Ploughing</td>
<td>0.191c</td>
</tr>
<tr>
<td></td>
<td>Erosion → Pre-sowing application</td>
<td>0.168c</td>
</tr>
<tr>
<td></td>
<td>Farm size → Ploughing</td>
<td>-0.121c</td>
</tr>
<tr>
<td>East vs. South</td>
<td>Erosion → Pre-sowing application</td>
<td>0.185b</td>
</tr>
<tr>
<td></td>
<td>Ploughing → Pre-sowing application</td>
<td>-0.142a</td>
</tr>
</tbody>
</table>

(Δ= differences in path coefficients; c = significant at 0.001 level; b = significant at 0.01; a = significant at 0.05 level; only significant paths were shown)

5.7 Discussion, conclusions and further research

Statistical analysis indicates that several factors have a direct or indirect influence on the use of glyphosate in German agriculture. This study provides initial findings about the positive and negative effects of individual farm parameters and farmers’ attitudes towards the application of glyphosate. This region-specific evaluation fills a gap in current research. Although this study is the first to take a causal analytic approach, several of our findings are in line with previous, less comprehensive studies. What limits this study is the fact that the results apply only to the respondents in our data set, which is not fully representative of all German agriculture. The results cannot therefore be generalized to include the entire agricultural sector.

The extent of glyphosate's use in Germany in the major modes—pre-harvest, pre-sowing and post-harvest—has been analysed in detail (cf. SCHMITZ & GARVERT, 2012; Steinmann et al., 2012, WIESE et al., 2016, 2016a, 2017). This study adds region- and farm-specific data. Pre-harvest glyphosate application has been legally restricted in Germany and is now allowed only on subareas where harvesting would otherwise be impossible. Pre-harvest use in Germany therefore differs considerably from other appli-
cations. Furthermore, in terms of the share of arable land to be treated, pre-harvest application of glyphosate is still considered separately from the other modes of application. Across all regions, farmers treat only a small proportion of their land before harvest, although that proportion is about three times higher in the East than in the rest of the country. Nevertheless, pre-harvest application of glyphosate can have a direct influence on yield, preventing losses from threshing as well as costs for drying (Kehlenbeck et al., 2015).

Comparing the three regions shows that farm size affects the amount of glyphosate used in a different manner. As also observed by Andert et al. (2016), operational procedures (e.g., acreage, tillage) seem more decisive for the amount of glyphosate use than geographical location, although location does, of course, play a role. Although large farms register higher consumption due to the greater amount of cropland (cf. Wiese et al., 2017), even family farms and extended family farms can adapt their cultivation systems to high glyphosate use (Wiese et al., 2016). Comparing the Northwest and South regions, our analysis indicates that bigger farms in the South use more mulch seeding, which leads indirectly to higher glyphosate use. Conversely, bigger farms in Region East use less glyphosate for pre-sowing applications, which is partly attributable to a low proportion of summer crops in the crop rotation. This also explains why pre-sowing treatment in the Northwest and South is greater than in the East. Moreover, when winters are particularly mild, farmers use glyphosate on cover crops that have not frozen off. Our results indicate that, due to the CAP reform of 2014 and the introduction of ‘greening’, the use of cover crops can be expected to increase (Roeder et al., 2016), leading to a higher use of glyphosate, especially before sowing. In contrast, it does not influence stubble application before seeding of cover crops.

Nonetheless, the suspect 'desire to save time' may have a positive influence on reducing tillage and increasing glyphosate use. This is confirmed especially in the Regions Northwest and South but not by farms in Region East, which are dominated by a high number of non-family workers. Calculating the work time distribution for arable farms (cf. Agri Benchmark, 2015) shows that cash crop farms are busiest in March and April and from August through October. Farmers with only minor resources in terms of manpower and machinery tend to use glyphosate at these times especially in order to save man-hours and to overcome working peaks (Schulte et al., 2016a).
In our study, glyphosate application is a strong indicator for protection against soil erosion. Combining reduced tillage and pre-sowing application of glyphosate increases the amount of organic material on the soil, thus helping reduce soil loss. At the same time, region-specific differences are apparent. The significant differences between Regions Northwest and South suggest that farmers in the South report a slightly higher intention to use glyphosate and reduce tillage to prevent erosion. Regions Northwest and East tend to be affected by wind erosion, whereas Region South suffers more water erosion (Federal Institute for Geosciences and Natural Resources, 2015, Kehlenbeck et al., 2015). It is assumed that glyphosate or reduced tillage is an effective instrument often used to prevent water erosion. If so, the increasing precipitation in recent years (Goeman et al., 2015) might strengthen the importance of reduced tillage and, thus, the need for glyphosate application.

While the occurrence of glyphosate-resistant weeds is mainly confined to arable farming systems that include glyphosate-resistant crops, increasing resistance against selective herbicides provides a major challenge for German farmers. So far, loss of efficacy has been limited for glyphosate in comparison to post-emergence ACCase and ALS inhibitors (Hull et al., 2014). Our analysis shows that glyphosate is a very important resistance management instrument in preventing resistance against selective herbicides. Pre-sowing treatment is particularly effective because it reduces selection pressure on the subsequent post-emergence herbicide (Kehlenbeck et al., 2015). At the same time, farmers who plough only a small area must clearly use more glyphosate to prevent the development of resistance to selective herbicides. This could indicate that farmers whose farming strategy is to reduce tillage face a higher risk of herbicide resistance since replacing tillage with a higher application rate and shorter intervals between herbicide applications could lead to this problem. Therefore, combining tillage with the correct dose and application timing for selective herbicides as well as for glyphosate provides the best means of resistance management. From experience with GMO cultivation, however, it is known that farmers may not pay adequate attention to this approach (Beckie, 2011; Givens et al., 2011) since it generally increases costs in varying degrees depending on soil type and weather conditions. However, our analysis shows that farmers do not plough more land in response to growing resistance against selective herbicides. Especially in areas where resistance has already been identified (e.g., the marsh-
land region in the northern part of Germany), a change is needed in farmers’ awareness. Although herbicides promote higher farm performance in the short term, over the long term their use can result in disadvantages such as a limited product portfolio due to herbicide resistance. According to the National Action Plan on the Sustainable Use of Plant Protection Products (Federal Office of Consumer Protection and Food Safety (2015), options besides herbicides—increased tillage, a later seeding date or another type of crop rotation—could be implemented to reduce the use of plant protection products. Moreover, the effectiveness of a pesticide tax (BOECKER & FINGER, 2016) should be investigated.

Conversely, a critical attitude towards glyphosate use is linked to more ploughing and lower reliance on glyphosate. The bad image and media criticism of glyphosate may explain this. Some farmers probably agree with the public disapproval of glyphosate and are therefore uncertain about its use in general. However, an earlier descriptive analysis (WIESE et al., 2016a) based on the data presented in this study showed that farms characterised by below-average cropping area and above-average plough use are especially critical of glyphosate use. Their established production systems most probably do not require a large amount of glyphosate. Suggesting that glyphosate can be replaced by other measures is easier for them to implement than for large farming operations with below-average manpower. To sum up, farmers' varying opinions influence the type of tillage as well the amount of glyphosate applied.

As stated in the introduction, this study was exploratory; therefore, no explicit formulation of hypotheses took place, and some of the factors in our model are single item constructs. Nevertheless, the study provides starting points for manifold paths of future research. Based on our results, an exact value for glyphosate use in German agriculture should be determined by showing cost–benefit effects, including the (opportunity) costs of mechanical weed control. The question arises to what extent agronomic measures (especially tillage) or the use of selective herbicides (which are more costly) can be reduced through the use of glyphosate. In addition, quantifying trade-offs between glyphosate use and alternative weed control methods would be one way to optimize consultation with farmers. Moreover, the question arises to what extent glyphosate waivers would increase externality costs. These include the effect on the quality of groundwater through increased nitrate leaching and the use of other herbicides or in-
creasing concentration of carbon dioxide through multiple crossings for mechanical tillage.

Finally, further data collection on the use of glyphosate in permanent crops, viticulture and fruit and vegetable production would also be of interest in agricultural research. Although the total acreage of these crops in Germany is not large, the intensity of glyphosate use on them is often high (Federal Ministry of food, agriculture and consumer protection, 2013; PAPA, 2016) and should therefore be examined more thoroughly. In summary, more research is still needed on the application patterns and economic evaluation of glyphosate and other herbicides in Germany.

5.8 Acknowledgement

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Yield effects associated with glyphosate usage in non-GMO arable farming: A review

Armin Wiese und Horst-Henning Steinmann
6.1 Abstract

Glyphosate is the most commonly used herbicide worldwide as well as in European non-GMO cropping systems. In recent years, many economic studies have attempted to assess the benefits of glyphosate use in European arable farming. Among impact on fuel consumption, labour costs and other agronomic factors, yield effects of glyphosate play a central role in economic calculations. So far, these yield effects have been based generally on estimates. To determine whether existing research gives evidence for yield effects in European cropping systems, we reviewed articles by combining bibliometric and meta-analysis approaches. We searched 11,900 peer-reviewed journals for glyphosate-related studies to get an overview of glyphosate research in general and of studies on glyphosate yield effects in non-GMO arable farming in particular. In all, we located 6,841 articles that address glyphosate topics. A cluster analysis showed that a large part of the research is related to glyphosate-resistant cropping systems and toxicological topics. However, information on glyphosate yield effects in non-GMO cropping systems is also available—albeit rarely. Sixty-seven papers address the yield or weed control effects of either postharvest, presowing or preharvest treatment, while only 42 address yield effects and of these, four studies were carried out in Europe. Considering the highly diverse glyphosate application patterns, after presenting and discussing the results of all 67 articles, we conclude that there is no scientific basis for published economic calculations on glyphosate yield benefits. To cover current cropping systems adequately, future studies need to be adapted to Europe-specific arable farming conditions.

**Keywords:** Bibliometric analysis, cluster analysis, glyphosate, review, tillage, yield

6.2 Introduction

Glyphosate was first approved in 1974 as a non-selective herbicide. It is used to eliminate unwanted plants in a wide range of application areas, particularly in agriculture. With more than 826 million kilograms of glyphosate applied in 2014, it is the most widely used pesticide worldwide (BENBROOK et al., 2016). Increasing glyphosate sales were observed in the 1990s. The introduction of glyphosate-resistant crops in some major arable farming regions in the world contributed substantially to this trend. However, a significant increase in glyphosate use since the early 1990s has also been detected in
regions with non-genetically modified organism (GMO) cropping systems, such as the European Union (EU). Today, glyphosate is the most extensively applied pesticide in the EU, and the application area in France, Germany and the United Kingdom (UK) comprises 30%–40% of the total arable area (Steinmann et al., 2012, Bouchet & Cocard, 2013, Garthwaite et al., 2014). Farmers in Europe rely on glyphosate for three different uses: (1) postharvest treatment to control perennial weeds and volunteer crops, (2) pre-sowing treatment to facilitate reduced tillage, and (3) preharvest applications to facilitate use of harvest machinery and to ensure desiccation of late weed infestations (Steinmann et al., 2012; Wiese et al., 2017).

A strong dependence on glyphosate use in the EU has led to public and scientific debates about its possible impacts. The public discussion is dominated by environmental and toxicological concerns, mostly focusing on possible negative side effects and less on positive ones, such as reduced soil erosion owing to a less intensive soil tillage. In contrast, in agricultural research, welfare and profitability calculations concerning glyphosate use are given priority (Schmitz & Garvert, 2012; Bouchet & Cocard, 2013; Wynn et al., 2014; Cook et al., 2010; Schulte et al., 2017). It is generally believed that glyphosate offers sizeable economic benefits to farmers. Calculations in these studies are based on assumptions about yield decreases when glyphosate is not applied; see, for example, Wynn et al. (2014), who estimate 20% and 30% higher yields of barley, oilseed rape and wheat in the UK and France, respectively. For such crops in France and the UK, it was calculated that using glyphosate in arable farming led to increased yields valued at €988 and €633 million per year, respectively (Wynn et al., 2014). Schmitz & Garvert (2012) calculated that, as a consequence of the absence of glyphosate and yield depressions, the EU would change from a net exporter of wheat and fodder to a net importer. For the EU as a whole, a contribution to welfare of €1.4 billion per year is attributed to glyphosate (Schmitz & Garvert, 2012).

The question arises whether field studies can confirm proposed glyphosate yield effects. Herbicidal weed control operations in general can result in such yield increases as 15% in wheat and 30% in maize (Oerke et al., 2006). However, the use of glyphosate is just one part of the herbicidal weed control program; the use of selective in-crop herbicides is standard practice. Furthermore, glyphosate use occurs mainly between harvest and sowing the next crop; therefore, mechanical tillage operations can have the same effect.
Nevertheless, since the effects of mechanical operations and glyphosate applications differ depending on the purpose of use, yield differences may result (Kehlenbeck et al., 2015). Owing to a significant increase in glyphosate use since the early 1990s (>500% in Germany), when also massive land use changes occurred as a result of the EU agrarian reform (Roundvell et al., 2002; Urruty et al., 2016), various application patterns came into use. These are characterized by different application schedules before harvest and during the off-season. According to the diversity of glyphosate use patterns and agronomical situations (Wiese et al., 2017), we would expect an analogously large variety of studies. However, we found no overview on glyphosate yield and weed control effects whatsoever. This research gap will be addressed in the present study. Outcomes from this review may help researchers to determine whether application practices need further field research.

A literature search was conducted to collect all available articles related to glyphosate. To provide an overview on glyphosate literature in general, glyphosate-related articles were analysed with bibliometric approaches. Furthermore, major research topics were identified through a co-citation cluster analysis. Glyphosate articles were then examined to determine their relation to field studies of yield and weed control effects in non-GMO arable farming. To determine whether current cropping systems are covered adequately, the literature search period was restricted from the early 1990s to the present (1991–2017). The results of our findings are presented and discussed below.

6.3 Data & Methods

The literature search, filtering procedure, and analysis can be described in four steps. Step 1 included the literature search (Figure 1). For the search, we used databases with a vast coverage of peer-reviewed journals. One option is the academic search engine Google Scholar. However, this search engine lacks the quality needed for its use as a bibliometric tool (Aguillo, 2011). Instead, we used the scientific databases Science Citation Index Expanded and Social Citation Index, which include more than 8,800 and 3,100 peer-reviewed journals, respectively. The databases were accessed with the online search engine Web of Science (WoS, 2018). The titles, abstracts and keywords of available articles were searched for the term glyphosate. The search period ranged from the
early 1990s to the present (1991–2017), and 6,841 articles were identified (as of 09/03/2017).

The databases used provide various data on articles. Some of them describe the articles bibliometrically. The geographical distribution of these articles was visualized with a world map. Furthermore, the articles were sorted by research area. All journals available on Web of Science are classified into approximately 250 research areas in the arts and humanities, science and social sciences (Clarivate Analytics, 2018). In addition, the chronological appearance of articles sorted by specific groups of research areas was charted on a line graph.

To detect a glyphosate research pattern, a cluster analysis was conducted. Clusters in this context are co-citation networks built by article information on cited references. Articles that are often cited together have an increased co-citation index. A group of articles with an increased co-citation index and therefore higher similarities are summarized as a cluster. Each cluster can be thought of an underlying theme, topic, or line of research. For calculating these co-citation clusters, we used CiteSpace. The clusters are based on the 50 most commonly cited articles each year and described by typical title terms, identified with log-likelihood ratio tests (Chen, 2014).

In Step 2, 4,886 articles that did not qualify for the scope of the research focus of this paper were excluded. Articles listed in the Social Science Citation Index were excluded. Only articles in three research areas remained in our sample: Agriculture, Plant Sciences and Entomology).

In Step 3, the final sample was generated. It focused on field studies in non-GMO cropping systems regarding yield effects and also weed control effects. The following major crops were considered relevant: soybeans, wheat, oilseed rape, barley, corn, sugar beets, potatoes and oats. Papers that focus on crops with herbicide-resistant traits were not reviewed. We distinguished three kinds of glyphosate application timings: preharvest (desiccation), postharvest, and presowing. The time frame of postharvest application is usually after crops are harvested in summer, whereas presowing applications usually occur in spring. The sample was collected by reading the title, abstract and keywords.
6.4 Results

6.4.2 Geographic location of authors

Figure 1 shows the worldwide distribution of glyphosate articles. A total of 55% (n = 3762) of all papers were published by authors from organizations located in North or South America. The highest research activity by researchers in the Americas is found in the USA (40.1%; n = 2736), followed by Brazil (10.1%; n = 689), Canada (6.3%; n = 623) and Argentina (3.3%; n = 227). The share of articles published by researchers in Europe is 28% (n = 1884). The greatest number of contributions are from France (n = 256), Germany (n = 225), Spain (n = 225) and England (n = 133). Overall, 832 articles were published by researchers located in Asia (12.2%), with more than half of them from China (n = 430). In Oceania, Australia (n = 277) and New Zealand (n = 68) were the areas with the highest output. A total of 28% (n = 145) of all articles in Africa were published by researchers from Egypt (n = 41).
6.4.3 Glyphosate articles related to research areas

Glyphosate-related articles cover a broad spectrum of scientific disciplines. The journals chosen for publication of 6,841 glyphosate-related articles fall into 99 of approximately 250 research areas (~40%). Table 1 lists the 10 most relevant research areas in relation to glyphosate articles. Because journals can be classified by more than one research area, the sum of the percentages of research areas is greater than 100%. The main research areas are agriculture (46%) and plant sciences (34%). The vast majority of the remaining research areas are related to toxicology, life sciences and environmental/ecological topics.

Figure 2. Number of glyphosate articles published in each country (n=6841; 1991-2017)
Table 1. Top 10 of 99 research areas of journals chosen for the publication of glyphosate-related articles. Articles included the term *glyphosate* in either the title, abstract or keywords (n = 6841; 1991–2017; Science Citation Index Expanded, Social Science Citation Index) (see appendix for full list).

<table>
<thead>
<tr>
<th>Research areas</th>
<th>% of 6841</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>46</td>
</tr>
<tr>
<td>Plant sciences</td>
<td>34</td>
</tr>
<tr>
<td>Environmental sciences, ecology</td>
<td>17.1</td>
</tr>
<tr>
<td>Chemistry</td>
<td>10.7</td>
</tr>
<tr>
<td>Toxicology</td>
<td>7.6</td>
</tr>
<tr>
<td>Biochemistry, molecular biology</td>
<td>6.1</td>
</tr>
<tr>
<td>Entomology</td>
<td>5</td>
</tr>
<tr>
<td>Food science and technology</td>
<td>5</td>
</tr>
<tr>
<td>Biotechnology, applied microbiology</td>
<td>3.3</td>
</tr>
<tr>
<td>Forestry</td>
<td>3</td>
</tr>
</tbody>
</table>

### 6.4.4 Timeline appearance of glyphosate articles

The number of articles with the term *glyphosate* in either the title, abstract or keywords published in each year from 1991 to 2016 is shown in Figure 1. The solid line represents all articles. The dotted line indicates the articles related to the research areas agronomy, plant science and entomology, which are regarded as topics that may also have a relation to applied field studies. The broken line represents all other research areas. Red dots show global glyphosate use in 1000 tons. The number of published articles has been increasing since the late 1990s. This trend is not retrogressive until 2016. In 1991, 107 articles were published. The number of articles published in 2016 reached a total of 562. However, the number of articles published per year related to agronomy, plant science and entomology since 2012 is less than that of articles from the other research areas.
Figure 3. Number of articles that include the term *glyphosate* in the topic (glyphosate appears in either the title, abstract or keywords; Science Citation Index Expanded, Social Science Citation Index; 1991–2016; n = 6818) and global glyphosate use (tons). *BENBROOK et al. (2016).

6.4.5 Literature cluster analysis

Table 2 shows the results of the cluster analysis. The clusters are arranged by mean year of appearance of the included articles. Based on the identified title terms, the clusters were characterized by names. Three clusters (Clusters 2, 3, and 5) are associated with glyphosate-resistant cropping systems, and the largest cluster (Cluster 4) tackles toxicological topics.
Table 2. Co-citation clusters. In the co-citation network, the 50 most commonly cited articles per year are considered (1991–2017). A total of 128 clusters are identified. The 5 most relevant clusters are displayed. Cluster names are based on the interpretation of the most commonly used title terms in each cluster. Title terms were detected through log-likelihood ratio tests.

<table>
<thead>
<tr>
<th>Cluster No</th>
<th>Cluster Name</th>
<th>N=</th>
<th>Mean year¹</th>
<th>Most relevant title terms</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>“EPSP Synthase”</td>
<td>50</td>
<td>1988</td>
<td>phosphate synthase, klebsiella pneumonia, rotational-echo double-resonance nmr</td>
</tr>
<tr>
<td>2</td>
<td>“Glyphosate-tolerant crops”</td>
<td>70</td>
<td>1996</td>
<td>glycine max, polymerase chain reaction, zea mays</td>
</tr>
<tr>
<td>3</td>
<td>“Herbicide-resistant weed management”</td>
<td>55</td>
<td>2001</td>
<td>conyza canadensis, lolium rigidum, herbicide resistance</td>
</tr>
<tr>
<td>4</td>
<td>“Toxicity”</td>
<td>77</td>
<td>2007</td>
<td>oxidative stress, risk assessment, ami-nomethylphosphonic acid</td>
</tr>
<tr>
<td>5</td>
<td>“Glyphosate resistance in weeds”</td>
<td>74</td>
<td>2009</td>
<td>herbicide resistance, glyphosate resistance, gene amplification</td>
</tr>
</tbody>
</table>

¹Mean year also incorporates the publication years of cited references.

6.4.6 Weed and yield control effects in non-GMO arable farming

This section presents the results of the articles regarding yield and weed control effects in non-GMO arable farming from 1991 to 2017. A total of 65 articles fall into the scope of this research paper. Most articles were published by authors located in the USA (n = 30). African and European researchers published seven articles, respectively. The majority of the articles address no-tillage systems (n = 34), 29 address reduced tillage systems, and eight studies include ploughing as a treatment. Of the eight crops analysed, wheat is the most commonly studied.
Table 3. Number of articles on weed and yield control effects in non-GMO arable farming (1991–2017) regarding origin, tillage, crops and glyphosate application timing.

<table>
<thead>
<tr>
<th>Origin</th>
<th>No</th>
<th>Tillage</th>
<th>No</th>
<th>Crop</th>
<th>No</th>
<th>Timing</th>
<th>No</th>
<th>Topic</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>30</td>
<td>No-tillage</td>
<td>34</td>
<td>Wheat</td>
<td>24</td>
<td>Postharvest</td>
<td>22</td>
<td>Weed control</td>
<td>47</td>
</tr>
<tr>
<td>Canada</td>
<td>20</td>
<td>Reduced tillage</td>
<td>29</td>
<td>Soybeans</td>
<td>18</td>
<td>Presowing</td>
<td>42</td>
<td>Yield</td>
<td>41</td>
</tr>
<tr>
<td>Europe</td>
<td>7</td>
<td>Ploughing</td>
<td>8</td>
<td>Corn</td>
<td>21</td>
<td>Preharvest</td>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Africa</td>
<td>7</td>
<td></td>
<td></td>
<td>Barley</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>South America</td>
<td>1</td>
<td></td>
<td></td>
<td>Oilseed rape</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>.</td>
<td></td>
<td></td>
<td></td>
<td>Oats</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>.</td>
<td></td>
<td></td>
<td></td>
<td>Sugar beets</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>.</td>
<td></td>
<td></td>
<td></td>
<td>Potatoes</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Tables 4–8 summarize the results separated by postharvest (n = 22), presowing (n = 42), and preharvest applications (n = 12). Section 3.4.1 summarizes the results of the articles with a focus on more than one application.

6.4.6.1 Postharvest, presowing and/or preharvest studies (table 4)

This section includes nine articles. These include studies seeking to determine if it is most effective to apply glyphosate postharvest, presowing or both, as well as articles investigating the efficacy of additional applied selective incrop or presowing herbicides. The crops studied were soybean, corn, wheat, barley, oats and oilseed rape. Among the studies analysed, no-tillage was more common than reduced tillage. Eight studies took place in North America and one in Norway.

6.4.6.2 Postharvest studies (table 5)

One study was conducted to determine whether postharvest glyphosate application or postharvest tillage is more effective (on Setaria species after summer wheat). Four studies analysed differences in weed control and/or yield effects between postharvest glyphosate application and other herbicides applied in spring. Two studies compared less intensive tillage combined with glyphosate application with more intensive tillage without glyphosate; both studies were conducted in Europe. Of the other studies, one was conducted in Australia, and all the others in North America. Three studies compared the effectiveness of herbicides, including the use of repeated treatments or different rates of application. One study was conducted to determine time optimum timing of postharvest herbicides.
6.4.6.3 Presowing studies (table 6)

In three presowing studies it is analysed which spring management practices additional to in-crop selective herbicides were most effective for yield increase or weed control. These practices included presowing applications of glyphosate, various nonselective herbicides, tillage and no treatment. Another eight studies determined the effects of glyphosate in comparison with other presowing herbicides or combinations of glyphosate with other herbicides. Studies analysing the timing of glyphosate application or effects on weeds only were also identified.

6.4.6.4 Pre-harvest studies (table 7)

Authors in North or South America published 9 of the 12 preharvest studies we identified; the other three studies were by authors in Europe. One study indicated a positive yield effect, while all other studies found either a yield loss or no yield effect. The most common crop studied was wheat (5), followed by soybeans (4), oilseed rape (3) and barley (2). Four studies addressed the effects of glyphosate on weeds.
Table 4. Postharvest, presowing or preharvest studies. ‘>’ one treatment is more effective than another. ‘=’ treatments show comparable results. P = ploughing, R = reduced tillage, N = no-tillage; post = postharvest; pres = presowing; preh = preharvest; W = wheat; S = soybeans; C = corn; B = barley; O = oats; OR = oil seed rape; the letter ”s” or “w” in front of a crop abbreviation indicates whether the crop was sown in spring or winter, respectively. GBH = glyphosate based herbicides. Na= information not available. DAT= Days after treatment.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Country</th>
<th>Duration (years)</th>
<th>Rotation /crop</th>
<th>Tillage</th>
<th>Timing of glyphosate</th>
<th>Research focus</th>
<th>Target (weed, volunteer crops)</th>
<th>Effect on target*</th>
<th>Yield effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smiley et al., 1992</td>
<td>USA</td>
<td>Na</td>
<td>SB</td>
<td>N</td>
<td>Post, Pres (both before sb)</td>
<td>Na</td>
<td>Na</td>
<td>a &gt; b &gt; c</td>
<td></td>
</tr>
<tr>
<td>Stachler et al., 1997</td>
<td>USA</td>
<td>2</td>
<td>S, C</td>
<td>N</td>
<td>Pres, Post (a) Post (0.84 kg/ha; 1.68 kg/ha) (b) Pres (0.84 kg/ha) (effect of other herbicides were also analysed)</td>
<td>Daucus carota</td>
<td>a &gt; 74% control next spring; b: 95% (site one) and 24% (site two), at 70 DAT</td>
<td>Na</td>
<td></td>
</tr>
<tr>
<td>Harker and Vanden Born, 1997</td>
<td>CDN</td>
<td>3</td>
<td>na</td>
<td>N, R</td>
<td>Pres, Post (a) Single and (b) split applications at 220 and 880 g/ha(-1) of (c) GBH (d) sethoxydim</td>
<td>Elytrigia repens</td>
<td>a often as effective as b; c &gt; d;</td>
<td>Na</td>
<td></td>
</tr>
<tr>
<td>Blackshaw, et al. 1999</td>
<td>USA</td>
<td>4</td>
<td>Sw- flax</td>
<td>R</td>
<td>Pres, Post (a) Post (b) Pres (c) Post and Pres (no details on crop-related timing of applications in abstract)</td>
<td>Hordeum jubatum</td>
<td>a &gt; b; c &gt; a, b</td>
<td>c &gt; a , b</td>
<td></td>
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<tr>
<td>Blackshaw, 2000</td>
<td>CDN</td>
<td>5</td>
<td>Sw</td>
<td>N, R</td>
<td>Preh, Post (a) Preh (b) Post</td>
<td>Hordeum jubatum</td>
<td>a = b</td>
<td>Na</td>
<td></td>
</tr>
<tr>
<td>Torresen et al., 2003</td>
<td>NO</td>
<td>8</td>
<td>SB, SW, O</td>
<td>R, N, P</td>
<td>Pres, Post, Preh</td>
<td>Effect of tillage and herbicides on grain yields and biomass.</td>
<td>Cirsium arvense, Elymus repens, Matricaria perforate, Poa annua, Stellaria media</td>
<td>For R: GBH + post-emergence herbicide necessary; E. repens in late harvested barley: GBH applied preh or pres more effective</td>
<td>Na</td>
</tr>
<tr>
<td>Reference</td>
<td>Country</td>
<td>Duration (years)</td>
<td>Rotation /crop</td>
<td>Tillage</td>
<td>Timing</td>
<td>Research focus</td>
<td>Target species</td>
<td>Effect on target</td>
<td>Yield effect</td>
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<tr>
<td>Shaw and Mack, 1991</td>
<td>USA</td>
<td>2</td>
<td>S</td>
<td>(tillage prior to application)</td>
<td>Post</td>
<td>(a) GBH, clopyralid, dicamba, Dowco 433 or imazapyr (post) (b) Fosamine, hexazine or picloram (post) (other herbicides were also used pres)</td>
<td>Brunichia ovata</td>
<td>a &gt; b</td>
<td>Dicamba &amp; GBH increased yield</td>
</tr>
<tr>
<td>Wicks et al., 1991</td>
<td>USA</td>
<td>8</td>
<td>WW – S – Fallow</td>
<td>R, N</td>
<td>Post (after WW)</td>
<td>(a) N + GBH (b) Rototilled</td>
<td>Na</td>
<td>Na</td>
<td>a &gt; b</td>
</tr>
<tr>
<td>Higgins et al., 1991</td>
<td>USA</td>
<td>2</td>
<td>W</td>
<td>R</td>
<td>Post</td>
<td>Glufosinate, GBH, sc-0224 and paraquat (all herbicides at three different rates)</td>
<td>Chenopodium album</td>
<td>Only glufosinate at low and minimum rates provided a greater than 70% control</td>
<td>Na</td>
</tr>
<tr>
<td>Donald and Prato, 1992</td>
<td>AUS</td>
<td>2–4</td>
<td>SW</td>
<td>N</td>
<td>Post, year before SW</td>
<td>(a) GBH (b) GBH + incrop herbicide</td>
<td>Cirsium arvense</td>
<td>b &gt; a</td>
<td>Na</td>
</tr>
</tbody>
</table>

**Table 5.** Postharvest studies. ‘>’ one treatment is more effective than another. ‘=’ treatments show comparable results. P = ploughing, R = reduced tillage, N = no-tillage; post = postharvest, pres = presowing, preh = preharvest; W = wheat; S = soybeans; C = corn; B = barley; O = oats; Or = Oilseed rape; the letter “s” or “w” in front of a crop abbreviation indicates whether the crop was sown in spring or winter, respectively. GBH = glyphosate based herbicide. Na = information not available.
<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Country</th>
<th>Year</th>
<th>Treatment</th>
<th>Timing</th>
<th>Herbicides/Weed Species</th>
<th>Result(s)</th>
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<tbody>
<tr>
<td>Wicks et al., 1996</td>
<td>USA</td>
<td>1996</td>
<td>WW - C - Fallow</td>
<td>Na</td>
<td>Post WW (a) Fall (GBH + atrazine) + spring (Metolachlor + dicamba) (b) Fall (Clomazone + Atrazin)</td>
<td>Na Na b &gt; = a <strong>Reduction of in-crop herbicides by e.g. glyphosate applications in combination with other herbicides possible?</strong></td>
</tr>
<tr>
<td>Samson et al., 1996</td>
<td>CDN</td>
<td>1996</td>
<td>SB continuous</td>
<td>N</td>
<td>Post (a) In-crop herbicides (b) In-crop herbicides + post GBH</td>
<td>Weeds (not specified) b &gt; a b &gt; a <strong>Reduction of in-crop herbicides can be achieved; Best timing is in August</strong></td>
</tr>
<tr>
<td>Webster et al., 1998</td>
<td>USA</td>
<td>1998</td>
<td>WW - C</td>
<td>Na</td>
<td>Post (July, August, September) ww</td>
<td>Reducing of in-crop herbicides E.g. Setaria faberi and Ambrosia trifida <strong>Reduction of in-crop herbicides can be achieved; Best timing is in August</strong></td>
</tr>
<tr>
<td>Kegode et al., 1999</td>
<td>USA</td>
<td>1999</td>
<td>SW</td>
<td>P, R, N</td>
<td>Post (a) Post tillage operations (b) GBH</td>
<td>Setaria viridis and Setaria glauca a = b Na <strong>Timing effects yield and varies from year to year.</strong></td>
</tr>
<tr>
<td>Wicks et al., 2000</td>
<td>USA</td>
<td>2000</td>
<td>S - WW - C</td>
<td>Na</td>
<td>Post (13, 21, 33d post) Atrazine in combination with other herbicides (also GBH)</td>
<td>Several weed species GBH as a partner leads to different results; depends on timing, weed and other factors <strong>Timing effects yield and varies from year to year.</strong></td>
</tr>
<tr>
<td>Tørresen et al., 1999</td>
<td>NO</td>
<td>1999</td>
<td>Spring cereals</td>
<td>P, R, N</td>
<td>Post (a) P (b) N + GBH + postemergence or R + GBH + postemergence</td>
<td>Winter annual, biennial and perennial, monocots and dicots a = b a = b <strong>Timing effects yield and varies from year to year.</strong></td>
</tr>
<tr>
<td>Mickelson et al., 2004</td>
<td>USA</td>
<td>2004</td>
<td>Small grains</td>
<td>Na</td>
<td>Post (late July to early Sept.) Timing of several post herbicides</td>
<td>Kochia scoparia GBH &amp; paraquat most effective (late August to early September) Na <strong>Timing effects yield and varies from year to year.</strong></td>
</tr>
<tr>
<td>Stone et al., 2005</td>
<td>USA</td>
<td>2005</td>
<td>WW</td>
<td>Na</td>
<td>Post Repeated treatments (a) 2,4d + Dicamba (two rates) (b) 2,4d + GBH (c) 2,4d + Premix Quinclorac (two rates) (d) 2,4d + Picloram</td>
<td>Convolvulus arvensis Reduction of stem density up to 88% and 96% depending on the location. Na <strong>Timing effects yield and varies from year to year.</strong></td>
</tr>
<tr>
<td>Wozniak and Gos, 2014</td>
<td>PL</td>
<td>2014</td>
<td>SW</td>
<td>P,R,N</td>
<td>Post (stubble of previous crop) (a) Ploughing (b) Reduced (c) No-tillage + GBH</td>
<td>Na Na a, b &gt; c <strong>Timing effects yield and varies from year to year.</strong></td>
</tr>
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</table>
Table 6. Presowing studies. Treatment with a higher effectiveness (+, =, -). P = ploughing, R = reduced tillage, N = no-tillage; post = postharvest, pres = pre-sowing, preh = pre-harvest; W = wheat; S = soybeans; C = corn; B = barley; O = oats; Or = oilseed rape; the letter “s” or “w” in front of a crop abbreviation indicates whether the crop was sown in spring or winter, respectively. GBH = glyphosate based herbicide. Na = information not available. 1 years

<table>
<thead>
<tr>
<th>Reference</th>
<th>Country</th>
<th>Duration 1</th>
<th>Rotation/crop</th>
<th>Tillage</th>
<th>Glyphosate related research focus</th>
<th>Target species</th>
<th>Effect on target</th>
<th>Yield effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heatherly et al., 1992</td>
<td>USA</td>
<td>3</td>
<td>S</td>
<td>R, N</td>
<td>(a) GBH + post cultivation</td>
<td>Na</td>
<td>Na</td>
<td>b &gt; a</td>
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<tr>
<td></td>
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<td></td>
<td>(b) Incrop-herbicide (pre and/or postemergence herbicides)</td>
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<tr>
<td>Bruff and Shaw, 1992</td>
<td>USA</td>
<td>2</td>
<td>S</td>
<td>R</td>
<td>(a) GBH + incrop herbicides</td>
<td>Sicklepod, pitted morningglory, hemp sesbania</td>
<td>a, b &gt; c, d</td>
<td>a, b &gt; c, d</td>
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<td></td>
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<td>(b) paraquat + incrop herbicides</td>
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<td>(c) tillage + incrop herbicides</td>
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<td>(d) none+ incrop herbicides</td>
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<tr>
<td>Leroux, 1993</td>
<td>CDN</td>
<td>3</td>
<td>SW</td>
<td>P</td>
<td>Effect of initial E. repens density on control with different amounts of GBH</td>
<td>Elytrigia repens</td>
<td>1.8 &gt; 0.9 &gt; 0.45 kg a.i. ha⁻¹; 0.45 kg a.i. ha⁻¹ can be used effectively below 70 shoots/m²</td>
<td>Na</td>
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<tr>
<td>Dowling and Wong, 1993</td>
<td>AUS</td>
<td>2</td>
<td>W - W</td>
<td>R, N</td>
<td>Pre-season: (a) no weed control (b) paraquat (0.20 kg a.i./ha) (c) GBH 0.18 kg a.i./ha (d) 4 gly applications of 0.72 kg a.i./ha (d) heavy grazing, incrop herbicides and tillage (e) cultivation plus trifluralin (f) direct drilling plus chlorosulfuron (g) direct drilling alone</td>
<td>Na</td>
<td>Na</td>
<td>d &gt; a, b, c</td>
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<td></td>
<td></td>
<td>e &gt; f, g</td>
</tr>
<tr>
<td>Glenn and Heimer, 1994</td>
<td>USA</td>
<td>3</td>
<td>C</td>
<td>N</td>
<td>(a) Different herbicides presowing and incrop (b) GBH (c) GBH and 2,4-D</td>
<td>Cirsium arvense</td>
<td>a, b &lt; c</td>
<td>Treatments that controlled Cirsium arvense generally increased corn yields compared with the weedy controls.</td>
</tr>
<tr>
<td>Heatherly et al., 1994</td>
<td>USA</td>
<td>4</td>
<td>S</td>
<td>Na</td>
<td>(i) irrigated; (ni) non-irrigated (a) GBH + selective herbicides (incrop) (b) GBH at a rate to kill existing weeds at planting (c) Paraquat at a rate to desiccate but not necessarily kill existing weeds</td>
<td>Weeds (species not defined)</td>
<td>a &gt; b &gt; c</td>
<td>(i) a &gt; b &gt; c</td>
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<td>(ni) a = b &gt; c</td>
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<tr>
<td>Author(s)</td>
<td>Year</td>
<td>Country</td>
<td>Type</td>
<td>Period</td>
<td>Treatment 1</td>
<td>Treatment 2</td>
<td>Response</td>
<td>Comment</td>
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<tr>
<td>Curran et al., 1994</td>
<td>CDN</td>
<td>2</td>
<td>C</td>
<td>R, N</td>
<td>(a) Incrop selective herbicides</td>
<td>Elytrigia repens</td>
<td>b, c &gt; a</td>
<td>Na</td>
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<td>(b) GBH</td>
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<td>(c) Atrazine plus simazine</td>
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<tr>
<td>Chandler et al., 1994</td>
<td>CDN</td>
<td>2</td>
<td>S-C</td>
<td>P, R, N</td>
<td>All variants with and without GBH.</td>
<td>Elytrigia repens</td>
<td>a &gt; b &gt; c &gt; d &gt; e</td>
<td>increased control with glyphosate</td>
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<td>(a) Fall moldboard plough</td>
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<td>(b) Spring moldboard plough</td>
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<td>(c) Fall chisel- plough</td>
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<td>(d) Spring chisel- plough</td>
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<td>(e) No- tillage</td>
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<td>Hamill and Zhang, 1995</td>
<td>USA</td>
<td>5</td>
<td>S, C</td>
<td>Na</td>
<td>Different rates of GBH and SC-0224 at 0.28, 0.56 and 0.84kg/ha (with or without addition of ammonium sulfate)</td>
<td>Agropyron repens</td>
<td>Increased coverage of weed over years at 0.28kg/ha</td>
<td>At 0.28 kg/ha soybean yield reduction</td>
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<td>Arshad et al., 1995</td>
<td>CDN</td>
<td>3</td>
<td>SB, Or</td>
<td>P, R, N</td>
<td>(a) P, tillage once in fall; twice in spring</td>
<td>Weeds (not specified)</td>
<td>a &gt; b &gt; c</td>
<td>SB: a &gt; b &gt; c Or: a &gt; b &gt; c</td>
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<td>(b) R, tillage once prior to seeding</td>
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<td>(c) N + GBH</td>
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<tr>
<td>Nandula et al., 1995</td>
<td>USA</td>
<td>2</td>
<td>C</td>
<td>N</td>
<td>(a) Incrop selective herbicides</td>
<td>Muhlenbergia Frondosa</td>
<td>a &gt; b</td>
<td>Na</td>
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<td>(b) GBH</td>
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<td>Vogel, 1995</td>
<td>ZW</td>
<td>6</td>
<td>C continuous</td>
<td>R</td>
<td>(a) GBH or intercrops</td>
<td>Perennials</td>
<td>a &gt; b</td>
<td>Na</td>
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<td>(b) Hand weeding (hoe and blade)</td>
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<td>Gill, 1995</td>
<td>CDN</td>
<td>5</td>
<td>B, OR, W</td>
<td>R, N</td>
<td>(a) Medium duty cultivator 8-10 cm in conventional tillage in fall and twice in spring</td>
<td>22 weed species (perennials, annual weedy and annual broadleaf populations)</td>
<td>Effects of (a,b,c) on weed frequency on occurrence, population density and relative abundance were weed specific</td>
<td>Na</td>
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<td>(b) Same tillage once prior to seeding</td>
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<td>(c) GBH in no-tillage</td>
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<td>Harker, 1995</td>
<td>CDN</td>
<td>2</td>
<td>OR, B</td>
<td>Na</td>
<td>(a) GBH (880g/ha)</td>
<td>Elytrigia repens</td>
<td>a &gt; b</td>
<td>Na</td>
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<td>(b) Split and single applications of incrop herbicides</td>
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<td>Soon and Darwent, 1997</td>
<td>CDN</td>
<td>6</td>
<td>SB continuous</td>
<td>R</td>
<td>Combinations of GBH and/or quizalofop before fall tillage</td>
<td>Elytrigia repens</td>
<td>Reduction of shoot density and rhizome dry weight by more than 96%</td>
<td>Reducing quackgrass populations resulted in significant yield increase</td>
</tr>
<tr>
<td>Reference</td>
<td>Country</td>
<td>Year</td>
<td>Treatments</td>
<td>Species</td>
<td>Results</td>
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</table>
| Wiese, 1996               | USA     | 1996 | (a) Sweep tillage at 3 week intervals + one or two annual 2,4 D applications during the 14-mo fallow period  
(b) Tillage and 2,4 D + Dicamba or a mixture of picloram + 2,4D applied once during first October of the first 14 month fallow period  
(c) N + GBH + 2,4-D monthly, two of three treatments were supplemented with dicamba or picloram + 2,4 D | Convolvulus arvensis | a, b and c controlled Convolvulus arvensis in two fallow periods and two winter wheat crops, a, b and c increased winter wheat yields to about twice the control |
| Bruce and Kells, 1997      | USA     | 1997 | (a) Selective Presowing and incrop selective herbicides  
(b) GBH | Elytrigia repens | a > b  
a = b |
| Avv, 1997                  | NG      | 1997 | (a) GBH  
(b) hoe | Imperata cylindrica | a > b  
a > b |
| Darwent, 1998              | CDN     | 1998 | (a) Incrop applications + GBH (before barley)  
(b) Additional GBH application before oilseed rape | Sonchus arvensis | (a) From 3.9 to 0.5  
(b) From 9.2 to 0.1 | Or and B yields increased as a result of reductions in perennial S. arvensis density. |
| Udensi, 1999               | NG      | 1999 | (a) GBH + cover crop  
(b) Hand weeding | Imperata cylindrica | a = b  
Na |
| Boydston et al., 2001      | USA     | 2001 | (a) GBH + dicamba + 2,4D, or fluroxypyr  
(b) Non-treated | Volunteer potato | a > b  
a = b |
| Swanton et al., 2002       | CDN     | 2002 | (a) GBH + mechanical weed control  
(b) GBH + hand application of incrop herbicides + mechanical control  
(c) GBH + broadcast application of incrop herbicides in corn and soybean | Weeds (not specified) | b, c > a  
For C and S: b, c > a  
For WW: a = b = c |
| Johnson et al., 2002       | CDN     | 2002 | (a) GBH 2 to 3 weeks before sowing  
(b) GBH 1d before sowing  
(c) GBH 3 to 4d after sowing | Na | For W: a > b  
For W: weed control correspond to yield responses  
For W: a > b > c  
For B (Year one): Narrow hoe > simulated sweep tillage  
(Year two): simulated sweep tillage > Narrow hoe |
| Chikoye et al., 2002       | CDN     | 2002 | (a) 2 times hand weeding  
(b) GBH or 5 times hand weeding | Imperata cylindrica (L.) Raeuschel | b > a  
b > a |
<table>
<thead>
<tr>
<th>Year</th>
<th>Location</th>
<th>Weather</th>
<th>Treatment 1</th>
<th>Treatment 2</th>
<th>Treatment 3</th>
<th>Treatment 4</th>
<th>Treatment 5</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chikoye, 2005</td>
<td>NG</td>
<td>C</td>
<td>R, N</td>
<td>Treatment combinations of GBH, hoe tillage, no-tillage, row spacing, corn cultivar and cover crops</td>
<td><em>Imperata cylindrica</em></td>
<td>Tillage + GBH + cover crop = optimal control</td>
<td>Tillage + narrow row corn spacing + GBH = positive effect on corn grain yield</td>
<td></td>
</tr>
<tr>
<td>Kombiok and Alhassan, 2007</td>
<td>Ghana</td>
<td>C</td>
<td>R, N</td>
<td>(a) Hand hoe in maize (b) Bullock (c) “Tractor” (d) N + GBH (e) N</td>
<td>Broad-leaved and grass weeds</td>
<td>grass weeds not affected by the tillage systems. a, e: broad-leaved weed populations a little bit higher than in b and c; d: 97% weed control 3 weeks after planting; at harvest similar to a;</td>
<td>a, b, c, d &gt; e bullock most efficient considering costs of herbicides, tractor services and labour requirements</td>
<td></td>
</tr>
<tr>
<td>Lenssen, 2008</td>
<td>USA</td>
<td>B</td>
<td>R, N</td>
<td>(a) GBH 10, 7, 5, 3 and 0 days before sowing (b) Early, mid and delayed planting. (c) Pres tillage with field cultivator. (d) N with GBH and N without GBH (none with incrop herbicides)</td>
<td>Na</td>
<td>Na</td>
<td>When planting early, no GBH necessary in N.</td>
<td></td>
</tr>
<tr>
<td>Jaremtchuk et al., 2008</td>
<td>USA</td>
<td>S</td>
<td>N</td>
<td>(a) GBH (b) GBH + mix-partners</td>
<td>Na</td>
<td>b &gt; a</td>
<td>Na</td>
<td></td>
</tr>
<tr>
<td>Feiza, 2010</td>
<td>LT</td>
<td>&gt;10</td>
<td>na</td>
<td>P, R,N</td>
<td>(a) N + GBH (b) Reduced tillage (c) Conventional tillage</td>
<td>Weeds (not specified)</td>
<td>b, c &gt; a</td>
<td>Na</td>
</tr>
<tr>
<td>Brighenti et al., 2012</td>
<td>BR</td>
<td>C</td>
<td>R</td>
<td>GBH (0.720, 1.440, 2.160, 2.880, and 3.600 g ha⁻¹))</td>
<td><em>Cynodon nlemfuensis</em></td>
<td>Doses from 1.232 to 1.439 suppress grass;</td>
<td>Na</td>
<td></td>
</tr>
<tr>
<td>Muoni et al., 2013</td>
<td>ZW</td>
<td>2</td>
<td>C</td>
<td>R</td>
<td>(a) Combining herbicides (e.g. GBH, atrazine and metalachlor) (b) Hand weeding</td>
<td>Weeds (not specified)</td>
<td>a &gt; b</td>
<td>a = b</td>
</tr>
<tr>
<td>Mavunganidze et al., 2014</td>
<td>S. Afr.</td>
<td>na</td>
<td>C</td>
<td>P, R</td>
<td>(a) Hand weeding (b) Cyanazine (c) GBH (d) Cyanazine + Alachlor</td>
<td>Na</td>
<td>Na</td>
<td>P: d &gt; b &gt; c &gt; a</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Reference</th>
<th>Country</th>
<th>Duration (years)</th>
<th>Crops</th>
<th>Growth stages</th>
<th>GBH related research focus</th>
<th>Target species</th>
<th>Effect on target</th>
<th>Yield effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ratnayake and Shaw, 1992</td>
<td>USA</td>
<td>2</td>
<td>S</td>
<td>R5,R6</td>
<td>(a) GBH</td>
<td>Na</td>
<td>Na</td>
<td>R5: (a, b, c) -</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(b) glufosinate</td>
<td></td>
<td></td>
<td>R6: (a) = ; (b,c) -</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(c) paraquat</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Darwent et al., 1994</td>
<td>CDN</td>
<td>3</td>
<td>B, w</td>
<td>1 and 2 weeks before harvest</td>
<td>Single and repeated (up to four) applications of GBH (with different rates)</td>
<td>Cirsium arvense</td>
<td>+</td>
<td>One year after single application: Wheat +, barley =</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Darwent et al., 1994</td>
<td>CDN</td>
<td>3</td>
<td>W</td>
<td>Late July to early September</td>
<td>(a) Preharvest GBH (0.45, 0.9 or 1.7 kg acid equivalent)</td>
<td>Na</td>
<td>Na</td>
<td>(a) lower yield loss than (b)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(b) Preharvest windrowing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(c) Direct cutting of standing crop</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ivany and Doohan, 1997</td>
<td>CDN</td>
<td>3</td>
<td>B, w</td>
<td>R3 to R6</td>
<td>GBH + tallow amine ethoxylate and ammonium sulfate in different combinations</td>
<td>Elytriga repens, Menthe arvensis</td>
<td>+</td>
<td>At &lt; 30% grain moisture no effect</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ellis et al., 1998</td>
<td>USA</td>
<td>2</td>
<td>S</td>
<td>Na</td>
<td>(a) GBH</td>
<td>Pitted morningglory, hemp sesbania, spotted spurge, common cocklebur, sicklepod</td>
<td>+</td>
<td>(a,b,c) =</td>
</tr>
</tbody>
</table>

Table 7. Preharvest studies. Effect on yield compared to no application (+, =, -). W = wheat; S = soybean; C = corn; B = barley; O = oats; Or= Oilseed rape; The letter “S” or “W” in front of a crop abbreviation indicates whether the crop was sown in spring or winter, respectively. GBH = glyphosate based herbicide. Na= information not available. 1application timing. 2see scale of Fehr et al., 1971. 3Zadok Scale.
<table>
<thead>
<tr>
<th>Reference</th>
<th>Country</th>
<th>Site</th>
<th>Treatment Details</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bennett and Shaw, 2000</td>
<td>USA</td>
<td>3 S</td>
<td>R5, R6, R7, R8³ (a) GBH + sodium chlorate (b) Paraquat + sodium chlorate + surfactant</td>
<td>Na Na R5,R6: (a,b) -</td>
</tr>
<tr>
<td>Bennett and Shaw, 2000</td>
<td>USA</td>
<td>2 S</td>
<td>Na (a) GBH + sodium chlorate (different rates) (b) other herbicide combinations</td>
<td>+ Na</td>
</tr>
<tr>
<td>Darwent et al., 2000</td>
<td>CDN</td>
<td>3 Or</td>
<td>Early August to Early September GBH at rates 0.45, 0.9 and 1.7 kg equivalent ha⁻¹</td>
<td>Na Na Little or no effect</td>
</tr>
<tr>
<td>Yenish and Young, 2000</td>
<td>USA</td>
<td>2 Sw</td>
<td>70-79, 85, 87; 7 d after hard dough treatment; 1 d prior to harvest GBH only</td>
<td>Na Na At milk stage: -</td>
</tr>
<tr>
<td>Pits et al., 2008</td>
<td>PL, UA</td>
<td>3 Or</td>
<td>(I) Full maturity and (II) 10 d after (a) miconazole- A – only in autumn at rate 0.7 l ha⁻¹, B – in autumn and spring at rate 0.7 l ha⁻¹, C – in autumn and spring at rate 1 l ha⁻¹ (b) di-I-P-menten (c) dimethipin (d) diquat (e) GBH</td>
<td>Na Na (a,II,A) - (a,II,B,C) + (b,c,II) - (d,II) - (c,II) -</td>
</tr>
<tr>
<td>Mitsis et al., 2011</td>
<td>GR</td>
<td>2 Or</td>
<td>35 d after anthesis Four levels of GBH doses</td>
<td>Na Na +</td>
</tr>
<tr>
<td>Jaskulski et al., 2014</td>
<td>PL</td>
<td>3 Ww</td>
<td>BBCH 85-87 GBH (1.0 kg ha⁻¹ and 2.0 kg ha⁻¹)) Volunteer winter wheat</td>
<td>Volunteер winter wheat - Na</td>
</tr>
</tbody>
</table>
6.5 Discussion

The present study gives a broad view of glyphosate research from 1991 to 2017. Glyphosate is the most commonly used pesticide worldwide and has been described as “a once-in-a-century” herbicide (Duke, 2008). However, despite its important role, little information on glyphosate yield effects in non-GMO cropping systems is available. Knowledge about yield effects is crucial since the purpose of pesticide application is to safeguard crop yield.

Nevertheless, since the early 1990s, the overall trend in articles published per year has been increasing. The most relevant research topics are related to glyphosate resistance in crops and weeds. Meanwhile, the number of articles about glyphosate in relationship to environmental, toxicological, ecological and other such topics is even greater than that of articles investigating its role in agronomy. This may be due to the increased sensitivity toward the possible side effects of glyphosate use (van Bruggen et al., 2018) but probably also reflects the parallel global rise in glyphosate sales (Benbrook et al., 2016) and increasing cases of glyphosate-resistant weed populations (Heap, 2016).

In all, we found 67 articles regarding the research focus of this review, mostly from the USA and Canada; only four were published by European institutions. However, conclusions can be drawn for European cropping systems based on the North American research. Because the agri-environmental conditions and crops cultivated show similarities, a certain degree of comparability can be assumed. However, the two regions also have substantial disparities, and consequently, the majority of studies do not represent the typical conditions of European cropping systems. The number of crops cultivated within a crop rotation is usually lower than in Europe (cf. Landis et al., 2008), and US soil tillage intensity is also lower; moreover, since North American farmers tend to practice reduced tillage or no-tillage, the studies examined refer mainly to these tillage types. Farmers in Europe are far more likely to decide between ploughing and reduced tillage than between reduced tillage and no-tillage. The share of farms practicing no-tillage in Europe, North America, and South America is 1%, 38%, and 47%, respectively (Derpsch et al., 2010). Only a minority of the studies we found involved inversion tillage as a trial variant.
The low number of postharvest studies compared with presowing studies reflects the reduced importance of this application in the dominant crops in America, such as soybeans and corn (Prince et al., 2012). In German arable farming by contrast, 60% of the area treated with glyphosate receives postharvest applications (Wiese et al., 2016). Primarily, it is oilseed rape stubble that is treated with glyphosate, followed by other winter crops. Nevertheless, no study on postharvest application on oilseed rape stubble is available. In general, glyphosate is diversely integrated into postharvest management and interacts with cultivation passes. So far, only one study has compared postharvest applications with postharvest tillage (in summer wheat). Furthermore, farmers also apply glyphosate to promote crop health, which can be achieved by destroying green matter that may harbour pests that could damage the crop following oilseed rape postharvest. One important pathogen is clubroot (Plasmodiophora brassicae) (Steinmann et al., 2012). Because control can be achieved through cultivation passes, it is important to determine the advantages of chemical control.

Another application that was not included in the research is glyphosate use before cultivation of sugar beets. Currently, glyphosate is commonly used on sugar beet fields in Germany (47%–50%; Schmitz and Garvert, 2012; Wiese et al., 2017). These glyphosate applications can also be replaced by selective in-crop herbicides. However, in the research, weed control in sugar beets is analysed without considering the effects of glyphosate. Furthermore, the interaction of glyphosate use with tillage practices and cover cropping result in various management scenarios (Gummert et al., 2012). Presowing application of glyphosate on corn is of less importance in Europe. For this crop, we have reviewed several studies from North America. The main focus in these studies is placed on no-till but to some extent also on reduced tillage systems.

To achieve significant results, the effects of glyphosate use—contrary to the available research—should be described across the entire crop rotation. Crop rotation practices in major European arable regions have changed in recent decades, and great differences can be detected between arable regions (Steinmann & Dobers, 2013).

Under specific circumstances, preharvest applications of glyphosate are related to the yield gain of harvested crops. Glyphosate applications can enable the harvest of heavily weed-infested crop stands, which would not otherwise be harvested; thus, glyphosate
indirectly affects yield. However, at the time of preharvest application, yield losses by competition could not be reversed since they are induced by crop-weed interaction earlier in the season. In the EU, preharvest application is used mostly as an instrument for harvest planning to ensure the homogenous maturation of crop stands or to promote drying of crops (STEINMANN et al., 2012), which is not related to yield increases. Accordingly, the preharvest studies analysed gave no evidence of a direct impact on yield. The lack of evidence about glyphosate yield effects probably leads to wrong assumptions, resulting in an enormous overestimation of its economic benefits. This probably also influences farmers’ beliefs concerning glyphosate yield effects, which in turn may unnecessarily intensify glyphosate use. Overuse should be avoided since it is uncertain whether the EU will continue to approve glyphosate use (EC, 2018), and overuse could unnecessarily further jeopardize approval.

6.6 Conclusion

Glyphosate is the most commonly used and analysed pesticide worldwide and in the EU. Nevertheless, our review reveals that there are nearly no useable studies available regarding yield effects in current non-GMO cropping systems. Based on the studies we found, we conclude that there is no scientific basis for published economic calculations on glyphosate benefits. Studies need to be adapted to EU-specific arable farming conditions to cover current cropping systems adequately. The findings of our analysis may influence agronomists to increase glyphosate research to enable calculation of its economic benefits and to promote more conservative and efficient glyphosate use.

6.7 Acknowledgements

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Kapitel 7

Diskussion & Schlussfolgerung
Diskussion & Schlussfolgerung

Glyphosat ist weltweit und auch in Europa der am häufigsten verwendete Pflanzen-
schutzmittel-Wirkstoff. Dennoch sind zur Ertragswirksamkeit und zum Einsatz im eu-
ropäischen und somit auch im deutschen Ackerbau kaum Analysen und Datengrundla-
gen verfügbar. Deshalb gibt es bislang kaum ausreichende Antworten auf Fragen, wie
landwirtschaftliche Betriebe Glyphosat anwenden und welche Ertragswirkungen durch
den Wirkstoff hervorgerufen werden. Im Rahmen der vorliegenden Dissertation wurde
ein umfangreicher Datensatz zum Einsatz von Glyphosat in Deutschland erhoben und
ausgewertet sowie weltweite Studien zu Ertragseffekten von Glyphosat im Nicht-GVO-
Ackerbau gesammelt und analysiert.

Um Daten zur Glyphosatanwendung zu gewinnen, wurde eine deutschlandweite Umfra-
ge durchgeführt, an der sowohl online als auch per Brief teilgenommen werden konnte.
Diese Erhebungsmethode hat Vor- und Nachteile im Vergleich zur Erhebung von An-
wendungsdaten aus einem festen Betriebsnetz (ROßBERG, 2016) oder aus Ackerschlag-
carteien (ANDERT et al., 2016). Auch wenn das Sample der Umfrage dieser Dissertation
mittels Plausibilitätsüberlegungen gründlich überprüft worden ist, kann bei Umfragen
kaum ausgeschlossen werden, dass auch fehlerhafte Angaben gemacht werden. Unter
Annahme einer gewissen Fehlervarianz im Sample steigt die Repräsentativität einer
Umfrage mit steigender Teilnehmeranzahl; diese ist im vorliegenden Fall mit 2.026
Teilnehmern sehr hoch (BARLETT et al., 2011). Im Gegensatz zur Datenerhebung aus
Ackerschlagcarteien oder aus einem Testbetriebsnetz besteht der Vorteil, dass die Teil-
nahme anonym erfolgt, während die anderen Optionen direkten Kontakt mit Landwirten
erfordern, weshalb von einer gewissen Hemmschwelle bei der Herausgabe sensibler
Betriebsdaten auszugehen ist. Auch bei einer Umfrage kann die Teilnahmeebereitschaft
der Zielgruppe unterschiedlich ausgeprägt sein (BOSNIJAK & BATINIC, 1999). Obwohl
die im Rahmen der vorliegenden Arbeit durchgeführte Umfrage Anwender als auch
Nichtanwender von Glyphosat adressierte und ein hoher Anteil Nichtanwender im
Sample sind, kann nicht ausgeschlossen werden, dass Glyphosatanwender ein größeres
Interesse an einer Teilnahme haben (MUTZ et al., 2018). Andererseits ist das Thema
„Glyphosat“ in der Landwirtschaft aktuell von hoher Brisanz – ebenso wie das Thema
„Tierwohl“. Diese Themen sind mitbestimmend für die Wahrnehmung der Landwirt-
schaft in der Öffentlichkeit. Deswegen ist es naheliegend, dass auch Nichtanwender ihre Meinung zum Glyphosateinsatz mitteilen wollen.


in Zukunft womöglich eine höhere Nachfrage bestehen, wodurch ein Innovationsfortschritt zu erwarten wäre. Würde statt eines Verbots eine Mengenreduktion das politische Ziel sein, wären die analysierten und betriebsstrukturell nun bekannten Nicht- oder Weniganwender nicht oder kaum betroffen, wohl aber die Vielanwender.

**Literatur**


Zusammenfassung

Glyphosat ist weltweit und auch in Europa der am häufigsten eingesetzte Pflanzenschutzmittel-Wirkstoff. In Deutschland und in der gesamten EU wird darüber diskutiert, ob Glyphosat weiterhin zulassungsfähig ist, aber auch die Notwendigkeit einzelner Anwendungen und der Anwendungsumfang stehen zur Debatte. Um Fragen zum zukünftigen Umgang mit Glyphosatherbiziden zu klären, sind zunächst jedoch weitere Erkenntnisse zum Einsatz, aber auch zur Ertragswirkung notwendig.

Ziel der vorliegenden Dissertation war es, zum Glyphosateinsatz Bestimmungsfaktoren und detaillierte Anwendungsmuster zu bestimmen sowie eine Übersicht über Auswirkungen auf den Ertrag von Kulturen im Nicht-GVO-Anbau zu erstellen. Zu diesem Zweck wurde mit einer Landwirte-Befragung ein Datensatz (n = 2026) zum Glyphosateinsatz generiert und ausgewertet, sowie eine Übersicht zu weltweiten Glyphosat-Studien erstellt (n = 6841), die dann auf Beziehungen zu Ertragswirkungen im Nicht-GVO-Anbau analysiert worden sind. Der Fragebogen umfasste 38 Fragekonstrukte bestehend aus betrieblichen Daten, Details zur Glyphosanwendung sowie fachlichen und persönlichen Einschätzungen.


Während es für Wirkungsstudien noch Forschungsbedarf gibt, liegen basierend auf dieser Arbeit bereits fundierte Erkenntnisse zur Anwendung von Glyphosat vor. Die empirische Analyse dieser Dissertation gibt Anlass zu der Vermutung, dass Glyphosat oftmals auch als Routineanwendung in stark rationalisierten Betriebsabläufen zum Einsatz kommt. Dies gilt insbesondere für die Stoppelanwendungen. Entsprechend den von Be-
trieb zu Betrieb unterschiedlichen Anwendungsmustern werden die Anpassungskosten
im Falle eines Glyphosatverbots auf einigen Betrieben sehr gering ausfallen oder gar
nicht vorhanden sein und auf anderen Betrieben sehr groß ausfallen. Einige Betriebe
werden ihr Anbaumanagement deutlich umstellen müssen.
Sehr geehrte Damen und Herren,

der Einsatz von Glyphosat ist in den vergangenen Jahren vermehrt Gegenstand politischer und gesell-
schaftlicher Diskussionen geworden, die oftmals emotional geführt werden. Als neutrale Institution möchten wir uns hiervon klar distanzieren. Nun ist die landwirtschaftliche Praxis gefordert, Antworten zum Glyphosateinsatz zu geben, um sachliche Erkenntnisse zu liefern. Zusammen mit dem Bundesminis-
terium für Ernährung und Landwirtschaft (BMEL) führen wir eine Umfrage unter konventionell wirt-
schaftenden Landwirten durch, um unterschiedliche Anwendungsgebiete des Glyphosateinsatzes zu un-
tersuchen und zu bewerten. Neben der Darstellung des wirtschaftlichen Nutzens für Landwirte möchten wir auch Beratungsempfehlungen für den nachhaltigen Einsatz entwickeln, sodass Sie als Landwirt un-
mittelbar von dieser Umfrage profitieren.

Um eine umfassende Darstellung bezüglich des Glyphosateinsatzes im deutschen Ackerbau machen zu können, sind wir auf Ihre Mithilfe angewiesen. Jeder Fragebogen zählt. Mit einem Fragebogen können in der Regel nicht alle Besonderheiten erfasst werden, sodass bestimmte Antwortmöglichkeiten vielleicht nicht ganz auf Sie zutreffen. Kreuzen Sie in so einem Fall bitte die Antwort an, mit der Sie sich am ehes-
ten identifizieren können. Selbstverständlich möchten auch Sie über die Ergebnisse dieser Umfrage informiert werden. Daher wer-
den wir die Ergebnisse nach der Auswertung in einschlägigen landwirtschaftlichen Fachjournalen veröffentli-
chen. Die Umfrage wird anonym durchgeführt und die Antworten können nicht zurückverfolgt werden. Herzlichen Dank für Ihre Teilnahme und Ihre Unterstützung unseres Projekts.

Mit freundlichen Grüßen
Zu Beginn der Befragung würden wir gerne einige generelle Informationen über Ihren Betrieb erfahren, damit die Ergebnisse besser einzuordnen sind.

1. In welchem Landkreis befindet sich Ihr Betrieb? (bitte KFZ-Kennzeichen angeben)

2. Betreiben Sie Ihren Betrieb im Haupt- oder im Nebenerwerb?

□ Haupterwerb □ Nebenerwerb

3. Aus welchem Betriebszweig erzielen Sie das größte Einkommen (Kreuzen Sie bitte nur eine Antwort an)?

□ Veredlungsbetrieb □ Futterbaubetrieb □ Gemischtbetrieb
□ Dauerkulturbetrieb □ Ackerbaubetrieb □ Sonstiges: ______________

4. Wie viele ha landwirtschaftliche Nutzfläche bewirtschaften Sie insgesamt?

5. Welche Kulturen haben Sie 2013/2014 angebaut, auf wie viel Hektar und wie hoch sind Ihre durchschnittlichen Erträge?

<table>
<thead>
<tr>
<th>Kultur</th>
<th>Anbauumfang (ha)</th>
<th>Grobe Schätzung des durchschnittlichen Ertragsniveaus (dt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winterweizen</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


1. ____________________________  2. ____________________________  3. ____________________________

7. Bitte nennen Sie uns die durchschnittliche Bodenpunktzahl (BP) Ihrer Flächen:

Ackerland: ca. _______ BP  Grünland: ca. _______ BP
8. Wie stufen Sie die Hangneigungen auf Ihren Flächen ein?

<table>
<thead>
<tr>
<th>Hanglage</th>
<th>Anteil der Ackerfläche (ungefähr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eben</td>
<td>(0-2%)</td>
</tr>
<tr>
<td>Leicht hängig</td>
<td>(2-7%)</td>
</tr>
<tr>
<td>Hanglagen</td>
<td>(&gt;7%)</td>
</tr>
</tbody>
</table>

9. Welche Bodenarten liegen auf Ihren bewirtschafteten Ackerflächen vor?

<table>
<thead>
<tr>
<th>Bodenart</th>
<th>% der bewirtschafteten Fläche (ungefähr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leichter Boden (Sandboden, lehmiger Sand)</td>
<td>%</td>
</tr>
<tr>
<td>Mittlerer Boden (sandiger Lehm, Lehm, schwerer Lehm)</td>
<td>%</td>
</tr>
<tr>
<td>Schwerer Boden (Sand Tonboden)</td>
<td>%</td>
</tr>
</tbody>
</table>

10. An dieser Stelle würden wir gerne einige Details zum Zustand Ihrer Böden erfahren. Bitte kreisen Sie die zutreffenden Zahlen ein, wie in folgendem Beispiel, in dem jemand sehr gerne Auto fährt.

Ich fahre gerne Auto ...... Trifft völlig zu 0 2 3 4 5 Trifft überhaupt nicht zu

Jemand der unentschlossen ist, ob er gerne Auto fährt oder nicht, antwortet wie folgt:

Ich fahre gerne Auto ...... Trifft völlig zu 1 2 3 4 5 Trifft überhaupt nicht zu

<table>
<thead>
<tr>
<th>Wie hat sich Ihr Bodenzustand in den letzten 10-30 Jahren verändert?</th>
<th>Ist viel besser geworden 1 2 3 4 5 Ist viel schlechter geworden</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sind bodenbürtige Krankheiten ein Problem auf Ihrem Betrieb?</td>
<td>Überhaupt nicht 1 2 3 4 5 Sehr großes Problem</td>
</tr>
<tr>
<td>Haben Sie auf Ihrem Standort Probleme mit durchwachsenden Unkräutern?</td>
<td>Überhaupt nicht 1 2 3 4 5 Sehr großes Problem</td>
</tr>
</tbody>
</table>


________________ ________________ ________________

12. Welche Zwischenfrüchte haben Sie 2013/2014 angebaut und zu welchen Kulturen?

<table>
<thead>
<tr>
<th>Zwischenfrüchte</th>
<th>Nachfolgende Frucht</th>
<th>Anbauumfang (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
13. Nehmen Sie an Agrarumweltmaßnahmen teil (mit vertraglich festgelegter Vergütung)?

□ ja  □ nein

14. Ich lege freiwillig andere Umweltmaßnahmen auf meinen Flächen an (unentgeltlich, z.B. Lerchenfenster oder Wildäcker)

□ ja  □ nein

Falls zutreffend, um welche Maßnahmen handelt es sich?

________________

15. Wie viele Arbeitskräfte arbeiten auf Ihrem Betrieb (inklusive Familien-Arbeitskräfte)?

<table>
<thead>
<tr>
<th>Vollzeitarbeitskräfte</th>
<th>Teilzeitarbeitskräfte (6-12 Monate)</th>
<th>Saisonarbeitskräfte (unter 6 Monaten)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

16. Wie sehr treffen folgende Fragen auf Ihren Betrieb zu?

| Bei Betrachtung Ihres Maschinenparks, wie modern würden Sie diesen einschätzen? | sehr modern | 1 2 3 4 5 sehr veraltet |
| Denken Sie, dass Sie über einen schlagkräftigen Maschinenbesatz für die Bodenbearbeitung verfügen? | sehr schlagkräftig | 1 2 3 4 5 wenig schlagkräftig |

17. Welche Tätigkeiten im Ackerbau lassen Sie auf Ihrem Betrieb durch Lohnunternehmer durchführen?

□ komplette Eigenmechanisierung  □ Bodenbearbeitung  □ Spritztätigkeiten

□ Stroh-/ Futterbergung  □ Mähdruscharbeiten  □ Sonstiges ____________

18. In welchem Umfang haben Sie im Jahr 2013/2014 die folgenden Bodenbearbeitungsverfahren angewendet?

<table>
<thead>
<tr>
<th>Pflügen</th>
<th>Pfluglose Bodenbearbeitung</th>
<th>Direktsaat</th>
<th>Anderes und zwar:</th>
</tr>
</thead>
<tbody>
<tr>
<td>............ha</td>
<td>..................ha</td>
<td>..................ha</td>
<td>..................ha</td>
</tr>
</tbody>
</table>

139
19. Wo würden Sie Ihre Getreideaussaattechnik einordnen?

- Saatbettkombination plus separate Drillmaschine □
- Zapfwellengetriebene Drillkombination (z.B. Kreiselegge mit Drillmaschine) □
- Gezogenes Mulch- oder Direktsaatgerät (Väderstad, Horsch Pronto, Köckerling, Amazone o.a.) □

Im nächsten Fragenblock würden wir gerne wissen, in welchen Bereichen Sie 2013/2014 glyphosat-haltige Herbizide verwendet haben.

20. Haben Sie im Wirtschaftsjahr 2013/2014 Glyphosat eingesetzt?
   □ ja  □ nein
   Wenn nicht, dann fahren Sie bitte mit Frage 25 fort.

   □ ja  □ nein
   Falls ja, wie viel Prozent mehr Glyphosat haben Sie im Vergleich zu „normalen Jahren“ eingesetzt?
   ____________________ %

22. Unter Vorerntebehandlung (Sikkation) ist die Applikation von Glyphosat in einen stehenden oder liegenden Bestand gemeint. Bitte geben Sie an, inwiefern dieses bei ihnen auf dem Betrieb eine Rolle spielt.

<table>
<thead>
<tr>
<th>Anbaufrucht</th>
<th>Behandelte Fläche in ha</th>
<th>Grund</th>
<th>Aufwandmenge in l/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wintergerste</td>
<td></td>
<td>□ Zwiewuchs</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>□ Durchwuchs (Ungras/Unkraut)</td>
<td></td>
</tr>
<tr>
<td>Winterraps</td>
<td></td>
<td>□ Zwiewuchs</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>□ Durchwuchs (Ungras/Unkraut)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>□ Zwiewuchs</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>□ Durchwuchs (Ungras/Unkraut)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>□ Zwiewuchs</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>□ Durchwuchs (Ungras/Unkraut)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>□ Zwiewuchs</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>□ Durchwuchs (Ungras/Unkraut)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>□ Zwiewuchs</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>□ Durchwuchs (Ungras/Unkraut)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>□ Zwiewuchs</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>□ Durchwuchs (Ungras/Unkraut)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>□ Zwiewuchs</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>□ Durchwuchs (Ungras/Unkraut)</td>
<td></td>
</tr>
</tbody>
</table>
23. Als **Stoppelbehandlung** verstehen wir die Applikation von Glyphosat nach der Ernte auf den Stoppelacker beziehungsweise auf eine Fläche, die bereits beackert wurde. Das zeitliche Fenster reicht von der Ernte bis etwa drei Wochen vor Aussaat der Folgefrucht.
Bitte geben Sie weiterhin an, wie Ihre Bodenbearbeitung nach der Ernte 2013/2014 aussah und ob Sie durch die Spritzung Arbeitsgänge zur Bodenbearbeitung einsparen konnten (Mehrfachnennungen sind möglich!).

<table>
<thead>
<tr>
<th>Feldfrucht, deren Stoppeln bzw. Überreste behandelt werden</th>
<th>Behandelte Fläche in ha</th>
<th>Aufwandmenge in l/ha</th>
<th>Art und Anzahl der mechanischen Stoppelbearbeitung</th>
<th>Durch Glyphosatanwendung Einsparung von</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>(Beispiel)</em> Winterraps</td>
<td>120</td>
<td>3</td>
<td>1 x Grubber 1 x Scheibenegge</td>
<td>1 x Grubber</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>□ keine (Direktsaat)</td>
<td>x Pflug</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>□ keine (Direktsaat)</td>
<td>□ keine Einsparung</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>□ keine (Direktsaat)</td>
<td>□ keine Einsparung</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>□ keine (Direktsaat)</td>
<td>□ keine Einsparung</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>□ keine (Direktsaat)</td>
<td>□ keine Einsparung</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>□ keine (Direktsaat)</td>
<td>□ keine Einsparung</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>□ keine (Direktsaat)</td>
<td>□ keine Einsparung</td>
</tr>
</tbody>
</table>

Bitte geben Sie weiterhin an, wie Ihre Bodenbearbeitung vor der Aussaat 2013/2014 aussah und ob Sie durch die Spritzung Arbeitsgänge zur Bodenbearbeitung einsparen konnten (Mehrfachnennungen sind möglich!).

<table>
<thead>
<tr>
<th>Anbaufrucht, zu der die Behandlung durchgeführt wird</th>
<th>Behandelte Fläche in ha</th>
<th>Aufwandmenge in l/ha</th>
<th>Art und Anzahl der Arbeitsgänge vor der Saat</th>
<th>Durch Glyphosatanwendung Einsparung von</th>
</tr>
</thead>
<tbody>
<tr>
<td>_ x Grubber/Egge</td>
<td>□ Pflug</td>
<td>□ _ x Grubber/Egge</td>
<td>□ Pflug</td>
<td>□ _ x Grubber/Egge</td>
</tr>
<tr>
<td>□ keine (Direktsaat)</td>
<td>□ keine (Direktsaat)</td>
<td>□ keine (Direktsaat)</td>
<td>□ keine (Direktsaat)</td>
<td>□ keine (Direktsaat)</td>
</tr>
</tbody>
</table>


□ nein  □ ja, und zwar __________________________

17. Geben Sie bitte an, welches Glyphosatprodukt Sie bevorzugt anwenden.

□ Roundup Powerflex □ Roundup Turbo □ Glyfos Dakar
□ Glyfos Supreme □ Dominator □ Sonstiges _____________

27. Nutzen Sie die folgenden Techniken im Ackerbau?

<table>
<thead>
<tr>
<th>Nein</th>
<th>Ja</th>
<th>Gelegentlich</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parallelfahrssystem oder automatisches Lenkfahrssystem</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>Am Traktor angebrachte Pflanzenbausensoren</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>Automatische Teilbreitenschaltung am Spritzgestänge</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>Spritzcomputer</td>
<td>□</td>
<td>□</td>
</tr>
</tbody>
</table>
28. Im nächsten Fragenblock thematisieren wir den Zwischenfruchtanbau sowie die Erosionsanfälligkeit auf Ihren Flächen. Bitte kreuzen Sie an, inwiefern die folgenden Aussagen auf Sie zutreffen.

<table>
<thead>
<tr>
<th>Aussage</th>
<th>Trifft voll und ganz zu</th>
<th>Trifft zu</th>
<th>Teils/Teils</th>
<th>Trifft nicht zu</th>
<th>Trifft ganz und gar nicht zu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wassererosion ist ein Problem auf meinem Betrieb</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>Winderosion ist ein Problem auf meinem Betrieb</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>Die Erosionsanfälligkeit des Bodens beeinflusst die Form der Bewirtschafterung</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>Ich baue gezielt Zwischenfrüchte an, um Erosion zu vermindern</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>Durch Glyphosatanwendungen wird der Zwischenfruchtanbau erleichtert</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
</tbody>
</table>

29. Pflanzenschutzberater und Forschungseinrichtungen berichten seit geraumer Zeit von einer zunehmenden Herbizidresistenz. Welche Erfahrungen haben Sie auf Ihrem Acker gemacht?

<table>
<thead>
<tr>
<th>Aussage</th>
<th>Trifft voll und ganz zu</th>
<th>Trifft zu</th>
<th>Teils/Teils</th>
<th>Trifft nicht zu</th>
<th>Trifft ganz und gar nicht zu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infolge von Herbizidresistenz unbrauchbar gewordene Wirkstoffe können durch neue ersetzt werden.</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>Auf meinem Betrieb wirken einige selektive Herbizide nicht mehr so gut wie früher</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>Wenn ja, nennen Sie bitte betroffene Unkräuter/Ungräser und Pflanzenschutzmittel:</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>Die Wirkung von Glyphosat hat in den letzten Jahren bereits nachgelassen.</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>Wenn ja, nennen Sie bitte betroffene Unkräuter/Ungräser:</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>Wenden Sie Glyphosat zum Anti-Resistenzmanagement an?</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
</tbody>
</table>
30. Wie erfolgreich schätzen Sie Ihren eigenen Betrieb im Vergleich zum Durchschnitt Ihrer Branche ein?

<table>
<thead>
<tr>
<th>Viel erfolgreicher</th>
<th>Erfolgreicher</th>
<th>Genauso erfolgreicher</th>
<th>Weniger erfolgreich</th>
<th>Viel weniger erfolgreicher</th>
</tr>
</thead>
<tbody>
<tr>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
</tbody>
</table>

31. Wie stehen Sie zu folgenden Statements bezüglich der zukünftigen Ausrichtung Ihres Betriebes?

<table>
<thead>
<tr>
<th>Wenn ich über die Entwicklung meines Betriebes in den vergangenen Jahren nachdenke, würde ich sagen, dass der Betrieb als zukunftsfähig bezeichnet werden kann</th>
<th>Trifft voll und ganz zu</th>
<th>Trifft zu</th>
<th>Teils/Teils</th>
<th>Trifft nicht zu</th>
<th>Trifft ganz und gar nicht zu</th>
</tr>
</thead>
<tbody>
<tr>
<td>□ □ □ □ □</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ich strebe in den nächsten Jahren einen Betriebswachstum (Ackerbau/Veredlung, etc.) an</th>
<th>Trifft voll und ganz zu</th>
<th>Trifft zu</th>
<th>Teils/Teils</th>
<th>Trifft nicht zu</th>
<th>Trifft ganz und gar nicht zu</th>
</tr>
</thead>
<tbody>
<tr>
<td>□ □ □ □ □</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Auch ohne den Einsatz von Glyphosat werde ich die bisherigen betriebswirtschaftlichen Ergebnisse erreichen</th>
<th>Trifft voll und ganz zu</th>
<th>Trifft zu</th>
<th>Teils/Teils</th>
<th>Trifft nicht zu</th>
<th>Trifft ganz und gar nicht zu</th>
</tr>
</thead>
<tbody>
<tr>
<td>□ □ □ □ □</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
</tbody>
</table>

31. Wie stehen Sie zu folgenden Aussagen in Hinblick auf den zukünftigen Einsatz von glyphosat-haltigen Herbiziden?

<table>
<thead>
<tr>
<th>Bei höheren Erzeugerpreisen würde ich mehr Glyphosat einsetzen.</th>
<th>Trifft voll und ganz zu</th>
<th>Trifft zu</th>
<th>Teils/Teils</th>
<th>Trifft nicht zu</th>
<th>Trifft ganz und gar nicht zu</th>
</tr>
</thead>
<tbody>
<tr>
<td>□ □ □ □ □</td>
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</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bei einer Verdopplung der Glyphosatpreise würde ich weniger Flächen mit dem Wirkstoff behandeln.</th>
<th>Trifft voll und ganz zu</th>
<th>Trifft zu</th>
<th>Teils/Teils</th>
<th>Trifft nicht zu</th>
<th>Trifft ganz und gar nicht zu</th>
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</thead>
<tbody>
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<td>□</td>
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</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Steigende Lohnkosten führen dazu, dass mehr Glyphosat auf meinen Flächen eingesetzt wird.</th>
<th>Trifft voll und ganz zu</th>
<th>Trifft zu</th>
<th>Teils/Teils</th>
<th>Trifft nicht zu</th>
<th>Trifft ganz und gar nicht zu</th>
</tr>
</thead>
<tbody>
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<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Die Ersparnis von Arbeitszeit ist für mich ausschlaggebend für den Glyphosateinsatz</th>
<th>Trifft voll und ganz zu</th>
<th>Trifft zu</th>
<th>Teils/Teils</th>
<th>Trifft nicht zu</th>
<th>Trifft ganz und gar nicht zu</th>
</tr>
</thead>
<tbody>
<tr>
<td>□ □ □ □ □</td>
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<td>□</td>
<td>□</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bei sinkenden Treibstoffpreisen würde ich weniger Glyphosat einsetzen und dafür mehr auf mechanische Bodenbearbeitung setzen</th>
<th>Trifft voll und ganz zu</th>
<th>Trifft zu</th>
<th>Teils/Teils</th>
<th>Trifft nicht zu</th>
<th>Trifft ganz und gar nicht zu</th>
</tr>
</thead>
<tbody>
<tr>
<td>□ □ □ □ □</td>
<td>□</td>
<td>□</td>
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<td>□</td>
<td>□</td>
</tr>
</tbody>
</table>
Die jüngsten Anwendungseinschränkungen von Glyphosat (z. B. kein Einsatz zur Abreifebeschleunigung, max. zwei Behandlungen pro Jahr) haben betriebliche Nachteile für mich zur Folge. □ □ □ □ □ □

Mit einer technisch ausgereifteren Bodenbearbeitungstechnik könnte ich weniger Glyphosat einsetzen. □ □ □ □ □ □

Wenn es bessere Technik zur Bekämpfung von Wurzelunkräutern (bspw. Quecke) gäbe, würde ich weniger Glyphosat einsetzen. □ □ □ □ □ □

32. Haben Sie Probleme bei Ihrer Bodenbearbeitung, die durch Glyphosatanwendungen besser zu lösen sind? Wenn ja, schildern Sie diese bitte im Folgenden:

33. Gegen Ende der Umfrage haben wir noch einige Fragen zur öffentlichen Diskussion über glyphosathaltige Mittel. Wie ist Ihre Meinung zu folgenden Aussagen?

<table>
<thead>
<tr>
<th>Aus sage</th>
<th>Trifft voll und ganz zu</th>
<th>Trifft zu</th>
<th>Teils/Teils</th>
<th>Trifft nicht zu</th>
<th>Trifft ganz und gar nicht zu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Die Kritik in den Medien am Glyphosat-</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>einsatz in Deutschland halte ich für gerechtfertigt</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Viele Glyphosatanwendungen können leicht</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>durch andere Maßnahmen ersetzt werden</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In der deutschen Landwirtschaft wird</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>Glyphosat zu intensiv eingesetzt</td>
<td></td>
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</tr>
<tr>
<td>Funde von Glyphosat in deutschen Gewässern</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
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<tr>
<td>sind ein Problem</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Glyphosat hat bei mir zu Auflaufschäden</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>geführt</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Es ist wichtiger Energie einzusparen als</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>Pflanzenschutzmittel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ich arbeite lieber mit Bodenbearbeitungsgeräten als mit Feldspritzen</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>Ich versuche gezielt Glyphosat einzusparen und führe dafür mehr Bodenbearbeitung durch.</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>Die Wirkung von Glyphosat auf Unkräuter/</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>Unkräuter kann in deutschen Ackerbausyste-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>men durch einen übermäßigen Einsatz abnehmen.</td>
<td></td>
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</tr>
</tbody>
</table>

34. Haben Sie einen Vorschlag oder ein gutes Beispiel aus Ihrem Betrieb, wie Glyphosat eingespart oder ersetzt werden kann? Wenn ja, schildern Sie dies bitte im Folgenden:
Vielen Dank für Ihre bisherigen Angaben! Abschließend haben wir noch zwei Fragen zum Betriebsleiter.

35. In welchem Jahr sind Sie geboren? ______________

36. Ich bin: □ ein Mann □ eine Frau

37. Falls Sie noch allgemeine Anmerkungen machen möchten, können Sie diese gerne im folgenden Feld eintragen:

__________________________________________________________________________
__________________________________________________________________________

Vielen Dank für Ihre Teilnahme!
Veröffentlichungen

Peer-review Journals


Peer-review Tagungsbeiträge


Sonstige Tagungsbeiträge


Praxisorientierte Zeitschriften

**Ausgewählte Vorträge**


Danksagungen

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