Economic assessment of alternatives for glyphosate application in arable farming

Ökonomische Bewertung von Alternativen zur Glyphosatanwendung im Ackerbau

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Abstract

Application and sales of herbicides with glyphosate have strongly increased in Germany during the past 10 years. This has raised a number of questions and discussions concerning glyphosate use. Therefore, this paper identifies and evaluates alternatives with an efficacy almost equivalent to glyphosate for different treatment-areas in terms of economic consequences for farms in comparison to glyphosate use by way of example.

With the help of exemplary crop rotations uses in arable farming for winter wheat, winter oilseed rape, winter barley, maize and summer barley were analyzed. Within a "worst case scenario" a complete abandonment of glyphosate applications was assumed. Different tillage systems (plough, no-plough) were considered. The only alternatives with an efficacy almost equivalent to glyphosate were mechanical measures. For the analyzed treatment-areas (desiccation, pre-sowing, stubble) no approved and efficient chemical alternative could be identified.

The economic advantages and disadvantages of substituting glyphosate by mechanical alternatives were strongly depending on the treatment-area, the efficacy concerning yield expectations (in comparison to glyphosate use), the tillage system, the necessity of grain drying as well as further operational factors such as the availability of sufficient field work days and mechanical equipment.

Keywords: Benefits, chemical and non-chemical alternatives, costs, mechanical weed control

Zusammenfassung

Die Anwendung und der Absatz glyphosathaltiger Herbizide haben in den vergangenen 10 Jahren in Deutschland stark zugenommen. Dies hat Fragen und Diskussionen zu deren Anwendung aufgeworfen. Daher wurden in dieser Arbeit hinreichend wirkungsäquivalente Alternativen zum Wirkstoff Glyphosat exemplarisch für ausgewählte Anwendungsbereiche identifiziert und hinsichtlich ihrer ökonomischen Auswirkungen für Betriebe im Vergleich mit der Anwendung von Glyphosat untersucht.

Anhand beispielhafter Fruchtfolgen wurden Anwendungen in den Ackerbaukulturen Winterweizen, Winterraps, Winterroggen, Mais und Sommergerste betrachtet und in einem „Worst Case Szenario" eine vollständige Substitution glyphosathaltiger Herbizide unterstellt. Berücksichtigt wurde dabei auch die Art der Bodenbearbeitung (mit Pflug, pfluglos). Als hinreichend wirkungsäquivalente Alternativen konnten lediglich mechanische Maßnahmen gefunden werden. Für die betrachteten Anwendungsbereiche (Sikkation, Vorsaat- oder Stoppelbehandlung) hingegen, wurden keine zugelassenen, ausreichend wirksamen chemischen Alternativen identifiziert.

Die ökonomischen Vor- und Nachteile der Substitution glyphosathaltiger Herbizide durch mechanische Maßnahmen hingen stark vom Anwendungsbereich, der Äquivalenz hinsichtlich der Ertragswirkungen (im Vergleich zur Glyphosatanwendung), der Art der Bodenbearbeitung, der Notwendigkeit einer Trocknung des Erntegutes sowie weiteren betriebsspezifischen Faktoren, wie der Verfügbarkeit ausreichender Feldarbeitstage und der Mechanisierung, ab.

Stichwörter: Chemische und nicht-chemische Alternativen, Kosten, mechanische Unkrautbekämpfung, Nutzen

Introduction

Application and sales of glyphosate herbicides have strongly increased in Germany over the past 10 years. Every year, about 40% of Germany's arable land is under glyphosate treatment (SCHULTE et al., 2015; STEINMANN et al., 2015). Since 2004, about 5,000 t of glyphosate are sold in Germany every year. At present about 33 glyphosate herbicides are approved in Germany. They are sold under 95 trade names. The 33 approved herbicides have in total 470 authorized uses, whereof 86 are for non-commercial users (BVL, 2015).

Especially for no-plough agriculture glyphosate use is of great importance as it allows controlling weeds efficiently before seeding without any tillage passes. It therefore enables conservation tillage on areas with high risk of erosion (STEINMANN and DOBERS, 2013; MAL et al., 2015; SCHMITZ et al., 2015). Even with additional tillage MAL et al. (2015) and SCHMITZ et al. (2015) predicted yield losses without glyphosate of up to 10%. Based on expert interviews SCHMITZ and GARVERT (2012) described glyphosate use as a standard in conservation tillage in many regions in Germany. According to their results 30 to 35% of all areas cultivated with winter crops and 50% of the area under winter oil seed rape production were treated with glyphosate.

In arable farming, glyphosate is applied pre-sowing (shortly before sowing or shortly after sowing before emergence), pre-harvest (to the standing crop shortly before harvest, desiccation) or post-harvest (after harvest, stubble treatment).

For glyphosate use in agriculture, several application regulations have to be considered in Germany since May 2014 (BVL, 2014):

- two applications are allowed per year at most,
- between two applications a waiting period of at least 90 days must be adhered,
- the application rate per year must not exceed 3.6 kg active substance per hectare,
- desiccation is only allowed as site specific application.

The present study assesses in particular the economic consequences at farm-scale of an abandonment of using glyphosate based on exemplary calculations for typical crop rotations in arable farming and compared the alternatives "weed management with glyphosate" and "weed management without glyphosate".

Methodology of the economic assessment

Economic parameters

The economic influence of an abandonment of glyphosate was calculated by the use of three economic parameters belonging to cost accounting and cost benefit analysis.

(1) The **p**lant **p**rotection **f**ree **r**evenues (PPFR) were derived by the **r**evenue (R) for each crop in a crop rotation (revenue = yield times price) less the **d**irect **c**osts (DC) resulting from either the glyphosate use or its substitute. For the direct costs **i**nterest **e**xpenses (IE) were calculated at an **i**nterest rate of 4% (i) for a period of three months.

$$\mathrm{PPFR} = \mathrm{R} - (\mathrm{DC} + \mathrm{IE})$$

(2) For each crop rotation the **n**et **p**resent **v**alue (NPV) was calculated over the period under review (T) by discounting the PPFR of each year (t). The NPV allows for a comparison of the economic efficiency of the entire three-year crop-rotations.

$$NPV = \sum_{t=1}^{T} \left(\frac{PPFR_t}{(1+i)^t}\right)$$

(3) To derive a value which shows the economic efficiency of a crop rotation on an annual basis the NPV was converted into an **a**nnuity (A) with the help of the **a**nnuity **f**actor (AF). The differences of the cultivation strategies` annuities show additional costs or gains of substituting glyphosate (comparison with and without glyphosate).

$$A = NPV * AF_{T,i}$$

$$AF_{T,i} = \frac{(1+i)^T * i}{(1+i)^T - 1}$$

Crops, crop rotations, treatment areas and possible alternatives to glyphosate

To evaluate the economic effect of an abandonment of glyphosate, five theoretic crop rotations where identified. Three of them include predominantly winter crops:

crop rotation 1 “winter”: winter oilseed rape – winter wheat – winter wheat
crop rotation 2 “winter”: maize – winter wheat – winter wheat
crop rotation 3 “winter”: winter oilseed rape – winter wheat – winter barley

The other two crop rotations include the summer crop spring barley:

crop rotation 1 “summer”: maize – winter wheat – spring barley
crop rotation 2 “summer”: winter oilseed rape – winter wheat – spring barley

To calculate the economic impact of the different application possibilities of glyphosate (pre-sowing, pre-harvest, post-harvest) different application variants were identified. Taking the application regulations of glyphosate into account, for winter crop dominated crop rotations three application variants were possible:

Variant 1: glyphosate is used for desiccation and pre-sowing treatment
Variant 2: glyphosate is used for stubble treatment
Variant 3: glyphosate is used for pre-sowing treatment

For the crop rotations containing spring barley, the following three variants were calculated:

Variant 1a: glyphosate is used for desiccation and pre-sowing treatment
Variant 2a: glyphosate is used for desiccation, stubble and pre-sowing treatment
Variant 2b: glyphosate is used for stubble and pre-sowing treatment

For each crop rotation the alternatives "management with glyphosate" and "management without glyphosate" were compared. Therefore, a decent alternative to glyphosate had to be found for each application possibility.

A “chemical” alternative for stubble treatment and pre-sowing application has to be approved for the relevant indication and should have an efficacy almost equivalent to that of the herbicide to be replaced. Due to this requirement there was no chemical alternative to glyphosate herbicides for stubble treatment and pre-sowing application. There was only one chemical alternative for desiccation in oilseed rape - the active ingredient diquat (for instance Reglone).

Mechanical alternatives that achieved an efficacy almost equivalent to glyphosate for stubble treatment (to eliminate volunteer plants, couch grass, weeds/weed grasses) and pre-sowing application (to eliminate volunteer plants, weeds/weed grasses, in particular resistant black grass and/or wind grass, mulching/cover crops and catch crop) were in both cases the application of additional one to three tillage passes on the entire field using appropriate equipment or combination of equipment. The repeated passes are needed to increase efficacy, but complete equivalence can only be achieved under specific conditions.

Each crop rotation is calculated for its three treatment variants, for the use of glyphosate and its alternative, for till and no-till systems and for “with drying of the harvest” and “without drying of the harvest”.

Figure 1 presents an overview of the application possibilities in a cropping strategy with glyphosate use and glyphosate-free alternatives in a plough and no-plough system.

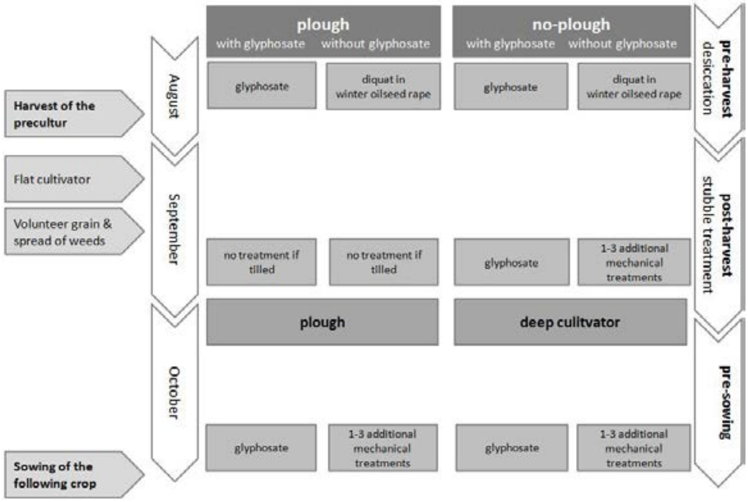

Fig. 1 Exemplary illustration of all application possibilities of glyphosate (pre-harvest, post-harvest, pre-sowing) and its alternatives for weed control in a crop rotation with a following winter crop for plough and no-plough systems. Application regulations are not considered.

Abb. 1 *Modellhafte Darstellung aller Anwendungsmöglichkeiten glyphosathaltiger Herbizide (Sikkation, Stoppel- und Vorsaatbehandlung) und deren Alternativen zur Bekämpfung von Unkraut und Ausfallpflanzen vor einer anschließenden Winterung ohne Berücksichtigung von Zulassungsbeschränkungen für Anbausysteme mit und ohne Pflug.*

For the variants with glyphosate the above mentioned application regulations (see introduction) were taken into account.

Yields, prices, cost components and calculation of revenues

To derive the PPFR, revenue and cost components were considered. The revenues, shown in Table 1, are based on the average producer prices and yields in Germany between the years 2007 and 2012.

Tab. 1 Yield and price assumptions (mean of the years 2007-2012) and assumption for the initial revenue for selected arable crops (minor differences are due to rounding), from AMI and Statistisches Bundesamt (different years).

Tab. 1 *Ertrags- und Erzeugerpreisannahmen (Mittelwerte der Jahre 2007-2012) sowie angenommene Ausgangerlöse für ausgewählte Ackerbaukulturen (geringfügige Abweichungen aufgrund von Rundung), nach AMI and Statistisches Bundesamt (verschiedene Jahre).*

	Winter wheat	**Winter barley**	**Spring barley**	**Winter oilseed rape**	**Maize**
Producer price (€/dt)	18.3	15.8	19.5	36.1	17.3
Yield (dt/ha)	74.5	63.7	49.2	36.6	99.4
Revenue (€/ha)	**1,365**	**1,006**	**957**	**1,320**	**1,717**

Table 2 shows the revenue and cost components considered, the underlying assumptions on machinery and prices and the calculation approach to derive the PPFR for arable crops.

For different agricultural measures (no glyphosate, no-plough) a yield decrease of 0 to 5% was applied to the yields shown in Table 1. In case of a chemical desiccation a reduction of yield losses or in other words a yield gain of 0 to 5% was assumed.

Tab. 2 Calculation approach of the plant protection free revenues in arable crops.

Tab. 2 *Berechnung der pflanzenschutzkostenfreien Leistung im Ackerbau.*

	With glyphosate use	**Without glyphosate use**	**Source**
Revenue			
Initial yield	Average yield in Germany between the years 2007 and 2012 (see Tab. 1)		STATISTISCHE JAHRBÜCHER and AMI MARKTBILANZEN (different years)
Yield decrease	0-5% yield decrease in no-till systems	0-5% yield decrease in glyphosate-free systems 0-5% yield decrease in no-till systems	Expert estimation and SCHWARZ and PALLUTT (2012)
Yield increase	0-5% reduction of yield losses on area with desiccation/ assumption: 50% of the area is under treatment	0-5% reduction of yield losses on area with desiccation (only relevant for desiccation in winter oilseed rape with diquat)	FEIFFER et al. (2005) FEIFFER (2007)
Producer price	Average producer prices in Germany between the years 2007 and 2012 (see Tab. 1)		STATISTISCHE JAHRBÜCHER and AMI MARKTBILANZEN (different years)
Revenue	**(Initial Yield – Yield Decreases + Yield Increases) * Producer Price**		
Direct costs of plant protection			
Desiccation (Pre-harvest)	Oilseed rape: 14.85 €/ha (=3 l Roundup Power Flex/ha x 9.9€/l x 50% of area treated) Cereals: 18.56 €/ha (=3.75 l Roundup Power Flex * 9.9 €/l x 50% of area treated)	Oilseed rape: 29 €/ha (=2 l Reglone/ha * 14.50 €/l x 50% of area treated)	Indication according to application regulation (BVL, 2015, status 10.02.15) Pesticide prices: Agravis price list 2014
Soil cultivation	24.11 €/ha (flat stubble cultivator, 4m, 83 kW)		KTBL-field work calculator, status11.11.2014
Stubble treatment (Post-harvest)	37.13 €/ha (=3,75 l Roundup Power Flex * 9,9 €/l)	24.11 €/ha per treatment (flat stubble cultivator, 4 m, 83kW, 1-3 treatments)	Indication according to application regulation (BVL, 2015, status 10.02.15) Pesticide prices: Agravis price list 2014 KTBL-field work calculator, status 11.11.2014
Soil cultivation	plough: 67 € (semi-mounted, 120kW, 8 wings, 2,8 m) deep stubble cultivator: 43.98 € (4,5 m, 120kW)		KTBL-field work calculator, status 11.11.2014
Pre-sowing	37.13 €/ha (=3.75 l Roundup Power Flex * 9.9 €/l)	24.11€/ha per treatment (flat stubble cultivator, 4 m, 83kW, 1-3 treatments)	Indication according to application regulation (BVL, 2015, status 10.02.15) Pesticide prices: Agravis price list 2014 KTBL-field work calculator, status 11.11.2014
Application	8.58 €/ha per treatment (attached plant sprayer, 27 m, 3.000 l, 67 kW, 200 l water/ha)		KTBL-field work calculator, status 11.11.2014
Interest expenses	4% p.a. for a period of 3 months		
Plant Protection Free Revenue = Revenue - Σ Direct Costs of Plant Protection			

The application rates of 3.75 l/ha Roundup Power Flex (as an example of an herbicide containing glyphosate) per hectare for all crops and application possibilities (except desiccation with glyphosate in oil seed rape: 3 l/ha) were in accordance with the current application regulations. In oil seed rape an alternative desiccation with the active substance diquat (indication assumed: 2 l of Reglone per hectare) was calculated additionally (BVL, 2015). The prices of Roundup Power Flex and Reglone were calculated with 9.90 and 14.50 €/l respectively (AGRAVIS, 2014). In accordance to the application regulations for glyphosate, a site specific desiccation of 50% of the area was assumed for all desiccation treatments. In the glyphosate-free variants, stubble and pre-sowing treatment was replaced by 1 to 3 passes with a flat stubble cultivator at 24.11 €/ha per treatment (KTBL-field work calculator, 2014). For all variants flat soil cultivation after harvesting was considered as a precondition for a successful weed management either with or without glyphosate. For expenditures an interest rate of 4% p.a. over 3 months was assumed.

All ranges mentioned above were incorporated into the calculations as minimum and maximum assumptions to consider uncertainties underlying the assumptions.

Results

Table 3 shows the results of glyphosate abandonment in arable farming for plough and no-plough systems with and without drying of the harvested grain for different crop rotations considered within the calculations.

Economic effect of an abandonment of glyphosate for pre-harvest, post-harvest and desiccation treatments

The economic consequences of glyphosate abandonment were crucially determined by the yield effect of the substituting measure. This is of greater importance than the slightly higher costs of a mechanical treatment as soon as more than one additional pass was necessary (glyphosate treatment including application: 45.70 €/ha; one tillage measure: 24.11 €/ha).

If there was no yield decrease, stubble and pre-sowing treatments could be substituted by mechanical measures without negative or with slightly positive economic effects. Under unfavourable conditions, when in spite of 2 to 3 additional tillage passes yield losses occurred, the lack of stubble treatment with glyphosate in crop rotations with predominantly winter crops caused additional annual costs of 55 to 89 € per hectare and in case of pre-sowing application of up to almost 100 € per hectare. With an average gross margin for example for wheat (bread wheat) of 600 to 900 € per hectare, the additional costs would account for about 6 to 17% of the gross margin. On average, an abandonment of glyphosate for stubble and pre-sowing treatments led to additional costs of 0 to 37 €/ha.

The abandonment of glyphosate without any replacement was especially difficult for desiccation when the missing treatment led to a subsequent cost-intensive drying of the harvest. In this case, on average (in combination with a substituted stubble and/or pre-sowing treatment) additional costs of about 50 to 100 €/ha arose.

Economic effect of tillage on the abandonment of glyphosate

The results showed that the substitution of glyphosate by additional tilling was not necessarily more expensive in any case. Within almost all the variants, mechanical weed control could provide the same or a better economic result under favourable conditions, when one additional tillage pass achieved an efficacy equivalent to glyphosate.

There was a tendency that it was less costly and easier to avoid the use of glyphosate in case of plough tillage which, however, might cause problems for regions at erosion risks.

Tab. 3 Annual costs of glyphosate abandonment shown as the differences of the annuities compared to glyphosate in € per ha and year of a cropping system with glyphosate and one with mechanical substitution. Negative signs indicate losses, positive signs indicate gains through an abandonment of glyphosate.

Tab. 3 *Jährliche Kosten des Verzichts auf Glyphosat dargestellt als Differenz der Annuitäten zur Anwendung von Glyphosat in €/ha und Jahr eines Anbausystems mit Glyphosat und eines mit mechanischer Substitution. Negative Vorzeichen bedeuten Verluste, positive Vorzeichen zusätzliche Einnahmen durch die Substitution von Glyphosat.*

Application variants						**Annual costs of glyphosate abandonment as Annuities (max/Ø/min) in €/ha and year**									**row**
	plough/ no-plough	**drying[1]**	**desic-cation**	**stubble**	**pre-sowing**	**max**	**Ø**	**min**	**max**	**Ø**	**min**	**max**	**Ø**	**min**	
						CR1			**CR2**			**CR3**			
Crop rotations including predominantly winter crops:						**WOR-WW-WW**			**Maize-WW-WW**			**WOR-WW-WB**			
1. desiccation & pre-sowing	plough	x	x		x	-103	**-57**	-11	-94	**-50**	-7	-95	**-52**	-8	**1**
	plough		x		x	-11	**7**	26	-7	**6**	18	-8	**9**	26	**2**
	no-plough	x	x		x	-172	**-85**	3	-172	**-78**	15	-144	**-65**	14	**3**
	no-plough		x		x	-56	**-26**	3	-71	**-28**	15	-34	**-10**	14	**4**
2. stubble	plough	x		x		0	**0**	0	0	**0**	0	0	**0**	0	**5**
	plough			x		0	**0**	0	0	**0**	0	0	**0**	0	**6**
	no-plough	x		x		-76	**-31**	14	-83	**-34**	15	-55	**-12**	30	**7**
	no-plough			x		-82	**-34**	14	-89	**-37**	15	-61	**-15**	30	**8**
3. pre-sowing	plough	x			x	-79	**-32**	14	-87	**-33**	22	-58	**-18**	22	**9**
	plough				x	-85	**-35**	14	-93	**-35**	22	-64	**-21**	22	**10**
	no-plough	x			x	-76	**-31**	14	-84	**-31**	22	-55	**-16**	22	**11**
	no-plough				x	-82	**-34**	14	-89	**-34**	22	-61	**-19**	22	**12**
Crop rotations including spring barley:						**Maize-WW-SB**			**WOR-WW-SB**						
1a. desiccation & pre-sowing	plough	x	x		x	-157	**-69**	1	-157	**-75**	7				**13**
	plough		x		x	-68	**-25**	19	-52	**-23**	7				**14**
	no-plough	x	x		x	-149	**-65**	19	-149	**-71**	7				**15**
	no-plough		x		x	-65	**-23**	19	-49	**-21**	7				**16**
1b. desiccation, stubble & pre-sowing	plough	x	x	x	x	-157	**-69**	19	-157	**-75**	7				**17**
	plough		x	x	x	-68	**-25**	19	-52	**-23**	7				**18**
	no-plough	x	x	x	x	-189	**-89**	11	-165	**-99**	-33				**19**
	no-plough		x	x	x	-105	**-47**	11	-65	**-49**	-33				**20**
2a. stubble & pre-sowing	plough	x		x	x	-82	**-30**	22	-73	**-29**	14				**21**
	plough			x	x	-86	**-32**	22	-79	**-32**	14				**22**
	no-plough	x		x	x	-96	**-30**	36	-96	**-33**	29				**23**
	no-plough			x	x	-101	**-32**	36	-101	**-36**	29				**24**
column:						**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	

[1] only if the crop is not desiccated

CR = crop rotation, WOR = Winter oilseed rape, WW = winter wheat, WB = winter barley, SB = spring barley

Tab. 4 Expected economic consequences at farm-level of an abandonment of glyphosate and substitution by mechanical measures.

Tab. 4 *Zu erwartende ökonomische Konsequenzen auf Betriebsebene durch eine Substitution von Glyphosat durch mechanische Maßnahmen.*

		plough/ crop drying	**plough/ no crop drying**	**no-plough/ crop drying**	**no-plough/ no crop drying**
Crop rotations "winter"	1. desiccation & pre-sowing				
	2. stubble				
	3. pre-sowing				
Crop rotations "summer"	1a. desiccation & pre-sowing				
	1b. desiccation, stubble & pre-sowing				
	2a. stubble & pre-sowing				

Legend	The abandonment of glyphosate does not cause economic losses.
	The abandonment of glyphosate leads to costs of 40 €/ha and year on average. Under favourable conditions there are no economic disadvantages or even positive effects.
	The abandonment of glyphosate leads to high costs of more than 40 €/ha and year on average. Even under favourable conditions, losses cannot be avoided.

An important prerequisite to substitute glyphosate by mechanical measures with only minimum economic disadvantages for farmers is an efficacy of the alternative almost equivalent to glyphosate without lower yields and farm specific capacities such as availability of field work days, manpower and equipment for tillage.

In case of these favourable conditions, the mechanical control measure may lead to an economically identical or even better result. Location, weather and farming practices are important factors influencing the economic consequences of the substitution of glyphosate. In case of unfavourable conditions considerable costs occur.

Table 4 summarizes the expected economic consequences at farm-level for the different variants. Dark grey colours show those combinations where economic losses by substituting glyphosate can hardly be avoided. Middle grey colours are combinations that on average result in economic losses but where under specific preconditions no economic disadvantages up to even economic advantages can be achieved. For combinations with light grey colours no losses by glyphosate substitution are to be expected at all.

Discussion

The increases in sales and application of glyphosate have raised questions on the appropriateness of this development leading to requests concerning the reduction of glyphosate use.

Glyphosate application has become a common measure of weed management over the past years in Germany due to several beneficial effects of this active ingredient. SCHULTE and THEUVSEN (2015) recently summarized these effects within a literature review and pointed out the use of conservation and minimal tillage, arable farming in areas at erosion risk, reduction of labour and machinery costs, fuel savings, anti-resistance management, phytosanitary aspects (eliminating the so called green bridges) and the ensurance of harvest (avoiding of lodging). Other authors also mention positive effects on yield (SCHMITZ and GARVERT, 2012; COOK et al., 2010). These economic advantages explain the "popularity" of glyphosate for farmers. SCHULTE et al. (2015) and STEINMANN et al. (2015) reported, that glyphosate is applied on about 40% of the arable land in Germany, whereof the majority concerns stubble treatments. According to ANDERT et al. (2015) glyphosate use was higher in eastern than in western Germany and in no plough systems.

Alternative measures to glyphosate use for the different treatment areas leading to comparable agronomic results are hardly to find. In our study only mechanical measures with appropriate machinery and 1 to 3 passes led to an equivalent efficacy. However, as the results showed, many factors determined the economic consequences of these alternative measures to substitute glyphosate, such as an efficacy almost equivalent to glyphosate application, the availability of sufficient field work days, sufficient manpower and equipment for the additional tillage. In addition it should not be necessary to dry the harvest. SCHMITZ and GARVERT (2012) calculated with a similar partial budgeting approach the farm-level effects of a ban of glyphosate and reported that gross margins would decrease in eastern Germany by 27%, in northern Germany by 3% and in the north-western coastal area by 36%. The differences between the regions in their study were on the one hand for the north-western coastal area due to resistance problems in black grass (*Alopecurus myosuroides)* where they assumed additional herbicide applications with sulfonylurea. For the region in eastern Germany they assumed that farmers would not use the plough due to restrictions in labour and would therefore result in a decrease of yield by 10%. Own calculations resulted in lower reductions of the gross margin - or in our case the plant protection free revenue - (on average up to 10% in case of additional drying of the harvest and on average up to 5% if no additional drying was necessary) since our assumptions concerning yield losses were only 0-5% and we did not assume that other herbicides were applied.

The underlying assumptions for the expected consequences of the substitution of glyphosate by mechanical measures are crucial for the economic result in any impact assessment and at the same time they entail considerable uncertainty. In the present study uncertainty was considered by deriving assumptions e.g. for expected changes in crop yields by expert judgement and by applying margins for the range of the most probable data.

Within tillage systems using the plough the substitution of glyphosate especially for the stubble-treatment did not cause economic losses. SCHMITZ et al. (2015) compared gross margins, direct and labor costs for different soil cultivation (conservation tillage and plough) for different crop rotations in different regions. In their calculation the conservation tillage with glyphosate led to higher gross margins (5 to 10%) due to lower costs (20% lower production costs, about 30% lower fuel consume).

The substitution of glyphosate by mechanical measures, however, is limited and not appropriate in any case. It is hardly possible to achieve a sustainable control of couch grass and other perennial weeds without glyphosate. Other herbicidal active ingredients have insufficient efficiency. Usually changes in crop rotations and tillage are not equivalent in efficiency concerning the above mentioned weeds. Replacing the glyphosate application by plough tillage clearly led to less economic consequences. For this reason the substitution of glyphosate application by mechanical measures would probably enhance plough tillage. In areas with high risks of erosion, the shift from no-plough to plough tillage can increase erosion. Other benefits of soil conserving tillage would at the same time be eliminated. By applying glyphosate herbicides as a pre-sowing treatment spread and development of weed species at risk of herbicide resistance can be specifically avoided. At locations at high risk of resistance glyphosate application remains an essential measure within resistance management for the time being.

The economic consequences of an abandonment of glyphosate and a substitution by mechanical measures depend on farm specific prerequisites such as the availability of sufficient manpower and equipment for additional tillage. ANDERT et al. (2015) showed that glyphosate use and no plough systems were both attributed to larger farms. Moreover, the potential for substituting glyphosate by mechanical measures such as more plough tillage depends on the risk of erosion at the farm location. An overall solution for an abandonment of glyphosate therefore cannot be expected and the decision by farmers will be taken case-by-case.

Whether an increase in prices of glyphosate would enhance the economic advantage of alternative measures can only be estimated theoretically. For equivalence in costs of three tillage passes (3 x 24.11 €/ha = 72.33 €/ha) with a glyphosate application ((3.75 l/ha Roundup Power Flex * 9.9 €/l) + 8.58 €/ha for application = 45.70 €/ha) prices of glyphosate must increase by more than 70% ((3.75 l/ha Roundup Power Flex * 17 €/l) + 8.58 €/ha for application = 72.33 €/ha).

Concerning the potential to reduce glyphosate use the largest theoretical potential for savings could be found in arable farming within winter wheat, the crop with the largest cropping area in Germany. According to estimations by JKI based on PAPA-data (panel for pesticide applications) about one third of the applied glyphosate is used within winter wheat production (KEHLENBECK *et al.*, 2015).

The economic impact assessment revealed that under certain conditions glyphosate needs not to be used. Consequently, it can be stated that glyphosate should not be regarded as a standard measure in arable crop production systems. Instead it should rather be considered whether glyphosate application in particular to stubble or pre-sowing application could be replaced by mechanical tillage with appropriate equipment. Such an approach should reduce the glyphosate quantity at the same time. Plough tillage should be taken into account more often, especially on soils that allow ploughing and have no risk of erosion. If this is not possible on the entire area, glyphosate should be applied at least to the most problematic parts of the fields (for example due to couch grass, erosion risk). Moreover, it should be considered whether mechanical tillage as an alternative measure could be applied alternating from year to year and lead to sufficient weed management results. In general, pre-harvest applications to combinable crops should be reduced to the necessary minimum.

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