American Journal of Experimental Agriculture
8(3): 144-151, 2015, Article no.AJEA.2015.157
ISSN: 2231-0606

SCIENCEDOMAIN *international*
www.sciencedomain.org

Herbicide Application in Precision Farming Based on Soil Organic Matter

Henning Nordmeyer[1*]

[1]*Julius Kühn-Institute, Institute for Plant Protection in Field Crops and Grassland, Braunschweig, Germany.*

Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

Article Information

DOI: 10.9734/AJEA/2015/17341
Editor(s):
(1) Rusu Teodor, Department of Technical and Soil Sciences, University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, Romania.
Reviewers:
(1) Anonymous, Brazil.
(2) Anonymous, Hungary.
(3) Anonymous, USA.
Complete Peer review History: http://www.sciencedomain.org/review-history.php?iid=1077&id=2&aid=8938

Original Research Article

Received 9th March 2015
Accepted 26th March 2015
Published 22nd April 2015

ABSTRACT

In the present study, the influence of soil properties on pre-emergence herbicide effectiveness was estimated in bioassays. Dose-response experiments were carried out to estimate the relationship between soil organic matter content and herbicide efficacy. Two weed species (*Alopecurus myosuroides* and *Stellaria media*) and two herbicides (pendimethalin, chlorotoluron) were included in the experiments. In bioassay trials on soil with varying organic matter content, dose-response curves were estimated for pendimethalin and chlorotoluron. Effective dose (ED_{50}) values were calculated. The experiments were conducted in a climate chamber under defined conditions. The results demonstrate that the efficacy of soil-applied herbicides is related to the soil organic matter content within agricultural fields. Therefore precise usage with variable herbicide application rates can be part of a precision farming concept. A reduction in herbicide is possible.

Keywords: Bioassay; chlorotoluron; dose response; herbicide efficacy; pendimethalin; weed.

1. INTRODUCTION

Herbicides are used in weed control worldwide in crop production on a large scale to prevent a reduction in yield. In that regard, soil-applied herbicides are still an important component in weed control concepts. Soil-applied pre-

**Corresponding author: E-mail: henning.nordmeyer@jki.bund.de;*

emergence herbicides are used to control germinating weeds in many crops. They are normally sprayed uniformly on the entire field. In general, the recommended dose rates are based on efficacy and dose justification trials. These recommendations are based on worst-case situations and do not take into account specific field situations like spatial soil (e.g. varying soil organic matter within fields) and weed variability.

Each herbicide has a unique set of chemical characteristics that influences its behaviour. The interaction between herbicide chemistry and soil properties affects the efficacy of herbicide weed control. Research has shown that soil characteristics (e.g. soil organic matter, pH) clearly influence bioavailability, plant uptake and herbicidal efficacy [1,2]. Also, the uneven occurrence of weeds can be correlated with soil characteristics [3].

Depending on their physical/chemical properties soil-applied herbicides are adsorbed more or less by the clay and organic matter (OM) found in soils, meaning that a certain percentage of the herbicide is not available to the plants. Adsorption of herbicides in soil is a key factor for soil bioavailability, plant uptake and efficacy. Herbicide adsorption varies with soil organic matter and other soil characteristics (e.g. clay content, mineral oxides, soil pH, soil water content). The important factor for the adsorption and bioavailability of most herbicides is the soil organic matter content [4-6]. This was investigated and confirmed in field trials [7]. In Germany, the organic matter content in agricultural soils was found to range from 1 to 15%. Clay content and other soil factors were often less correlated. Herbicide adsorption was described dependent on clay content in Arizona soils [8]. But besides soil factors, also environmental factors (e.g. temperature, soil moisture) can influence herbicide activity. It must basically be stated that the efficacy of soil-applied herbicides depends on the application rate and their availability to weeds.

The interactions between soil organic matter and herbicides are often studied in the laboratory using batch-equilibrium experiments in combination with techniques that quantify the chemical and structural characteristics of organic matter and bioassay tests [9]. Greenhouse bioassays are a simple and sensitive tool to detect efficacy and phytotoxicity of herbicides [10-12]. Herbicide adsorption to soil can be described using soil/organic matter (K_{oc}) and soil/soil solution coefficients (K_d). The K_{oc} and K_d values are defined as the ratio between the amount of herbicide adsorbed and the amount in soil solution [13]. The soil organic matter and/or humic matter fraction is highly correlated with the adsorption of herbicides in soils. In literature soil organic matter is considered as the single most important soil constituent influencing herbicide sorption in soils. Pedersen et al. [9] showed the relationship between adsorption and the effective doses of five soil-applied herbicides. Gaultier et al. [14] showed that the sorption of 2,4-D by soil was positively correlated with soil organic matter content. The objective of the study was to quantify the variability of soil properties and 2,4-D sorption. These results are supported by further sorption experiments.

Normally, according to label recommendations, herbicides are sprayed with a uniform application rate throughout the entire field. But each field has a natural variability in soil characteristics and weed occurrence [15-17]. Soil parameters are known to vary spatially. Therefore, herbicide application according to soil parameters is conceivable [18]. Nolte et al. [19] used variable rate technologies for soil-applied herbicides.

Depending on field history, fields vary in organic matter content and weed occurrence. This means that a full area application with a uniform application rate is not an appropriate application of herbicides. According to small-scale soil variability, differences in herbicide adsorption and the availability of herbicides to plants can be generally assumed. Blumhorst et al. [20] reported that, in most cases, the optimum rate of herbicide could be determined with a linear regression equation based on organic matter content. Knezevic et al. [21] reported different herbicide application rates depending on soil organic matter content. Soils with high organic matter content and a high adsorptive capacity need a higher herbicide application rate to ensure sufficient effectiveness.

In precision farming, variable rate technologies offer the possibility to spray herbicides according to field heterogeneity [22]. However, soil information is often not available. With global positioning system (GPS) technology and soil sensors [23], soil variability can be mapped precisely. Furthermore, spatially variable herbicide application according to weed distribution or varying soil properties offers the opportunity for herbicide minimisation and the protection of beneficial weeds. This is in accordance with the principles of integrated pest management (IPM) and the national plan of action. The challenge is to bring the right amount of herbicide to the right place in the field. This means an appropriate application of herbicides. It can reduce herbicide use and can lead to economic and ecological benefits.

The aim of this project was to investigate the herbicidal effectiveness of soil-applied herbicides on arable weeds, depending on soil organic matter. Bioassay trials with different weed species (*Alopecurus myosuroides, Stellaria media*), herbicides (pendimethalin, chlorotoluron), soils and dose rates were carried out. The hypothesis is that, in a field varying widely in organic matter, the use of herbicides can be adjusted to small-scale field differences to reduce herbicide use in comparison to a uniform application.

2. MATERIALS AND METHODS

Bioassay trials for different herbicides, weed species and soils were conducted to estimate the relationship between soil organic matter and herbicide doses. Herbicide dose-response curves were estimated and ED_{50} values were calculated. For the experiments, two weed species were chosen to test the effectiveness of the herbicides.

Weed species tested in the study were *Alopecurus myosuroides* and *Stellaria media*. Herbicides used were chlorotoluron and pendimethalin. The herbicides are registered in Germany for the control of monocotyledonous and dicotyledonous weeds in agricultural fields before and after emergence in several cultures, mainly in cereals.

Experiment 1: Herbicide efficacy was tested with soil samples varying in soil organic matter (OM) content. Other soil properties (e.g. pH) were not tested. Soil samples were taken from an agricultural field in Germany (latitude 521254.6 N, longitude 103726.2 E) at different locations (Fig. 1.) (sampling points 64, 70, 73) from the topsoil layer (0–20 cm). The soil was collected with a hand auger. According to organic matter content, three areas of the field were selected and sampled. The soils were sieved (3 mm), well mixed, placed in plastic pots (6x6 cm) and planted with weeds. Organic matter was estimated by measuring organic carbon (dry combustion) and multiplication with the standard factor 1.72. For the sampling points an organic matter content of 1.9% (point 73), 2.2% (point 70) and 3.5% (point 64) was calculated.

For the bioassay test the weed seeds were sown in potting compost under greenhouse conditions. The plants were cultivated in a climate chamber with 16 hours light at temperatures from 20 to 24°C during the day and 15 to 16°C at night. A relative air humidity of 50 to 55% was recorded during the day and 55 to 60% during the night. The pots were irrigated as needed for 14 days and the fresh weight of the plants was estimated for each pot. The experimental layout was always a complete randomized design with 4 replicates.

For *Alopecurus myosuroides* and *Stellaria media*, five plants at the cotyledon stage were transplanted into each pot using a dibber, with 300 g of homogeneous soil from the different sampling points. The herbicide efficacy of chlorotoluron was estimated by spraying 5 application rates (0, 0.525, 1.05, 1.68, 2.1 kg ai/ha) with four replications. The herbicide was applied at growth stage 11-12 (1 to 2 leaves).

Herbicides were applied with the use of a moving-nozzle cabinet sprayer equipped with a flat-fan nozzle tip (Tee Jet 8002EVS, Tee Jet Technologies GmbH, Ludwigsburg, Germany) calibrated to deliver 300 l ha^{-1} of spray solution at 210 kPa in a single pass over the soil.

Experiment 2: The herbicide efficacy of pendimethalin was estimated by spraying 4 herbicide application rates (0.5, 1.0, 2.0, 4.0 kg ai/ha) with four replications.

A sandy soil with an organic matter content of 4.1% was selected. Soil samples were taken from an agricultural field from the topsoil layer. For the experiments soil samples with different organic matter content were compounded through the addition of a substrate with no natural humus content (quartz sand). Quartz sand and soil were well mixed to reach 0.25, 2.5, 3.0 and 3.5% organic matter content in the soil samples. *Stellaria media* was sown with 20 seeds per pot (sowing depth 2–3 mm). After they had emerged, plants were separated to 7 plants per pot. The herbicide was applied before emergence. For cultivating the plants, herbicide application, experimental layout and test conditions, see experiment 1.

2.1 Statistical Analysis

The data sets were analysed for normal distribution using the Kolmogorov-Smirnov test and subsequently tested using one-way ANOVA and the Duncan test for significant differences between treatments (p<0.05). Statistical analyses were performed in Statgraphics Centurion XV. Dose-response curves were conducted by the Excel macro BIOASSAY97 [24]. The effective dose (ED_{10}, ED_{30}, ED_{50} and ED_{90}-values) was conducted using the statistical program R version 3.03.

3. RESULTS AND DISCUSSION

Efficacy of 4 application rates of pendimethalin can be seen in Fig. 2. The efficacy on *Stellaria media* is shown depending on soil organic matter content. In general, an increasing application rate up to 4 kg ai/ha shows an increasing efficacy against *Stellaria media*. All organic matter levels show an increasing efficacy with increasing application rates. At level 3.5%, OM efficacy increased from 10% at 0.5 kg ai/ha to 56% at the 4 kg ai/ha application rate. At level 2.5%, OM efficacy increased from 4% at 0.5 kg ai/ha to 74% at the 4 kg ai/ha application rate. At the lowest organic matter content (< 0.1%), all application rates show nearly the same efficacy (nearly 90%). It is characteristic that the efficacy is very low for dose rates of 0.5 and 1 kg ai/ha at OM levels 2.5, 3.0 and 3.5%. At lower OM levels, the efficacy increased significantly. Differences in efficacy between the tested dose rates are greater in the soils' organic matter content (see Fig. 2, for example, 4.3 and 0.43% OM).

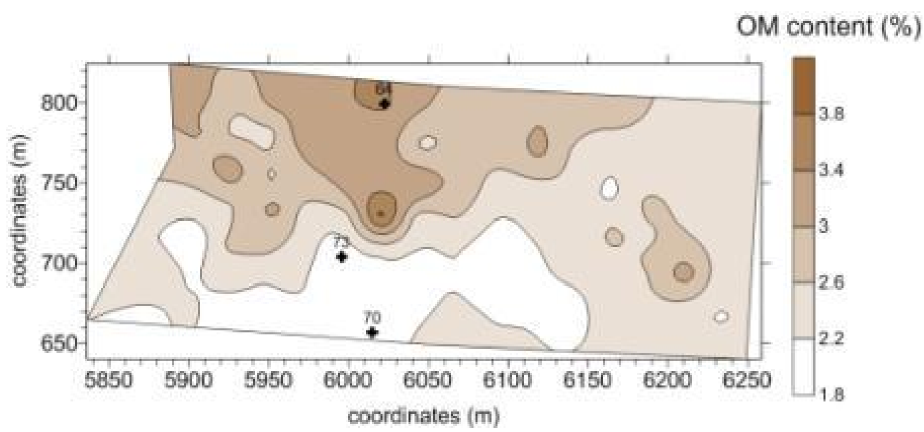

Fig. 1. Agricultural field (2013) with different soil sampling points (64, 70, 73) varying in soil organic matter content (OM)

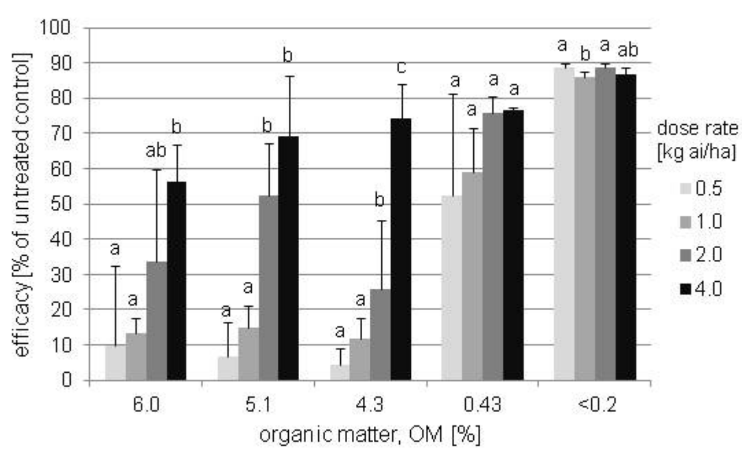

Fig. 2. Herbicidal effects of different concentrations of pendimethalin against *Stellaria media* in soils with varying organic matter content (n=4). Columns with different letters are significantly different. Vertical bars represent the standard deviation

Fig. 3 shows the efficacy of chlorotoluron against *Alopecurus myosuroides*, demonstrating efficacy in dependence on the soil organic matter content. Soil 70 (OM = 2.2%) already shows good weed control (>80%) with low doses (0.525 and 1.05 kg ai/ha). It results in an efficiency of up to 90%. Higher application rates do not result in greater efficacy. Soil 64 (OM = 3.5%) shows a slower increase in efficacy against *Alopecurus myosuroides* in comparison to soil 70. A maximum efficacy (82%) was reached with an application rate of 2.1 kg/ha. Efficacy was lower than in soil 70. It is obvious that soil organic matter content influences herbicide efficacy.

Fig. 4 shows fitted dose-response curves (21 days after application) of chlorotoluron applied to *Stellaria media.* Differences in curve progression are small. From the efficacy curves (Fig. 2 and 3) ED values were calculated (Table 1, Table 2). The ED_{10}, ED_{30}, ED_{30} and ED_{90} values show great differences between soil 70 and soil 64 (Table 1). The factor is about 3 to 5. The ED values for *Stellaria media* show only small differences between soil samples 73 and 64. For the farmer this means that he needs a higher herbicide dose rate at location 64 for effective weed control in comparison to location 70.

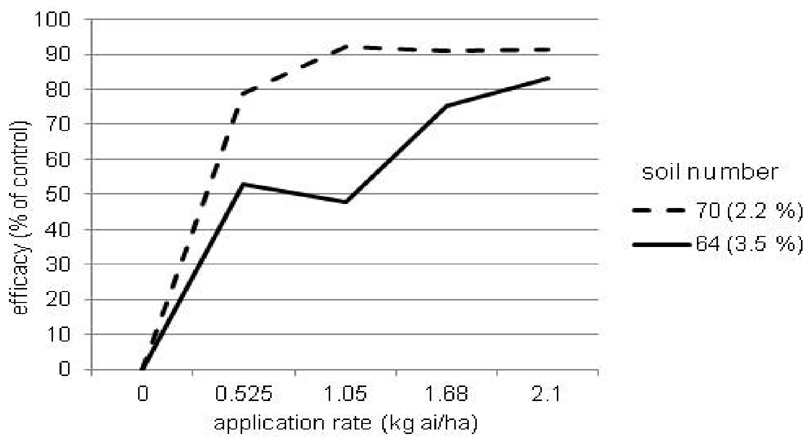

Fig. 3. Efficacy of chlorotoluron against *Alopecurus myosuroides* depending to soil organic matter (soil 70 and 64)

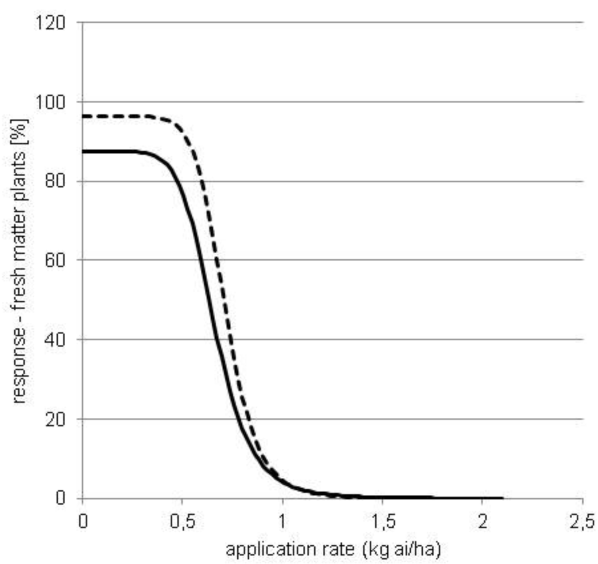

Fig. 4. Fitted dose-response curves (21 days after application) of pendimethalin applied to *Stellaria media*

Table 1. Effective dose of chlorotoluron applied to *Alopecurus myosuroides* – calculated ED values (dose rate)

	Soil sample 70 (2.2% OM)	Soil sample 64 (3.5% OM)
ED_{10}	0.02	0.06
ED_{30}	0.06	0.25
ED_{50}	0.14	0.61
ED_{90}	1.26	6.21

Table 2. Effective dose of pendimethalin applied to *Stellaria media* – calculated ED values (dose rate)

	Soil sample 73 (1.9% OM)	Soil sample 64 (3.5% OM)
ED_{10}	0.48	0.56
ED_{30}	0.58	0.65
ED_{50}	0.66	0.71
ED_{90}	0.89	0.91

In this study the effect of soil organic matter on herbicide efficacy was determined. Soil-applied herbicides (pre-emergence or early post-emergence) can be a very important component in weed control. This is particularly applicable for the control of herbicide-resistant weeds. After spraying soil-applied herbicides, bioavailability in the soils depends on the herbicide properties, weather conditions and soil factors such as texture, moisture, pH and organic matter. For the efficacy assessment of soil-applied herbicides, it is important to know the different factors that affect their fate. The behaviour and plant uptake of pre-emergence herbicides is strongly influenced by soil properties. Herbicide adsorption varies with soil organic matter content. Soils with high organic matter content are more adsorptive. These soils may require higher rates. Many investigations have shown soil organic matter content varying between fields or within field [4-6].

The results demonstrate the relationship between soil organic matter and herbicide efficacy. The experiments confirm the results of other investigations demonstrating that soil organic matter is an important factor for herbicide adsorption. Knezevic et al. [22] used dose-response curves to determine the effective application rate that provides 90% weed control. Knezevic et al. [21] used an experimental herbicide KIH-485 as a model substance. The results from Pedersen et al. [9] indicate the possibility of adjusting the herbicide application rate according to soil factors. This can be an important part of integrated weed management, as pointed out by Swanton et al. [25].

The results show that variable rate application could be done in a precision farming concept within fields with varying organic matter content according to Fig. 1. This could be a good approach to reduce herbicide use and that will allow the reduction of costs at the same time. But to describe the relationship between soil organic matter and herbicide efficacy more investigations are necessary.

Under field conditions, there is a complex interaction of several soil factors affecting the bioavailability of herbicides. Some factors have a high temporal variability (e.g. soil moisture) whereas others have low variability (e.g. soil organic matter). Dry soil conditions will lead to low plant uptake even though we have low adsorption due to low organic matter content. This makes it difficult to find appropriate application rates based on soil organic matter. Other soil factors (e.g. soil texture, soil moisture, pH) and weather conditions at the time of application should be considered. The strong relationship between soil organic matter content and herbicide adsorption and effectiveness is only valid if all other factors are optimal. It is only in these conditions that using a herbicide application rate according to the organic matter content can be varied without a loss of efficacy.

However, this is only one step required for the precise usage of herbicides according to soil variability. In further investigations it will be necessary to clarify how to implement the results in agricultural practice and precision farming. Economic [26] and ecological benefits [27] of precision weed control are obvious. In economic analysis the potential of herbicide savings was shown [28,29]. Depending on crop, weed, soil, sowing date, soil cultivation and wheather conditions, it is not possible to make any general statements. Therefore, in particular cases savings can range from 0 to 100%. A reduction in herbicide use reducing per se environmental risks. Therefore herbicide application based on soil organic matter can provide an essential contribution to use herbicides more targeted.

4. CONCLUSION

In a field varying in organic matter content, the use of herbicides can be reduced if herbicides are sprayed with the right amount in the right place. Herbicides must be sprayed as required by the situation. Detailed information on soil heterogeneity at the field scale is required. In this case, the potential benefits of site-specific herbicide application are obvious. It leads to reduced exposure of herbicides to the environment, better weed control, reduced crop injury and lower costs. Furthermore, small-scale variation in herbicide application requires specific application techniques with high accuracy in spatial application. The hypothesis that in a field varying widely in organic matter, the use of herbicides can be adjusted to small-scale field differences was confirmed by the results. The results demonstrate that farmers can adjust the dose rate of soil applied herbicides. Economic and ecological benefits can be expected. to soil organic matter without efficacy loss.

COMPETING INTERESTS

Author has declared that no competing interests exist.

REFERENCES

1. Weber JB. Behavior of dinitroaniline herbicides in soils. Weed Technology. 1990;4(2): 394-406.
2. Wilson JS, Foy CL. Influence of various soil properties on the adsorption and desorption of ICIA-0051 in five soils. Weed Technology. 1992;6(3):583-586.
3. Nordmeyer H, Dunker M. Variable weed densities and soil properties in a weed mapping concept for patchy weed control. In: Stafford JV. (Ed.), Precision Agriculture 1999: Proceedings of the 2nd European Conference on Precision Agriculture. 1999; part 1:453-462.
4. Weber JB, Weed SB, Waldrep TW. Effect of soil constituents on herbicide activity in modified soil field plots. Weed Science. 1974;22(6):454-459.
5. Ben-Hur M, Letey J, Farmer WJ, Williams CF, Nelson SD. Soluble and solid organic matter effects on atrazine adsorption in cultivated soils. Soil Science Society of America Journal. 2003;67(4):1140-1146.
6. Farenhorst A. Importance of soil organic matter fractions in soil-landscape and regional assessments of pesticide sorption and leaching in soil. Soil Science Society of America Journal. 2006;70(3):1005-1012.
7. Haberhauer G, Pfeiffer L, Gerzabek MH, et al. Response of sorption processes of MCPA to the amount and origin of organic matter in a long-term field experiment. European Journal of Soil Science. 2001;52(2):279-286.
8. Moomaw RS, Klein RN, Martin AR, Roeth FW, Shea PJ, Wicks GA, Wilson RG. Factors that affect soil-applied herbicides. University of Nebraska, Institute of Agriculture and Natural Resources, Cooperative Extension Service. 1992; Publication No.:G92-1081-A. Available:http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=2219&context=extensionhist
9. Pedersen HJ, Kudsk P, Helweg A. Adsorption and ED50 values of five soil-applied herbicides. Pesticide Science. 1995;44(1):131-136.
10. Riddle RN, O`Sullivan J, Swanton CJ, Van Acker RC. Field and greenhouse bioassays to determine mesotrione residues in soil. Weed Technology. 2013; 27(4):565-572.
11. Szmigielski AM, Schoenau JJ, Johnson EN, Holm FA, Sapsford KL, Liu JX. Development of a laboratory bioassay and effect of soil properties on sulfentrazone phytotoxicity in soil. Weed Technology. 2009;23(3):486-491.
12. Ranft RD, Seefeldt SS, Zhang M, Barnes DL. Development of a bioassay for troclopyr residues and comparison with a laboratory extraction. Weed Technology. 2010;24(4):538-543.
13. Weber JB, Wilkerson GG, Linker HM, Wilcut JW, Leidy RB, Senseman S, Witt WW, Barrett M, Vencill WK, Shaw DR, Mueller TC, Miller DK, Brecke BJ, Talbert RE, Peeper TF. A proposal to standardize soil/solution herbicide distribution coefficients. Weed Science. 2000;48(1): 75-88.
14. Gaultier J, Farenhorst A, Crow G. Spatial variability of soil properties and 2,4-D sorption in a hummocky field as affected by landscape position and soil depth. Canadian Journal of Soil Science. 2006; 86(1):89-95.
15. Reisinger P, Pecze ZS, Kiss B. Precision developments in the preemergent weed control of sunflower. Journal of Plant Diseases and Protection. 2008;Special Issue 21:177-180.
16. Nordmeyer H. Patchy weed distribution and site-specific weed control in winter cereals. Precision Agriculture. 2006;7(3): 219-231.
17. Nordmeyer H. Spatial and temporal dynamics of *Apera spica-venti* seedling

populations. Crop Protection. 2009;28(10): 831-837.
18. Gonese JU, Weber JB Herbicide rate recommendations: Soil parameter equations vs. registered rate recommendations. Weed Technology. 1998;12(2):235-242.
19. Nolte KD, Siemens MC, Andrade-Sanchez P. Integrating variable rate technologies for soil-applied herbicides in Arizona vegetable production. University of Arizona, College of Agriculture and Life Sciences, Cooperative Extension, Tucson, Arizona. 2011;5. Available:http://extension.arizona.edu/sites/extension.arizona.edu/files/pubs/az1538.pdf
20. Blumhorst MR, Weber JB, Swain LR. Efficacy of selected herbicides as influenced by soil properties. Weed Technology. 1990;4(2):279-283.
21. Knezevic SZ, Datta A, Scott J, et al. Dose-response curves of KIH-485 for preemergence weed control in corn. Weed Technology. 2009;23(1):34-39.
22. Pätzold S, Mertens FM, Bornemann L, Koleczek B, Franke J, Feilhauer H, Welp G. Soil heterogeneity at the field scale: A challenge for precision crop protection. Precision Agriculture. 2008;9(6):367-390.
23. Mertens FM, Pätzold S, Welp G. Spatial heterogeneity of soil properties and its mapping with apparent electrical conductivity. Journal Plant Nutrition Soil Science. 2008;171(2):146-154.
24. Onofri A. Bioassay 97: A new Excel VBA Macro to perform statistical analysis on pesticide dose-response data (Version 2.651 update 01.06.2011). Rivista Italiana di Agrometeorologia. 2005;3:40-45.
25. Swanton CJ, Mahoney KJ, Chandler K, Gulden RH. Integrated weed management: knowledge-based weed management systems. Weed Science. 2008;56(2):168-172.
26. Takács-György K, Lencsés E, Takács I. Economic benefits of precision weed control and why its uptake is so slow. Studies in Agricultural Economics. 2013; 115:40-46.
27. Maxwell BD, Luschei EC. Justification for site-specific weed management based on ecology and economics. Weed Science. 2005;53(2):221-227.
28. Timmermann C, Gerhards R, Krohmann P, Kühbauch W. The economic impact of site specific weed control. Precis. Agric. 2003; 4(3):249-260.
29. Takács-György K, Reisinger P, Takács E, Takács I. Economic analysis of precision plant protection by stochastic simulation based on finite elements method. Journal of Plant Diseases and Protection. 2008; Special Issue 21:181-186.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history.php?iid=1077&id=2&aid=8938