Journal für Kulturpflanzen, 64 (4). S. 105–111, 2012, ISSN 1867-0911 Verlag Eugen Ulmer KG, Stuttgart

Annett Gummert, Erwin Ladewig, Bernward Märländer

Guidelines for integrated pest management in sugar beet cultivation – weed control

Leitlinien für den integrierten Pflanzenschutz im Zuckerrübenanbau – Unkrautkontrolle

Abstract

The sustainable use of pesticides and the implementation of general principles of integrated pest management (IPM) are demanded from EU-legislation. IPM guidelines go beyond these basic requirements and describe crop- or sector-specifically how to further develop plant protection practice towards sustainability. The recently published guidelines for IPM in sugar beet cultivation were jointly developed by scientists, sugar beet extension experts and representatives of various interest groups related to sugar beet cultivation. With participation of these stakeholders in the development process it was possible to prepare a concerted realisation of the EU's demand on crop-specific guidelines and to provide an accepted tool for communication with the society at the same time.

The weed-section of these guidelines contains preventive and direct control measures for weed control in sugar beet cultivation. The focus is put on herbicidal weed control and its non-chemical alternatives as well as options for optimisation of herbicide use in order to keep it to the necessary minimum. After evaluation of advantages and disadvantages of the presented measures, it is concluded that at present weed control with herbicides is a prerequisite for economic and sustainable sugar beet cultivation in Germany.

Key words: EU-Directive 2009/128/EC, necessary minimum, sustainable use of herbicides

Zusammenfassung

Die EU-Rahmenrichtlinie zur nachhaltigen Anwendung von Pflanzenschutzmitteln fordert die Anwendung der allgemeinen Grundsätze des integrierten Pflanzenschutzes (IPS). IPS-Leitlinien gehen über diese Basisanforderungen hinaus und beschreiben eine nachhaltige Pflanzenschutzpraxis spezifisch für eine Kulturart oder einen Sektor. In Zusammenarbeit zwischen Wissenschaftlern, Anbauexperten und Interessensvertretern der gesamten Wertschöpfungskette Zuckerrübe wurden Leitlinien für den integrierten Pflanzenschutz im Zuckerrübenanbau entwickelt und abgestimmt. Damit stehen abgestimmte Handlungsanweisungen für die Praxis und gleichzeitig ein Instrument für die Kommunikation mit der Gesellschaft zur Verfügung.

In diesem Beitrag wird ein Auszug aus den Leitlinien zur Unkrautkontrolle in Zuckerrüben vorgestellt und diskutiert. Nichtchemische Alternativen zur Unkrautkontrolle mit Herbiziden werden darin erläutert und Wege aufgezeigt, wie der Herbizideinsatz optimiert und auf das notwendige Maß begrenzt werden kann. Zudem wird herausgestellt, warum die Unkrautkontrolle mit Herbiziden derzeit die einzige praktikable und nachhaltige Maßnahme für einen wirtschaftlichen Zuckerrübenanbau ist.

Stichwörter: EU-Richtlinie 2009/128/EG, nachhaltiger Einsatz von Herbiziden, notwendiges Maß

Institute
Institute of Sugar Beet Research, Göttingen

Correspondence
Annett Gummert, Institute of Sugar Beet Research, Holtenser Landstraße 77, 37079 Göttingen, Germany, E-Mail: gummert@ifz-goettingen.de

Accepted
1 March 2012

1 Introduction

EU-Directive 2009/128/EC establishes a framework for the sustainable use of pesticides. One of its key components is the implementation of integrated pest management[1] (IPM) in all Member States as from 2014. Accordingly, the general principles of IPM, which are described in the directive (Annex III), set the future common requirements for integrated plant protection within the EU. In addition to the mandatory demands of the directive, the EU-Member States are encouraged to implement crop- or sector-specific IPM guidelines on a voluntary basis. It is expected that the application of general IPM principles and crop- or sector-specific IPM guidelines by all farmers will result in a better targeted use of all available crop protection measures, including pesticides. This will contribute to a further reduction of the risks to human and animal health as well as the environment, and decrease the dependency on pesticide use. The IPM-strategy is furthermore an essential part of the German National Action Plan on Sustainable Use of Plant Protection Products (BMELV, 2008) to increase growers' acceptance and social awareness of IPM.

With regard to article 14 of the EU-Directive, public authorities and/or organisations representing professional users of plant protection products may draw up IPM guidelines. However, to date, no acknowledged guidelines for any crop or sector have been published and experiences in developing them are scarce. From 2009 to 2011 sugar beet-specific IPM guidelines for Germany were developed at the Institute of Sugar Beet Research (IfZ) within the scope of a funded project. The outcome is presented in a brochure in German language (Gummert et al., 2011) which is now being distributed amongst stakeholders, advisers and growers. The development of these guidelines facilitated the definition of an 'integrated way' of plant protection in sugar beet cultivation against the background of the current opportunities under participation of all interest groups.

Weeds cover a main topic of the IPM guidelines as young sugar beet plants are weak competitors and weeds can considerably decrease yield. Nowadays, weed control with herbicides is the most important and most complex plant protection measure in sugar beet cultivation. Tank mixtures of herbicides are usually sprayed several times after crop establishment as post-emergence treatments with considerably reduced application rates compared to approved ones (Märländer et al., 2003; Vasel et al., 2012). According to the NEPTUN-survey[2] in 2009 (Rossberg et al., 2010), the herbicide treatment frequency in Germany was 3.76 (80%) on average and the treatment index 2.25 (69% of all pesticide applications). The high share of herbicides on total pesticide use demonstrates the importance of weed control for economic sugar beet cultivation.

Due to the specific aim of the project, which was more an interactive communication process than an analytical approach or experiment, structure and content of this article are different from other original papers. At first, the development procedure of the guidelines is explained. Afterwards, the practical situation of weed control in sugar beet and its scientific background are described, providing the basis for the definition of integrated weed management. Finally, the weed-specific section of the guidelines is presented in English language to enable a broader availability in the scientific community.

2 Methodological approach

The IPM guidelines for sugar beet cultivation refer to the EU's IPM principles and comprise a general guideline as well as several pathogen-specific guidelines, including weeds, wherein the currently available IPM measures and possible restrictions are described in detail. The general guideline contains superior principles that are applicable and relevant for all pests and diseases. The pathogen-specific guidelines focus on IPM regarding the most important pathogens of the sugar beet crop (i.e. seedling, soil-borne and foliar diseases, pests, weeds). Each guideline itself follows the content and structure of the IPM principles according to Annex III of 2009/128/EC and covers the following topics: preventive measures, monitoring tools, threshold values and decision-making systems, non-chemical and chemical control measures, reduction to the necessary minimum, anti-resistance strategies, check of success based on records and monitoring. The pathogen-specific guidelines also include additional information that explain the recommendations and instructions given.

The development process was organised as follows: A literature review on the relevant pests and diseases of the sugar beet crop and suitable integrated control strategies served as a basis for a first proposal of the guidelines. This included gathering information from scientific journals, farmers' magazines, reference books as well as recommendations from extension or internet services for plant protection. In the following, a project-linked working group of sugar beet experts (Tab. 1) extensively discussed the proposals and decided on the final wording of the guidelines. This interactive and consensual approach included regular meetings and round table discussions with additional exchange of information or comments via e-mail and consultations of scientists with specific expertise. During this process, particular importance was attached to possible conflicts of interest that a farmer might come across when deciding for or against a measure. Concerning such issues like soil cultivation regime or choice of control measure, it was important for the working group to stress the corresponding advantages and disadvantages. Thus, the

[1] 'Integrated pest management' means careful consideration of all available plant protection methods and subsequent integration of appropriate measures that discourage the development of populations of harmful organisms and keep the use of plant protection products and other forms of intervention to levels that are economically and ecologically justified and reduce or minimise risks to human health and the environment. ... (definition of IPM, Art. 3, EU-Directive 2009/128/EC)

[2] NEPTUN = Netzwerk zur Ermittlung der Pflanzenschutzmittelanwendung in unterschiedlichen, landwirtschaftlich relevanten Naturräumen Deutschlands

Tab. 1. Composition of the project-linked working group IPM, Germany 2009–2011

The participating institutions of the **working group** represented:
- sugar beet growers and growers associations
- sugar industry
- official advisory services
- breeding companies
- companies of the plant protection industry
- Julius Kühn-Institut (JKI)
- Federal Office of Consumer Protection and Food Safety (BVL)
- internet based advisory systems (BISZ, ISIP, LIZ)

grower was left in charge of decision-making, in order to enable farm- or field-specific adaptations.

3 Background

Sugar beets are sown in rows of 45 or 50 cm distance providing a large surface area for weeds to germinate and grow. Moreover, young sugar beet plants grow slowly, which leads to a relatively low competitiveness especially in the early development stages (BRÄUTIGAM, 1998). When sugar beets are cultivated without any weed control measure, white sugar yield losses can reach up to 95% (PETERSEN, 2003). Even lower weed infestations can significantly decrease root yield: one single plant per m^2 of *Chenopodium album* (a common weed species in sugar beet) e.g., can cause a white sugar yield loss of 5–9%, when emerging in the 2- to 5-leaf-stage of the sugar beet plants (WELLMANN, 1999). After chemical control with herbicides, the remaining weeds can still decrease white sugar yield by 5–15% depending on site, weed flora and application date or duration of weed infestation, respectively. These losses are lower the earlier the weeds are controlled or the later the weeds occur in the field (BRANDES, 2000; MITTLER et al., 2002). Tall lignified weed species might also impair mechanised harvesting and beet processing (KNOTT, 2002). In addition, weeds can act as (intermediate) hosts for pests and diseases (WISLER and NORRIS, 2005; BRENDLER et al., 2008). Hence, weed control is an indispensable prerequisite for sugar beet cultivation (MÄRLÄNDER et al., 2003).

The key approach of integrated weed management as a part of IPM is to minimise the occurrence of weed problems in a crop and to manage weed populations using cultural and biological as well as chemical solutions (NAYLOR and DRUMMOND, 2002). In sugar beet cultivation, the preventive and cultural plant protection measures like crop rotation and soil cultivation (Tab. 2) are not sufficient on their own so that direct measures are essential for an adequate weed control. Thermal and mechanical techniques can be used for non-chemical weed control. However, flame weeding has a lot of disadvantages (cost-intensive, inefficient) and cannot be recommended for practice. Mechanical weed control (e.g. tractor hoeing) can be used for inter-row weeding until canopy closure of the crop. It is applicable when herbicides have been sprayed in bands over the row or to replace a late herbicide application or to manage difficult-to-control weeds (MAY and WILSON, 2006). When using this technique, the adverse side effects like damage of plant leaves or increasing risk of soil erosion have to be taken into account. Mere hoeing is almost exclusively used in organic farming and only of minor importance in conventional cultivation due to the low efficacy of intra-row weed control (KOUWENHOVEN et al., 1991) and the high amount of labour needed for manual intra-row weeding. For hand weeding in organic farming, 50–125 (200) working hours per ha and costs of 380–960 € per ha are assumed, depending on weed infestation and wage level (KOLBE and PETZOLD, 2002; KÖNIG et al., 2005; ÖKOLANDBAU, 2012). Improvements in mechanical weed control systems (vision guidance, automatic intra-row weeding) are still in their experimental stage and do not have much commercial application yet (VAN DER WEIDE et al., 2008). Consequently, for a decision on the general weed management procedure (mechanical and/or chemical), the omission of herbicides and savings in herbicide costs have to be balanced against a relatively low hoe working rate and the availability and costs of labour for hand weeding.

Chemical weed control with herbicides is used on 99.8% of the sugar beet acreage in Germany – mainly as overall post-emergence applications with reduced doses (BUHRE et al., 2011). In order to achieve satisfactory broad-spectrum weed control, different selective herbicides (active ingredients) are combined in tank mixtures and applied in sequential low dose applications after sugar beet emergence. Nowadays, typical tank mixtures of herbicides achieve an efficacy of > 95% with herbicide costs of 215 € per ha on average (BISZ, 2012; VASEL et al., 2012). As the efficacy of active ingredients and cost effectiveness of weed control is best when herbicides are applied at weed cotyledon stage and weeds emerge in 'waves', repeated applications are necessary. In Germany, 3.5 post-emergence treatments are common, applied in intervals of 12 days on average (VASEL et al., 2012). Especially in conservation tillage systems the application of non-selective herbicides before sowing is gaining more and more importance (BUHRE et al., 2011).

The choice of herbicide mixture, application rate, frequency and timing (intervals) is determined by field-specific conditions (e.g. soil moisture) and primarily by the weed community present. Therefore, correct identification of weed species is needed. Another aspect governing the selection of herbicide mixture, dosage and application timing, is the fact that herbicides have the potential to damage the crop plant (BEISSNER, 2000). To avoid injury, growth depressions or leaf damage of sugar beet plants, herbicide use has to be carefully adjusted especially to the prevailing weather conditions.

Finally, a target-oriented adaptation of herbicide use to the field-specific situation is currently the most important measure of integrated weed management. When this is performed accurately, the professional user meets the requirement of keeping pesticide use restricted to the necessary minimum. Further reductions in herbicide use may be achieved by a combination of herbicide applica-

tions as band sprays over the row and mechanical weed control between rows. However, this method requires appropriate equipment and entails several disadvantages (see Tab. 2) which limit its applicability and acceptance. Site-specific herbicide applications (Gerhards and Oebel, 2006) and the strategy of low dosage herbicide applications (Bruns et al., 2008) offer further reduction possibilities. But such systems necessitate advanced application techniques and a comprehensive knowledge, and thus are not suitable for each farm at present.

The use of threshold values is an essential component for decision making (whether and when to apply plant protection measures) and enables an optimisation of pesticide application. Nevertheless, although thresholds depending on weed density or time (critical periods) have been identified (Wellmann, 1999; Kobusch, 2003), they have not been established in weed control in sugar beet to date. This is because these thresholds refer to late development stages of weeds, but the conventional post-emergence herbicides have to be applied at cotyledon to first true leaf stage of weeds – which does not coincide with the critical period – due to a lack of efficacy of most of the selective sugar beet herbicides on larger weeds (Petersen, 2003; May and Wilson, 2006). The cultivation of herbicide tolerant varieties, including herbicide application at the 8–10 leaves stage of crop and weeds, would offer the potential to overcome these constraints (Knott, 2002). However, such varieties are not expected to come soon for socio-political reasons (Märländer, 2005).

The application of anti-resistance strategies represents another IPM principle. Maintaining the effectiveness of herbicides for the future is especially important for weed control in sugar beet cultivation as there are only few active ingredients available on the market. The standard procedure of applying herbicides in mixtures of different active ingredients and the fact that sugar beets are grown in rotations with crops where other active ingredients are used, already reduce the risk of selecting resistant weed species (Moss, 2002). However, in recent years the appearance of *Chenopodium album* plants resistant to metamitron (a key herbicide in sugar beet cultivation) has been reported for other European countries. The associated target-site resistance was presumably caused by intensive atrazine use in maize in the 1980s (Mechant et al., 2008; Thiel et al., 2010). Anti-resistance strategies therefore must not only be focussed in the sugar beet crop, but have to be applied in the whole rotation.

The check of success of a plant protection measure based on records and monitoring (the last IPM principle of the EU-Directive) doesn't need to be regarded weed-specifically, since the issue of documentation is already addressed in the general IPM guideline for sugar beet cultivation.

4 IPM guideline weeds

The following table (Tab. 2) is a translation of the sugar beet-specific IPM guideline for weeds originally written in German (Gummert et al., 2011). The term weeds includes monocotyledonous and dicotyledonous weeds as well as bolters and volunteer plants from previous crops.

Tab. 2. Sugar beet-specific guideline for integrated pest management: weeds

Preventive measures	Comments and supplementary information
Efficient control, especially of difficult-to-control weeds, has to be done throughout the whole crop rotation.	The normally used herbicides in sugar beet crop do not control all weeds adequately. Management of such difficult-to-control weeds results in higher application rates of herbicides and is, to some extent, only possible with laborious hand weeding. Some difficult-to-control weeds in sugar beet are easier to control in preceding cereals. Alternation of winter crops such as cereals with spring sown sugar beet offers good options for control of autumn germinating grasses.
Depending on the soil cultivation regime, weed control usually starts with stubble cleaning and sub-soiling after harvest of the previous crop. In addition, good seedbed preparation for sugar beet can also help to optimise weed control.	Repeated soil cultivation after harvest of the previous crop incorporates weed seeds like volunteer grains into the soil and stimulates germination. Careful seed bed preparation should result in even and optimal emergence of sugar beet seedlings. This should also promote uniform weed emergence allowing effective weed control with low herbicide inputs.
Establishment of a homogeneous sugar beet stand without gaps and with a high population density should be aimed at.	A uniform and high field emergence along with a population density of at least 80,000 sugar beet plants per ha usually leads to earlier canopy closure and enhances the competitiveness of the beets. The result is a better weed suppression compared to lower plant population densities. Use should be made of varieties that have good tops which will shade the weeds. Gaps in the plant stand as well as late and uneven canopy closure increase the risk of late weed infestations. This can significantly increase the amount of herbicide needed. Failure to control late weed infestations can cause yield losses and considerable harvesting problems.

Tab. 2. Continued

Preventive measures	
In regions with a high risk of prolonged periods of low temperatures (between 2 and 10°C) after sowing, varieties with a lower tendency to bolting should be sown.	Sugar beet is a biennial crop that in the first year develops storage roots and in the second, induced by cold temperatures (vernalisation), produces bolters (seed production). Long periods of coldness after sowing may induce bolting in the first year. Use of varieties with a lower tendency to bolt can reduce the effort needed for removal of bolters (by chemical or non-chemical measures). However, a compromise between desirable characteristics of a variety may have to be found. Depending on the expected occurrence of pathogens, the feature 'tendency to bolting' might be of minor importance.
Monitoring	
The occurrence of weeds and the composition of the weed community have to be monitored by field observations.	Early identification of weed species present is an important prerequisite governing the choice of herbicides and optimal adjustment of application rates in order to achieve weed control in a cost-effective and environmentally friendly manner. Internet applications (BISZ: *http://bisz.suedzucker.de*, LIZ: *http://www.liz-online.de*) provide an easy and quick identification of all relevant weed species.
Threshold values	
–	Threshold values for weed control are currently not relevant in sugar beet. Although thresholds have been identified for some weed species, their use is not feasible owing to the lack of effective herbicides for controlling important dicotyledonous weeds at late development stages. Moreover, the application of threshold values is not worthwhile because weed control is most effective (lowest input of herbicides needed) at the cotyledon stage of weeds.
Direct control	
Chemical and non-chemical measures are available for weed control in sugar beet crop. Control measures should aim at an early and preferably entire weed removal. This is also necessary from a phytosanitary point of view, because many weed species are (intermediate) hosts for pests and diseases of sugar beets.	Weed control is the most important yield-securing measure in sugar beet cultivation. Uncontrolled weeds compete with the sugar beets and restrict growth. Severe yield losses can occur and machine harvesting can be impaired or even become impossible. Chemical weed control with herbicides is a highly profitable and effective technique. Mechanical weed control with hoeing machines is not sufficient with currently available techniques – many weed plants remain unaffected within the crop row, especially those nearest to the sugar beet plants. Therefore, supplementary band spraying of herbicides or manual removal of remaining weeds is necessary after hoeing. Flame weeding can be applied as a pre-emergence control measure either on the whole field or in a band on the crop rows. However, due to the uncertain efficacy and high costs (low area efficiency, high energy input), its applicability in practice is limited.
Chemical weed control uses repeated applications of herbicide mixtures adapted to the field-specific weed community.	A combination of active ingredients, which is flexibly adapted to the field-specific weed community and the weather, is essential for achieving effective and lasting control. For a highly efficient weed control, it is crucial to optimise the mix of active ingredients, including the use of additives, application rates and time of application, whilst minimising negative effects on crop development. Therefore, regional advice from approved extension services (official advisory services, sugar beet growers associations, sugar industry) has to be considered. Internet based applications give assistance in selecting appropriate herbicide mixes taking into account the important weeds, weather and soil conditions, application date and previous applications. Post-emergence herbicides are applied when the weeds are at cotyledon stage, which is the optimal development stage for herbicide applications. Remaining weed infestations or specific difficult-to-control weeds might require the application of non-selective herbicides prior to sugar beet sowing, especially in conservation tillage systems. Herbicides that achieve efficient weed control along with the least side effects on human health, non-target organisms and the environment have to be preferred, provided that they are recommended by the advisory services.
Mechanical weed control can be conducted until canopy closure of the beets. When using this method, growers have to weigh its advantages and disadvantages.	Some difficult-to-control weeds and weed beets can only be managed (to some extent) by mechanical measures. Weed control with hoeing machines can significantly increase the risk of soil erosion on prone fields. Thus, the use of hoeing is not suitable for erosion-minimising sugar beet cultivation systems such as direct drilling or conservation tillage. When hoeing, beet damage has to be avoided as damage lesions on leaf surface or beet top can allow pathogens to invade the plant.

Tab. 2. Continued

Direct control	
Control of bolters and weed beets growing in sugar beet fields has to be carried out before flowering with mechanical or chemical measures.	Control of bolters is highly important for sustainable sugar beet cultivation. Each bolter can produce thousands of seeds that remain dormant in the soil seed bank. These can germinate in subsequent years, often 10 or more, leading to severe, long-term problems with weed beets. Sugar beet cultivation on heavily infested fields can become impossible for many years. The approved extension services give information on threshold values and appropriate control measures (e.g. via internet at BISZ: *http://bisz.suedzucker.de*, ISIP: *http://www.isip.de*, LIZ: *http://www.liz-online.de*).
Reduction to the necessary minimum	
Usually, herbicides are applied repeatedly after beet emergence at the cotyledon stage of the weeds (post-emergence application). Choice of herbicides and application dates are adapted to the field-specific weed community.	At the cotyledon stage of weeds, herbicides can be applied at low rates, provided that conditions are favourable. Repeated herbicide applications to control newly emerged weed seedlings result in a relatively low total amount of herbicides being used. The adaptation of a mixture of active ingredients according to the field-specific weed flora further minimises herbicide use. Weed infestations remaining after the preceding crop should be removed by non-selective herbicides sprayed before sowing, because applications after sowing have the potential to damage the crop.
A further reduction of total herbicide use may be achieved by reduced doses or site-specific weed management (partial applications). The advantages and disadvantages of such measures have to be considered taking into account their effectiveness and profitability.	The normal procedure of repeating herbicide applications after beet emergence generally avoids unnecessary high application rates. Further reductions in herbicide use can be achieved by using various approaches adapted to the weed infestation present and farm-specific options.
• mechanical weed control in combination with band spraying	The combination of hoeing and band spraying is possible. Restricting factors are: technical equipment (machinery) available on the farm, reduced area efficiency and higher labour costs compared to exclusive use of herbicides. Problems may arise concerning soil erosion.
• site-specific weed management	Site-specific weed control (partial applications) enables saving of herbicides and eventually a reduction in working and machine hours. It is applicable for instance against weeds that occur in aggregated patches.
• low dosage herbicide application	The strategy of low dosage herbicide mixtures includes high numbers of active ingredients in combination with substantially reduced application rates (approx. $-\,^2/_3$). Provided that the weather is favourable, this strategy can increase efficacy, reduce herbicide costs and decrease treatment index. Pre-conditions are: knowledge about the weed flora, absence of difficult-to-control weeds, timely herbicide applications and good management. Nevertheless, this strategy of repeated applications of very low herbicide doses of each active ingredient runs the risk of selecting less sensitive weed populations that would have been controlled using the approved rate.
Anti-resistance strategies	
Anti-resistance strategies have to be used within the whole crop rotation. Sugar beet-specific strategies are not necessary at the moment.	The repeated use of a relatively small number of available active ingredients in sugar beet exerts a constant selection pressure on the weed community. However, this pressure is significantly reduced by the usual mixing of herbicides with different active ingredients and modes of action. Nevertheless, it is essential to keep a careful watch for the appearance of resistance. Incidences of reduced efficacy should be communicated to approved extension services. If possible, at least two active ingredients with different modes of action adapted to the weed flora should be used. Information from approved extension services and producers of plant protection products have to be considered.

5 Outlook

Performing weed control in sugar beet following the presented guideline keeps herbicide use to the necessary minimum and ensures compliance with EU-regulation and the target to achieve the sustainable use of pesticides. So far, the responsible application of herbicides is the most efficient way to manage weed populations in sugar beets in Germany. Notwithstanding that there are farmers with specific knowledge or equipment, who are able to further reduce herbicide usage with innovative techniques and who are one step ahead. The aim now should be to inform

all growers about the meaning and importance of IPM and its opportunities. In this context, a key role in improving the level of weed control towards sustainability is held by independent extension services that are capable of informing growers about new techniques and advanced weed control measures in an appropriate manner. The guidelines for IPM in sugar beet can give a contribution to that.

Since in Germany sugar beets are only grown under contract, the IPM guidelines could be implemented into the basic agreement on sugar beet cultivation between growers and sugar company ('Branchenvereinbarung'), in order to promote a widespread application of IPM. Besides of its intended purpose as a handbook with instructions and recommendations for sugar beet growing, the guidelines could also be used as a tool for communication with the society and thereby inform about the efforts made to achieve a sustainable use of pesticides according to EU-Directive 2009/128/EC. This can help to improve knowledge about and acceptance of plant protection in integrated crop production.

Finally, IPM is considered as an approach which is innovation driven and dynamic. The continuous development of new tools and improvement of existing technologies (e.g. breeding for tolerance) and their implementation in practice by a fast knowledge transfer are important for a further progress of IPM. Consequently, the IPM guidelines have to continuously be adjusted to the state of the art.

Acknowledgement

This project was financially supported by the Federal Ministry of Food, Agriculture and Consumer Protection as part of the innovation funding of the Federal Agency for Agriculture and Food.

References

BEISSNER, L., 2000: Einfluss von Herbiziden auf Stoffwechsel und Ertragsbildung von Zuckerrüben. Zuckerindustrie **125**, 721-726.

BMELV, 2008: National Action Plan on Sustainable Use of Plant Protection Products. Federal Ministry of Food, Agriculture and Consumer Protection, Bonn.

BISZ, 2012: Beratung und Information für den süddeutschen Zuckerrübenanbau – Pflanzenschutz, Herbizidempfehlungen, regional. Available at: http://bisz.suedzucker.de [accessed: 27 January 2012].

BRANDES, A., 2000: Ertrag und Qualität von Zuckerrüben in Abhängigkeit von Restverunkrautung und Standort. Dissertation, Universität Göttingen.

BRÄUTIGAM, H., 1998: Untersuchungen zur Konkurrenz zwischen Unkraut und Zuckerrüben – Auftreten, Ursachen und Konsequenzen für die Unkrautregulierung. Dissertation, Universität Göttingen.

BRENDLER, F., B. HOLTSCHULTE, W. RIECKMANN, 2008: Zuckerrübe – Krankheiten, Schädlinge, Unkräuter. Gelsenkirchen, Verlag Th. Mann.

BRUNS, C., E. LADEWIG, B. MÄRLÄNDER, 2008: Strategien zur Reduktion des Herbizideinsatzes im Zuckerrübenanbau. Journal of Plant Diseases and Protection, Special Issue **XXI**, 479-482.

BUHRE, C., P. FECKE, F. NELLES, G. SCHLINKER, E. LADEWIG, 2011: Entwicklungen im Pflanzenschutz in Zuckerrüben aus der Umfrage Produktionstechnik im Vergleich zur Erhebung NEPTUN. Sugar Industry **136**, 742-749.

GERHARDS, R., H. OEBEL, 2006: Practical experiences with a system for site-specific weed control in arable crops using real-time image analysis and GPS-controlled patch spraying. Weed Research **46**, 185-193.

GUMMERT, A., E. LADEWIG, P. LUKASHYK, B. MÄRLÄNDER, 2011: Leitlinien des integrierten Pflanzenschutzes im Zuckerrübenanbau. Institut für Zuckerrübenforschung, Göttingen (ed.). Available at: http://www.ifz-goettingen.de/site/de/441/weitere-publikationen.html.

KNOTT, C.M., 2002: Weed Control in other Arable and Field Vegetable Crops. In: NAYLOR, R.E.L. (ed.): Weed Management Handbook, pp. 359-398. Oxford, Blackwell Publishing.

KOBUSCH, H., 2003: Unkrautbekämpfung in Zuckerrüben – Ermittlung der Kritischen Periode. Dissertation, Universität Hohenheim.

KOLBE, H., W. PETZOLD, 2002: Zuckerrübenanbau im Ökologischen Landbau – Informationen für Praxis und Beratung. Sächsische Landesanstalt für Landwirtschaft, Dresden (ed.).

KOUWENHOVEN, J.K., J.D.A. WEVERS, B.J. POST, 1991: Possibilities of mechanical post-emergence weed control in sugar beet. Soil & Tillage Research **21**, 85-95.

KÖNIG, H.P., A. MEYERCORDT, H.-J. KOCH, 2005: Zuckerrüben ökologisch anbauen – Ein Leitfaden für die Praxis. Institut für Zuckerrübenforschung, Göttingen (ed.).

MÄRLÄNDER, B., 2005: Weed Control in Sugar Beet using Genetically Modified Herbicide-tolerant Varieties – A Review of the Economics for Cultivation in Europe. J. Agronomy & Crop Science **191**, 64-74.

MÄRLÄNDER, B., C. HOFFMANN, H.-J. KOCH, E. LADEWIG, R. MERKES, J. PETERSEN, N. STOCKFISCH, 2003: Environmental Situation and Yield Performance of the Sugar Beet Crop in Germany: Heading for Sustainable Development. J. Agronomy & Crop Science **189**, 201-226.

MAY, M.J., R.G. WILSON, 2006: Weeds and Weed Control. In: DRAYCOTT, A.P. (ed.): Sugar Beet, pp. 359-386. Oxford, Blackwell Publishing.

MECHANT, E., T. DE MAREZ, O. HERMANN, R. OLSSON, R. BULCKE, 2008: Target site resistance to metamitron in *Chenopodium album* L. Journal of Plant Diseases and Protection, Special Issue **XXI**, 37-40.

MITTLER, S., J. PETERSEN, H.-J. KOCH, 2002: Bekämpfungsschwellen bei der Unkrautregulierung in Zuckerrüben. Journal of Plant Diseases and Protection, Special Issue **XVIII**, 499-509.

MOSS, S.R., 2002: Herbicide-Resistant Weeds. In: NAYLOR, R.E.L. (ed.): Weed Management Handbook, pp. 225-252. Oxford, Blackwell Publishing.

NAYLOR, R.E.L., C. DRUMMOND, 2002: Integrated Weed Management. In: NAYLOR, R.E.L. (ed.): Weed Management Handbook, pp. 302-310. Oxford, Blackwell Publishing.

ÖKOLANDBAU, 2012: Kulturdatenblatt Zuckerrübe. Available at: http://www.oekolandbau.de/erzeuger/pflanzenbau/hackfruechte/ [accessed: 27 January 2012].

PETERSEN, J., 2003: A Review on Weed Control in Sugarbeet: From tolerance zero to period threshold. In: INDERJIT (ed.): Weed Biology and Management, pp. 467-483. Dordrecht, Kluwer Academic Publishers.

ROSSBERG, D., E.-H. VASEL, E. LADEWIG, 2010: NEPTUN 2009 – Zuckerrübe. Berichte aus dem Julius Kühn-Institut **152**, 45 S.

THIEL, H., C. KLUTH, M. VARRELMANN, 2010: A new molecular method for the rapid detection of a metamitron-resistant target site in *Chenopodium album*. Pest Manag. Sci. **66**, 1011-1017.

VAN DER WEIDE, R.Y., P.O. BLEEKER, V.T.J.M. ACHTEN, L.A.P. LOTZ, F. FOGELBERG, B. MELANDER, 2008: Innovation in mechanical weed control in crop rows. Weed Research **48**, 215-224.

VASEL, E.-H., E. LADEWIG, B. MÄRLÄNDER, 2012: Weed composition and herbicide use strategies in sugar beet cultivation in Germany. Journal für Kulturpflanzen **64** (4), 112-125.

WELLMANN, A., 1999: Konkurrenzbeziehungen und Schadensprognose in Zuckerrüben bei variiertem zeitlichen Auftreten von *Chenopodium album* L. und *Chamomilla recutita* (L.) Rauschert. Dissertation, Universität Göttingen.

WISLER, G.C., R.F. NORRIS, 2005: Interactions between weeds and cultivated plants as related to management of plant pathogens. Weed Science **53**, 914-917.