Weed spectrum and selectivity of tembotrione under varying environmental conditions

Unkrautspektrum und Selektivität von Tembotrione unter verschiedenen Umweltbedingungen

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Summary

Tembotrione is a novel HPPD maize herbicide effective against a wide range of broadleaf and grass weeds. Some characteristics of this compound are described in this paper linking weed and crop responses following tembotrione applications to environmental parameters or use conditions.

The activity of HPPD herbicides is very much dependant on the availability of light. Increasing illumination intensities following application augmented the activity levels of several comparable HPPD compounds in a growth chamber experiment. Tembotrione was shown to be more efficacious at low and high illumination intensities compared to standard herbicides applied at the same rate. At the high intensity, tembotrione retained its high efficacy from two up to four weeks after application showing a rapid and strong herbicidal activity.

The activity following post-emergent treatments of tembotrione against broadleaf weeds was influenced by soil characteristics such as soil texture and organic matter content in a glasshouse test. The level of weed suppression clearly declined stronger on heavier soils than on lighter soils at a rather low application rate of 12.5 g a.i./ha and lower. This is a clear indication of residual efficacy of tembotrione.

The selectivity of tembotrione was tested on numerous maize varieties following post-emergent treatment with tembotrione alone or in mixture with the safener isoxadifen-ethyl under field conditions in Germany in comparison to a standard herbicide. The level of crop phytotoxicity tended to increase in the following order: Tembotrione plus safener, standard herbicide to tembotrione alone. Only the mixture of tembotrione with safener did not cause significant adverse effects on maize.

Another field experiment in the USA examined crop phytotoxicity using one maize variety in a situation of in-furrow soil insecticide treatment followed by a post-emergent application of tembotrione (plus/minus isoxadifen-ethyl) and standard herbicides. The maximum observed crop response for tembotrione plus isoxadifen-ethyl was again negligibly low, while applications of tembotrione alone or standard herbicides caused instances of unacceptable maize phytotoxicity.

Keywords: Efficacy, HPPD, isoxadifen-ethyl, maize, safener

Zusammenfassung

Tembotrione ist ein neues HPPD Mais-Herbizid mit breiter Wirkung gegen ein- und zweikeimblättrige Unkräuter. Einige Eigenschaften von Tembotrione werden in den dargestellten Versuchen aufgezeigt, die den Einfluss von Umweltparametern bzw. Applikationsbedingungen auf die Unkrautwirkung bzw. die Kulturpflanzenselektivität von Tembotrione beschreiben.

Die Wirkung von HPPD-Herbiziden ist sehr stark lichtabhängig. Bei mehreren HPPD-Herbiziden erwies sich eine erhöhte Beleuchtungsstärke nach Applikation förderlich für die Effizienz der Unkrautbekämpfung in einem Klimakammer-Versuch. Tembotrione zeigte im Vergleich zu anderen HPPD-Standards bei gleicher Aufwandmenge sowohl bei geringer als auch bei hoher Beleuchtungsstärke eine höhere herbizide Aktivität. Bei hoher Beleuchtungsstärke blieb Tembotrione auf hohem Wirkniveau von zwei bis vier Wochen nach Applikation. Somit zeigte Tembotrione eine schnelle, starke und nachhaltige herbizide Wirkung.

Die Wirkung bei Nachauflauf-Anwendung von Tembotrione gegen breitblättrige Unkräuter wurde in einem Gewächshaus-Versuch durch die Eigenschaften der eingesetzten Böden wie die Textur und den Gehalt an organischer Substanz beeinflusst. Unter einer relativ niedrigen Aufwandmenge von 12,5 g a.i./ha sank das Wirkniveau auf schweren Böden stärker ab als auf leichten Böden. Dies ist ein klarer Hinweis auf eine Residualwirkung von Tembotrione.

Die Kulturverträglichkeit von Tembotrione allein und in Mischung mit dem Safener Isoxadifen-ethyl wurde nach

Anwendung im Nachauflauf in einem Feldversuch in Deutschland anhand einer Vielzahl von Maissorten und im Vergleich zu einem Standardherbizid geprüft. Tendenziell nahm die Phytotoxizität gegenüber Mais in der Reihenfolge Tembotrione plus Safener, Standardherbizid und Tembotrione allein zu. Nur in der Variante Tembotrione mit Safener ergab sich eine breite Verträglichkeit gegenüber allen Maissorten.

In einem weiteren Feldversuch zur Kulturverträglichkeit in Mais wurden in den USA verschiedene Bodeninsektizide mit der Saat in die Furche appliziert und anschließend eine Herbizid-Anwendung im Nachauflauf von Tembotrione allein und mit dem Safener Isoxadifen-ethyl im Vergleich zu einem Standardherbizid evaluiert. Für die Mischung von Tembotrione mit Safener wurde auch hier eine sehr gute Kulturverträglichkeit beobachtet, während es bei allen anderen Anwendungen zu einer nicht akzeptablen Schädigung des Mais kam.

Stichwörter: HPPD, Isoxadifen-Ethyl, Mais, Safener, Wirksamkeit

1. Introduction

Tembotrione was first launched as a maize herbicide in 2007 by Bayer CropScience. Its chemical and biological properties are described in detail in VAN ALMSICK et al. (2009). Tembotrione inhibits the enzyme 4-hydroxyphenylpyruvate dioxygenase (HPPD) efficiently in numerous weed species. The compound is sold in various mixtures and formulations, e.g. under the trade names Auxo®, Capreno®, Laudis® or Soberan®. The performance of tembotrione as a herbicide was presented at several international conferences (e.g. ZOLLINGER and RIES, 2006; YOUNG et al., 2007, LAMORE et al., 2010) and in several scientific papers (e.g. WILLIAMS II and PATAKI, 2008).

HPPD is an enzyme of the biosynthetic pathway that converts tyrosine to plastoquinone and tocopherol. Plastoquinone is a cofactor for the phytoene desaturase, a component of the carotenoid biosynthetic pathway. The depletion of plastoquinone levels by inhibition of HPPD results in depletion of carotenoids and an absence of chloroplast development in emerging foliar tissue which then appears bleached and stunted (HAWKES, 2007). As carotenoids play key roles in photosynthesis and in photoprotection there is a clear involvement of light in the expression of the herbicidal activity of HPPD inhibitors.

A number of trial results are presented here which help to further describe this unique and highly selective maize herbicide when combined with the safener isoxadifen-ethyl (SANTEL, 2009). The advantages of chemical safeners, e.g. isoxadifen-ethyl, to improve the selectivity towards maize following herbicide treatment are exemplarily described by HACKER et al. (2002).

The efficacy of herbicides can be directly influenced by environmental conditions, such as temperature, soil factors or illumination intensity, or use conditions, such as fertilizer treatments or additional pesticide applications. The objective of the described experiments was to characterise the impact of some of these parameters (light and soil factors) on the efficacy and the selectivity of tembotrione. Especially crop responses to pesticide applications represent a sensitive property of efficacious herbicides which makes it imperative to assess selectivity under varying environmental and use conditions in the field. Some examples of such field trials for tembotrione are presented in this paper.

2. Materials and methods

2.1 Growth chamber trials with different light regimes

To investigate the role of light on the efficacy of tembotrione, a growth chamber trial was conducted using two chambers with different illumination intensities. Ten monocotyledonous and dicotyledonous species were used in the test: *Digitaria sanguinalis*, *Echinochloa crus-galli*, *Setaria faberi*, *Setaria viridis*, *Abutilon theophrasti*, *Amaranthus retroflexus*, *Chenopodium album*, *Pharbitis pupurea*, *Polygonum convolvulus* and *Xanthium strumarium*. The test species (3 to 20 plants per pot depending on species) were raised in 8 cm diameter pots containing a sandy loam soil in a

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glasshouse up until the time of being treated. Growth conditions comprised a 12 h day/night light regime with a daytime temperature of 21 °C and a relative humidity of 60 % and a night temperature of 13 °C and a relative humidity of 80 %.

The plants were treated on a track sprayer fitted with a flat fan nozzle delivering 300 l/ha water. The following dose rates were employed: 150, 100, 75, 50, and 0 g a.i./ha. Tembotrione was formulated as an experimental suspension concentrate. Plants were treated post-emergent at the 2-3 leaf stage (BBCH 12-13) without replication. After application, plants were cultivated in two separate growth chambers under the same growing conditions as described earlier except for two different light regimes. One growth chamber was illuminated with a high illumination intensity of ca. 28000 Lux and the other with a low illumination intensity of ca. 8000 Lux. Test plants were monitored for four weeks and the efficacy of tembotrione was visually assessed after 2, 3 and 4 weeks.

2.2 Glasshouse trials with different soils

Under the conditions of a post-emergence treatment a proportion of the applied amount of a herbicide reaches the soil surface and may contribute to the overall efficacy via root uptake. This soil activity can be, however, significantly influenced by soil factors. Therefore, this experiment examined the efficacy of tembotrione against broadleaf weeds grown in different soils following post-emergent treatment. Test plants were grown in the soils described in Table 1.

The following dicotyledonous species were treated post-emergent at the 2-3 leaf stage (BBCH 12-13) without replication at rates of 50, 25, 12.5, 6.25, and 0 g/ha tembotrione, formulated as a wettable powder: *Abutilon theophrasti, Amaranthus retroflexus, Ambrosia elatior, Bidens pilosa, Chenopodium album, Euphorbia heterophylla, Kochia scoparia, Pharbitis pupurea, Polygonum convolvulus* and *Xanthium strumarium.* The experiments were conducted in the glasshouse under a 14 h day and a 10 h night regime with a daytime temperature of 24 °C and a night temperature of 16 °C and a relative humidity of 60 % day and night. The herbicidal activity of tembotrione was visually evaluated 4 weeks following treatment. All other test parameters related to the cultivation of plants and to the application were the same as described in paragraph 2.1.

Tab. 1 Description of soils used according to texture and organic matter content.

Tab. 1 *Beschreibung der Böden nach Bodenart und Gehalt an organischer Substanz.*

	Soil texture	Organic matter [%]
Trebur soil	clayey loam (tL)	4.3
Standard soil	silty loam (uL)	2.5
Schwanheim soil	loamy sand (lS)	1.6

2.3 Field trials on selectivity in maize varieties

A field trial with 71 maize varieties was carried out in Germany in 2001 at the Bayer CropScience Research Station in Gersthofen to identify possible differences in the tolerance of maize varieties to the application of tembotrione. Each variety was sown in two rows on two plots of 213 m^2 size. The herbicides were applied at BBCH 14-16 to all varieties in two replicates. Maize was treated with tembotrione (300 g a.i./ha), tembotrione plus isoxadifen-ethyl (300 + 150 g a.i./ha) and a standard herbicide (300 g a.i./ha) using a plot sprayer at 300 l/ha water volume. The tembotrione use rate in this experiment was exaggerated and three times higher than the currently recommended rate. Phytotoxicity was visually assessed at 7, 14, 28 and 42 days after application in comparison to the untreated control and the maximum value per plot was selected within replicate treatments.

2.4 Field trials on maize selectivity with in-furrow insecticide treatment

The tolerance of maize to herbicide applications can be reduced, when herbicides are applied after 'in furrow'-application of insecticides into the row for the control of corn root worm or other soil insects. The potential interaction between insecticide application and herbicide treatment on the tolerance of maize was assessed for tembotrione in a field trial in USA in 2001 at the Bayer CropScience Midwest

Field Research Station in Champain county, Illinois.

During the planting of maize, several insecticides were applied in-furrow to control soil insects. For each insecticide treatment, two rows of maize were treated per plot of approx. 19 m^2 size with two replicates per treatment. The following insecticides were applied at highest recommended rates as in-furrow treatments: Terbufos, chlorpyrifos, triazamate, tefluthrin and fipronil.

The post-emergent treatments with tembotrione (200 g a.i./ha) alone and in mixture with isoxadifen-ethyl (200 + 100 g a.i./ha) as well as with two herbicide standards (210 and 70 g a.i./ha, respectively) were done at BBCH 13. After herbicide application the phytotoxicity was assessed visually in comparison to the untreated control for each plot and each individual insecticide-herbicide combination at 6 and 21 days after the application and expressed as maximum phytotoxicity within replicate treatments.

3. Results

3.1 Influence of illumination intensity on the performance of tembotrione

The results in Figure 1 show the development of the mean efficacy over time for the different herbicide treatments applied under two different light regimes at a dose rate of 75 g a.i./ha. The figure shows that in terms of overall efficacy against the ten weed species tested, tembotrione provided the highest levels of control under both light regimes whereby especially the brighter conditions favoured a very fast burn-down of the weeds. The control levels provided by tembotrione two weeks after application (= 2 WAA) was at least 10 % better than that of two HPPD standard herbicides.

Under lower illumination intensities, the two WAA control levels of all tested compounds were at least 10 % lower for the same rates than under the bright conditions. All compounds tested followed a similar trend. The ranking of the compounds according to their mean efficacy was under both light regimes the same: Tembotrione > standard A > standard B.

Under the conditions of lower illumination intensities, the efficacy levels for all tested herbicides increased on average for the duration of the experiment from 2 WAA up to the 4 WAA assessment.

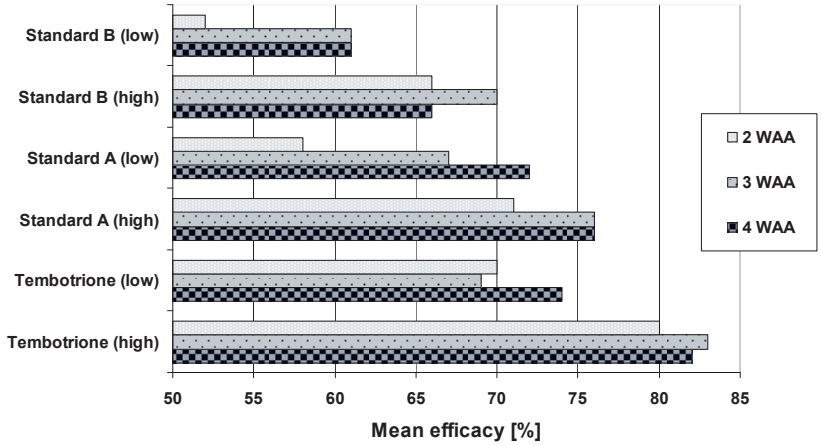

Fig. 1 Mean efficacy (% of untreated control) of tembotrione and HPPD standard compounds A and B against several weed species grown under high and low illumination intensities in growth chambers (WAA = weeks after application).

Abb. 1 *Durchschnittliche Wirkung (in % der unbehandelten Kontrolle) von Tembotrione und anderen HPPD-Wirkstoffen gegen mehrere Unkraut-Spezies unter hoher und niedriger Beleuchtungsstärke in Klimakammern.*

Under the high illumination intensity the initial 2 WAA efficacy for tembotrione is virtually the same as the final assessment after 4 weeks. This demonstrates that under high illumination conditions tembotrione can be expected to show a very fast herbicidal activity.

3.2 Influence of different soils on the performance of tembotrione

The three different soils employed in this glasshouse experiment as growth medium of the test weeds showed a wide spectrum of soil texture and organic matter content (Tab. 1). The coarser the soil texture is, the lower the organic matter content (e.g. Schwanheim soil). Figure 2 relates the mean efficacy of tembotrione following post-emergent treatment at varying use rates to the soils used.

The overall efficacy against dicotyledonous weeds (mean of all rates per soil) was most pronounced in the Schwanheim soil followed by the Standard soil and then the Trebur soil. Distinguishing the application rates, the mean efficacy at the highest dose rate of 50 g/ha was fairly equal at all soils. Only at the lower applications rates, the herbicidal activity was stronger diminished in heavier soils, especially in the Trebur soil, compared to the lighter soils. It can therefore be shown that the efficacy of tembotrione has a residual component affected by the kind of soil and evident at rates of 12.5 g/ha and lower.

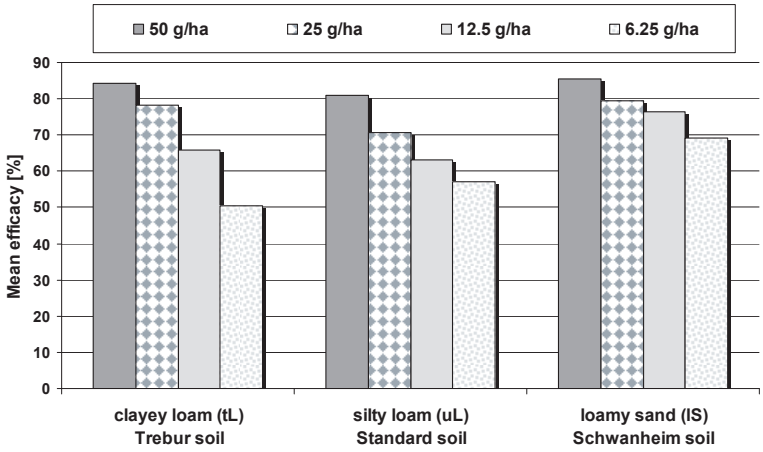

Fig. 2 Mean efficacy of tembotrione applied post-emergent against dicotyledonous weed species growing in different soils at four weeks after application.

Abb. 2 *Durchschnittliche Wirkung von Tembotrione nach Nachauflauf-Anwendung gegen dikotyle Unkräuter, die auf unterschiedlichen Böden aufgezogen wurden, vier Wochen nach Applikation.*

3.3 Field trials on crop tolerance of maize varieties

The tolerance of crops to herbicide treatments is known to differ between maize varieties. As demonstrated in Figure 3, in the present study almost all varieties tolerated the herbicide-safener combination of tembotrione plus isoxadifen-ethyl at 300+150 g a.i./ha without substantial phytotoxicity. Just two varieties showed a marginal phytotoxicty of up to 15 %.

Tembotrione used without safener was less selective with phytotoxicity ratings between 10-30 % in approx. 60 % of the varieties tested. The herbicide standard at 300 g a.i./ha showed as well a reduced selectivity although less pronounced with approx. 15 % of the varieties tested showing phytotoxicity of up to 30 %,

The composition tembotrione plus isoxadifen-ethyl at the exaggerated rate of 300+150 g a.i./ha achieves a complete crop tolerance in the vast majority of the common maize varieties.

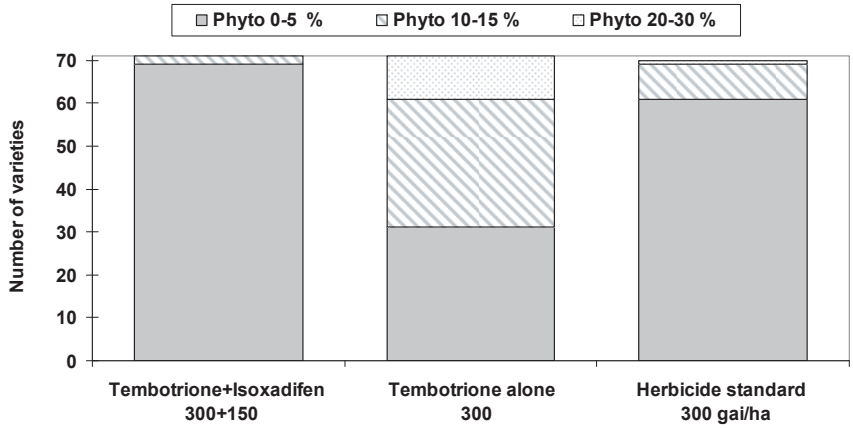

Fig. 3 Crop tolerance of maize varieties to post-emergent herbicide applications under field conditions (Gersthofen, Germany, 2001) expressed as level of phytotoxicity (Phyto).

Abb. 3 *Kulturverträglichkeit von Maissorten auf Herbizidanwendungen im Nachauflauf unter Feldbedingungen (Gersthofen, Germany, 2001) ausgedrückt als Niveau phytotoxischer Effekte (Phyto).*

3.4 Effect of tembotrione on maize with prior soil application of insecticides

Herbicide treatments in this field experiment showed clear differences in crop tolerance of maize (Fig. 4). Tembotrione alone at 200 g a.i./ha was not selective enough while the tank mixture with the safener isoxadifen-ethyl at 200+100 g a.i./ha achieved a complete selectivity in maize despite a preceeding in-furrow application of soil insecticides. The standard herbicide 1 at 210 g a.i./ha and standard 2 at 70 g a.i./ha also showed phytotoxic effects against the maize variety in combination with in-furrow insecticide treatments, albeit less pronounced than with tembotrione alone.

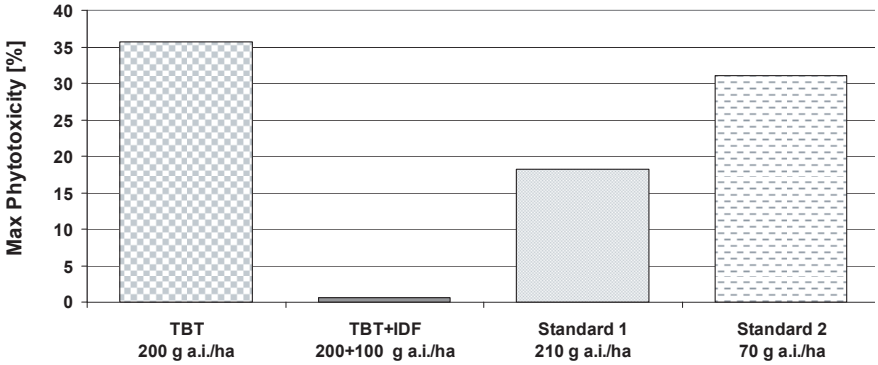

Fig. 4 Maize selectivity following in-furrow application of soil insecticides and subsequent post-emergent herbicide treatments under field conditions (Champain county, Illinois, USA, 2001) expressed as maximum phytotoxicity (TBT = tembotrione, IDF = isoxadifen-ethyl).

Abb. 4 *Verträglichkeit von Mais nach Anwendung von Bodeninsektiziden in der Saatfurche mit nachfolgender Nachauflauf-Anwendung von Herbiziden unter Feldbedingungen (Champain county, Illinois, USA, 2001) ausgedrückt als maximale Phytotoxizität (TBT = tembotrione, IDF = isoxadifen-ethyl).*

4. Discussion

Some additional features of tembotrione have been acquired with the results of the presented trials linking weed and crop responses to tembotrione with environmental parameters or use conditions.

The results on the herbicidal efficacy related to different light regimes in growth chambers showed a more rapid and stronger herbicidal activity of tembotrione compared to other HPPD standard herbicides. This property can be expected to be even more valid in a field situation where much higher illumination intensities occur. A contributing factor to this may be the good xylem and phloem systemicity of tembotrione as described by SCHULTE and KÖCHER (2009) once the compound has penetrated into the inner parts of the plants. The uptake of tembotrione by roots following post-emergent treatment is contributing to the overall efficacy as shown in an experiment with different soils. This clearly indicates residual activity.

The previously observed high selectivity of tembotrione in maize, if applied together with the safener isoxadifen-ethyl (SCHULTE and KÖCHER, 2009), was confirmed on a wide range of varieties and an extended range of use conditions in the field. Even in cases where additional production factors able to cause negative crop responses, like the in-furrow application of insecticides, are combined with tembotrione plus safener treatments, the very good maize selectivity was not impaired.

Hence, tembotrione was demonstrated to combine a fast herbicidal activity with a robust and broad maize selectivity when applied with a safener under various environmental and use conditions.

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