Summary
Experiments were conducted on five arable fields to study herbicide saving rates and temporal dynamics of weed populations in a crop rotation and in continuous maize using site-specific weed control from 1997–2003. Data related to weed population dynamics were collected in all crops and entered into a model to predict density of selected weed species for following years.

Site-specific weed control resulted in high herbicide saving rates in fields with the crop rotation. Weed seedling density of grass weeds (monocots) and broadleaved weeds (dicots) did not increase in the rotation fields but did increase in continuous maize over the period of study. Predicted densities of *Echinochloa crus-galli* (L.) P. Beauv. and *Chenopodium album* L. often corresponded closely to the observed data. Therefore, the model can help to develop management strategies for site-specific weed control.

Keywords
Site-specific weed control, weed dynamics.

INTRODUCTION
In the context of a German reduction program for chemical plant protection, herbicide use in Germany will be more strictly reduced in the future (Zwerger 2004). Site-specific weed control has been successfully applied in various crops resulting in a significant reduction of herbicide use (Gerhards and Christensen 2003). This method accomplishes the German demands and objectives in future weed control strategies (Zwerger 2004). However, farmers fear that site-specific weed management may increase weed populations in subsequent years, when no herbicides rather than reduced rates are applied within arable fields.

Dynamics of weed populations are influenced by efficacy of weed control, weed seed production, weather conditions, farm practices and other factors (Nordmeyer and Niemann 1998). Nevertheless, only a few studies are available to quantify those effects. In this study the temporal dynamics of weed species were analysed under long-term site-specific weed control in a crop rotation and in continuous maize. In order to study temporal dynamics of dominant weed species, data on emerged weed seedlings, efficacy of weed control and numbers of viable seeds per plant were collected in arable fields at Dikopshof Research Station Bonn in Germany between 1997 and 2003. Data were entered into a weed population model published by Zwerger and Hurle (1990) to predict the dynamics of selected weed populations for the following years under site-specific weed control based on the results of the study in the rotation and in continuous maize. If the model predictions correspond to the observed weed seedling numbers, decision rules for field management using site-specific weed control can be derived.

MATERIALS AND METHODS

Experimental fields
Experiments were carried out in four fields where winter wheat (ww) winter barley (wb) maize (m) and sugar beet (sb) were rotated and in one field sown to continuous maize (cm) at Dikopshof Research Station near Bonn in Germany, between 1997 and 2003. The fields had a size of 2.4 to 5.8 ha.

Weed mapping
Weed seedling density was observed in all crops prior to and after post emergence herbicide application. Weed seedlings were counted in a 0.4 m² frame placed at all intersection points of a regular 15 m × 7.5 m grid that was established in the experimental fields. Weeds were grouped according to their varying sensitivity to herbicides. Thresholds for grass weeds, *Galium aparine* L. and broadleaved weeds (Gerhards and Kübbauch 1993) were set and treatment maps were derived for all crops. Decision rules for site-specific weed control varied between row crops and cereals according to their differing competitive ability to weeds. Linear triangulation interpolation was used to estimate weed seedling density at unsampled positions between grid points based on the prior to herbicide application sampled density values (Gerhards *et al.* 1997).

Site-specific weed control
An experimental sprayer (Rau-Company) with a 15 m boom divided into five sections of 3 m, which were separately turned on and off from a control unit via solenoid valves (Timmermann *et al.* 2003), was used to apply herbicides. During herbicide application the sprayer was linked to an on-board computer loaded with the treatment map. A differential mode GPS was used for real time location of the patches to be spray. Herbicide doses

Temporal dynamics of weed populations in arable fields using long-term site-specific weed control

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were varied automatically by changing the pressure in the line.

Population dynamic parameters  The number of seeds for weeds that survived herbicide application was counted prior to harvest. Data related to seed loss in soil were taken from literature (Schweizer and Zimdahl 1984)

Modelling temporal dynamics of weed species  The weed population model (1) published by Zwerger and Hurle (1990) was used to predict temporal dynamics of the dominant weed species *E. crus-galli* and *C. album* in one field of the crop rotation and in continuous maize until 2003, starting with the observed seedling densities of 1999. The observed data were used to predict density of the selected weed species for the respective subsequent year. The model was applied to all grid points and data was averaged over all grid points.

\[
S_{t+1} = S_t (1 - v) + (S_t a (1 - m)) S_u
\]

\[
S_{t+1} = \text{viable seeds at the beginning of vegetation period, year } t+1
\]

\[
S_t = \text{viable seeds at the beginning of vegetation period, year } t
\]

\[
v = \text{seed loss rate caused by fatal germination, predation}
\]

\[
a = \text{emergence rate}
\]

\[
m = \text{rate of mortality due to herbicide application}
\]

\[
S_u = \text{seed production}
\]

RESULTS

Table 1 shows herbicide saving rates resulting from site-specific weed control in all crops and fields for the years 2002 and 2003. Site-specific weed control resulted in high herbicide saving rates in all crops of study. However, saving rates differed between crops, fields and years. The highest herbicide savings against broadleaved weeds and grass weeds were observed in cereals. Here, between 52% and 100% of the total area remained untreated for broadleaved weeds and between 49% and 100% of the area remained untreated for grass weeds for post emergence herbicide application. In maize and sugar beet, site-specific weed control resulted in saving rates of only 0–14%. Savings of grass weed herbicides were higher in the row crops. In continuous maize, no herbicides could be saved in 2002 because of the high weed infestation within that field.

The average densities of grass weeds and broadleaved weeds did not increase in fields of the crop rotation. In continuous maize, density of emerged weed species was much higher than in the crop rotation over all years of study. Grass weed and broadleaved weed density increased until 2002. In 2003 the density level decreased to the level of the first year of observation (Figure 1). Also, the density of weed species other than *E. crus-galli* and *C. album* was extremely high in continuous maize.

In Table 2, the observed parameters for population dynamics of *E. crus-galli* are given. The rate of mortality was high for all years except 2001. In 2001, efficacy of weed control was insufficient due to late application of herbicide. Seed production was high in 1999 and 2000 and then declined. For the model, literature parameters of 0.4 for seed loss rate (Schweizer and Zimdahl 1984) and 0.03 for emergence rate (Kaul 1992) were used. For *C. album* observed population dynamics parameters in continuous maize and in the crop rotation are presented in Table 3. The mortality rate for *C. album* was high in all years in both rotations. Except for one year, the mortality rate was higher in the crop rotation than in continuous maize. Seed production of *C. album* was higher in continuous maize than in the crop rotation in all years except 2001. For the model, literature parameters of 0.4 for continuous maize and 0.7 for the crop rotation for seed loss rate (Schweizer and Zimdahl 1984) and 0.03 for both continuous maize and the crop rotation for emergence rate (Kaul 1992) were used.

Table 1. Herbicide savings (%) in winter wheat (ww), winter barley (wb), sugar beet (sb), maize (m) and continuous maize (cm) resulting from site-specific weed control applied in 2002 and 2003.

<table>
<thead>
<tr>
<th>Field (size)</th>
<th>Crop</th>
<th>Savings (dicots / monocots)</th>
<th>Crop</th>
<th>Savings (dicots / monocots)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field 1 (2.75 ha)</td>
<td>ww</td>
<td>98% / 89%</td>
<td>wb</td>
<td>100% / 81%</td>
</tr>
<tr>
<td>Field 2 (5.3 ha)</td>
<td>ww</td>
<td>67% / 80%</td>
<td>wb</td>
<td>76% / 89%</td>
</tr>
<tr>
<td>Field 3 (2.4 ha)</td>
<td>wb</td>
<td>0% / 81%</td>
<td>ww</td>
<td>52% / 49%</td>
</tr>
<tr>
<td>Field 4 (5.8 ha)</td>
<td>m</td>
<td>0% / 36%</td>
<td>sb</td>
<td>14% / 64%</td>
</tr>
<tr>
<td>Field 5 (2.2 ha)</td>
<td>cm</td>
<td>0% / 0%</td>
<td>cm</td>
<td>11% / 52%</td>
</tr>
</tbody>
</table>

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In continuous maize, the density of E. crus-galli increased from 1999 until 2002 (Figure 2), while the density of C. album decreased (Figure 3). The latter was probably caused by competition between weed species.

Table 2. Weed population parameters observed for E. crus-galli in continuous maize.

<table>
<thead>
<tr>
<th>Year</th>
<th>Rate of mortality</th>
<th>Seed production</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999</td>
<td>0.83</td>
<td>200</td>
</tr>
<tr>
<td>2000</td>
<td>0.88</td>
<td>900</td>
</tr>
<tr>
<td>2001</td>
<td>−0.12</td>
<td>35</td>
</tr>
<tr>
<td>2002</td>
<td>0.88</td>
<td>35</td>
</tr>
</tbody>
</table>

* Averaged over sampling points.

Table 3. Weed population parameters observed for C. album in continuous maize or crop rotation.

<table>
<thead>
<tr>
<th>Year</th>
<th>Rate of mortality</th>
<th>Seed production</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Continuous maize</td>
<td>Crop rotation</td>
</tr>
<tr>
<td></td>
<td>Continuous maize</td>
<td>Crop rotation</td>
</tr>
<tr>
<td>1999</td>
<td>0.95</td>
<td>1</td>
</tr>
<tr>
<td>2000</td>
<td>0.98</td>
<td>1</td>
</tr>
<tr>
<td>2001</td>
<td>0.74</td>
<td>0.93</td>
</tr>
<tr>
<td>2002</td>
<td>0.95</td>
<td>0.93</td>
</tr>
</tbody>
</table>

* Averaged over sampling points.

In the crop rotation E. crus-galli only occurred in maize in 1997 and 2001 (data not shown). C. album preferred the summer annual crops maize and sugar beet (Figure 4). The predicted density of selected weeds corresponded closely to the observed values in continuous maize, but not in the rotation (Figure 4). The model did not predict the effects of different crops on weed population dynamics well.

Figure 2. Observed and predicted density of emerged seedlings of E. crus-galli in continuous maize (field 5).

Figure 3. Observed and predicted density of emerged seedlings of C. album in continuous maize.

Figure 4. Observed and predicted density of emerged seedlings of C. album in the crop rotation (field 3).
DISCUSSION

The results of this study show that site-specific weed control has potential for saving herbicide costs. With the use of site-specific weed management, the average weed density did not increase in middle term with the crop rotation. However, in continuous maize weed density was very high (>40 plants m⁻²) at the beginning of study and increased until 2002. All fields of the crop rotation were ploughed every year, burying weed seeds in deeper soil layers, while continuous maize has been cultivated without ploughing until 2002. So in continuous maize there was no failed germination, indicating that most weed seeds accumulated in the top layer of the soil. The efficacy of weed control was very low in 2001 in continuous maize, so a high number of weed seedlings survived weed control and produced seeds. The high seed rain into the top layer of soil probably explains the high number of new emerged weed seedlings in 2002. Between 2002 and 2003, the whole field was ploughed, in order to move seeds in deeper soil layers and populations decreased.

A simple weed population model could be used to predict temporal weed population dynamics in continuous maize. If predictions were made for crop rotations, characteristic population parameters need to be taken into account. The number of weed seedlings varied significantly between the different crops, which can be explained by the different competitive ability of these crops.

Weed densities have been found to be spatially variable. Dunker et al. (2002) used a weed population model in combination with a cellular automata model to estimate weed densities at different locations in the field. This approach needs to be adapted to different crop rotations and weed management strategies. Analysing dynamics of weeds under the influence of patch spraying improves our understanding of dynamics of weed populations and thus can be included in decision algorithms (Christensen et al. 2003), which are strongly needed to derive sustainable weed control strategies using site-specific weed control.

REFERENCES


