The effect and dynamics of weed competition on maize in Germany and Benin

Wirkung und Dynamik der Unkrautkonkurrenz auf Mais in Deutschland und Benin

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Summary

Four field experiments were carried out in maize at one location in Southern Germany (2009 and 2010) and at two locations in West Atacora, Benin (2010), to determine and compare the effect and dynamics of weed competition under two different environments. Further aims were to determine the critical period for weed control in Benin to provide recommendations to farmers on weed control strategies. Weeds were removed at different crop growth stages of the crop: Emergence, 4-, 8-, 10-leaf stage and flowering and maize plots were kept weed-free until harvest. In Benin, weeds were additionally removed until the aforementioned growth stages and then allowed to reemerge until harvest. Crop growth parameters and weed biomass were monitored over the whole growing season. Dry grain yield was recorded at harvest. Logistic and Gompertz equations were used to determine the critical period for weed control. The four main weeds in Germany were the dicotyledonous species *Chenopodium album*, *Galium aparine*, *Stellaria media* and *Capsella bursa-pastoris*. In Benin, the two grasses *Setaria pumila* and *Bulbostylis hispidula* and the two dicotyledonous weeds *Stachytarpheta indica* and *Mitracarpus villosus* prevailed. For all sites, the main weeds were primarily annual species. In Germany, grain yield levels without weed competition ranged from 8.5 to 10.3 t/ha; in Benin the average yield was considerably lower (3.4 t/ha). As expected, yield loss increased significantly with duration of weed competition and yield losses were highest in the control amounting to 49–86 % (Germany) and 38–58 % (Benin). For Benin, the results confirmed that weeds have to be controlled from about the 4-leaf stage until almost flowering to reduce yield loss below 20 %. As weed control is mainly done by hand, this is difficult to achieve due to the shortage of family labor and the high costs of hired labor.

Keywords: Critical period for weed control, crop-weed interaction, Gompertz curve, logistic curve, non-linear regression, yield loss

Zusammenfassung

Vier Feldversuche wurden an einem Standort in Süddeutschland (2009-2010) und an zwei Standorten in West Atacora, Benin (2010), durchgeführt, um den Effekt und die Dynamik der Unkrautkonkurrenz auf die Kulturpflanze Mais in zwei verschiedenen Umgebungen zu bestimmen und zu vergleichen. Weitere Ziele waren die Bestimmung des kritischen Zeitintervalls für die Unkrautbekämpfung in Mais im Benin um die Beratung der Landwirte im Benin zu verbessern. Die Unkräuter wurden von einem bestimmten Wachstumsstadien der Kulturpflanze an entfernt: Auflauf, 4-, 8-, 10-Blattstadium und Blüte und die Parzellen wurden dann bis zur Ernte unkrautfrei gehalten. Im Benin wurden zusätzlich die Unkräuter bis zu den entsprechenden Wachstumsstadien entfernt, danach auflaufende Unkräuter wurden bis zur Ernte nicht mehr entfernt. Wachstumsparameter der Kulturpflanzen und die Unkrautbiomasse wurden während der Vegetationszeit beobachtet. Der Kornertrag wurde bei der Ernte bestimmt. Logistische und Gompertz-Gleichungen wurden zur Bestimmung der zeitbezogenen Schadensschwelle verwendet. In Deutschland waren die vier dikotylen Leitunkräuter *Chenopodium album*, *Galium aparine*, *Stellaria media* und *Capsella bursa-pastoris*. Dagegen dominierten im Benin die zwei Ungräser *Setaria pumila* und *Bulbostylis hispidula* sowie die zweikeimblättrigen Unkräuter *Stachytarpheta indica* und *Mitracarpus villosus*. In allen Versuchen dominierten einjährige Unkräuter. In Deutschland lagen die Erträge ohne Unkrautkonkurrenz zwischen 8.5 t/ha (2010) und 10.3 t/ha (2009), im Benin lag der durchschnittliche Ertrag deutlich tiefer (3.4 t/ha). Wie erwartet, stieg der Ertragsverlust mit zunehmender Dauer der Unkrautkonkurrenz an. Er war in der Kontrolle am höchsten und lag zwischen 49-86 % in Deutschland und 38-58 % im Benin. Für Benin zeigen die Ergebnisse, dass Unkräuter etwa vom 4-Blatt-Stadium bis beinahe zur Blüte bekämpft werden müssen, um den Ertragsverlust unter 20 % zu halten. Da die Unkrautbekämpfung vor allem von Hand erfolgt, ist dies schwierig zu erreichen, da die Arbeitszeit der Familien begrenzt und die Lohnkosten für Arbeiter relativ hoch sind.

Stichwörter: Ertragsverlust, Gompertz-Gleichung, logistische Gleichung, nicht lineare Regression, Unkraut-Kulturpflanzen-Interaktion, zeitbezogene Schadensschwelle

1. Introduction

Maize is the most important crop in terms of tons of grain produced worldwide (ANONYMOUS, 2010a). In general, weeds can cause high yield losses in crops. OERKE (2005) estimated that the potential yield losses caused by weeds amount to 34 %. In maize, an effective weed control is indispensable because of its low competitiveness in early growth stages at least in temperate climates. In Europe, weed control in maize is mainly conducted with herbicides. As maize plants become more susceptible to herbicides from the 6-leaf stage onwards due to changes in the leaf surface structure, herbicides are applied early (BÄR et al., 2010). Whereas in Germany, maize is mainly produced for fodder (silage and grain) (ANONYMOUS, 2010a), in Benin, maize is of high importance as a main staple food crop and is the third most important food crop after cassava and yam (ANONYMOUS, 2003). In spite of its alimentary and economical importance in Benin, the grain yield of maize is still very low (around 1.4 t/ha) (ANONYMOUS, 2010b). VISSOH (2004) identified poor weed control as one of the main constraints. According to AKOBUNDU (1987), yield losses are almost about 40-60 % in maize fields without weed control in tropical regions. Weed control is primarily done by hoeing (HARSH, 2004). In Benin, few studies have addressed the effect and dynamics of weeds in maize. Better understanding of this topic could help farmers to increase yields.

The critical period for weed control or the critical period of weed interference was defined by SWANTON and WEISE (1991) as the time period, when it is crucial to maintain the field weed-free to prevent yield loss. This period depends on different factors such as planting pattern, weed species and environmental conditions (SWANTON and WEISE, 1991). Therefore, the determination of the critical period for weed control for Benin is important, as the combination of these factors may be different compared to environments where the critical period for weed control has already been determined. In addition, the determination of the critical period for weed control could be especially helpful to schedule weeding when it is most effective and therefore reduce time of weeding and unburden women and children. Thus, the aim of this study was to examine the effect and dynamics of weeds on yield in maize and to determine the critical period for weed control. Similar field trials were carried out in Germany to allow for comparison between a high input (fossil fuel, fertilizer, pesticides) system in temperate climate and the low input, tropical system in Benin.

2. Materials and methods

2,1 Experimental sites

Two field experiments were carried out at Ihinger Hof (48°74' North, 8°93' East), a research station of the University of Hohenheim, Germany, during 2009 and 2010. The climate is temperate with an average annual temperature of 8.1 °C and average rainfall of 694 mm per year. Both experiments were carried out on two nearby fields. The soil type of both fields was a para-brown soil (luvisol). Maize was sown at a density of 85'000 seeds/ha of Companero (a variety for grain production) on April 21st 2009 and Ravello (a variety for grain, silage and biogas production) on April 21st 2010. Row spacing was 0.75 m and seed spacing was 15.6 cm. Nitrogen (N) was applied as urea at a rate of 150 kg N/ha in 2009 and 140 kg N/ha in 2010. Two experimental sites, Djougou (10°14' North, 1°23' East) and Natitingou (10°19' North, 1°23' East), were chosen in Benin after a survey including 105 farms in seven districts. The survey was carried out to get an overview of the most important weeds in the region and results will be published elsewhere. The two sites are located in the North Western part of the country, the West Atacora zone, and were selected according to the weed infestation, which aimed to be characteristic for the region, and the farmers' acceptance and ability to participate in the field experiments. The climate at both sites is tropical with one rainy season from May to October, corresponding also to the growing season of maize and other crops. Annual rainfall in Djougou is approximately 1200 mm on average and 1150 mm in Natitingou. Highest rainfall is expected in August and September. The soil at both sites is a ferruginous tropical soil. Maize was sown at a seed density of 79000 seeds/ha after the first rain, in Djougou on June 10th 2010 and on June 22nd 2010 in Natitingou. Row spacing was 0.75 m and seed spacing was 0.40 m. To be in accordance with regional farming practices, two seeds were placed together in each hole. A composite variety called DMR-ESRW (downy mildew and streak resistant, early maturing, white-open pollinated variety), which is common to the farmers of the region for grain production and has a short growing cycle, was used. Fertilization was conducted two times according to the recommendations of the agricultural extension service: first, 200 kg/ha of NPKSB (14-23-14-5-1) two weeks after sowing and one month later N was applied as urea at rate of 46 kg N/ha. All management practices were carried out manually.

2.2 Experimental design

The field trials had a randomised complete block design (RCBD) with four repetitions. Plot size was 3 m (4 maize rows) by 16 m, whereas each plot was divided into two subplots in size of 3 m by 7.5 m, one for data collection during the growth period and the other for harvesting. In the trial in Germany in 2009, the following treatments were included: Continuously weed-free (WF), weedy until 4-leaf stage (WU4L), weedy until 8-leaf stage (WU8L) and an untreated control, which was never weed-free referred to as weedy (W; Tab. 1).

For the experiment in 2010 in Germany, a further treatment, weedy until flowering (WUF), was included. In Benin, the following treatments were carried out in addition: Weed-free until 4-leaf stage (WFU4L), weed-free until 8-leaf stage (WFU8L), weed-free until 10-leaf stage (WFU10L) and weed-free until flowering (WFUF) (Tab. 1). Weeds were removed by careful pulling, cutting and shallow hoeing to avoid any effect due to nutrient mineralisation.

Tab. 1 Overview of the different treatments, abbreviation, description and in which trial they have been carried out.

Tab. 1 *Übersicht über die verschiedenen Versuchsglieder, Abkürzungen und Beschreibung sowie in welchen Versuchen sie durchgeführt wurden.*

Treatment	Description	Carried out in
W	Weedy, untreated control	Benin, Germany
WU4L	Weedy until 4-leaf stage	Benin, Germany
WU8L	Weedy until 8-leaf stage	Benin, Germany
WU10L	Weedy until 10-leaf stage	Benin, Germany
WUF	Weedy until flowering	Benin, Ihinger Hof 2010
WF	Continuously kept weed-free	Benin, Germany
WFU4L	Weed-free until 4-leaf stage	Benin
WFU8L	Weed-free until 8-leaf stage	Benin
WFU10L	Weed-free until 10-leaf stage	Benin
WFUF	Weed-free until flowering	Benin

2.3 Data collection

In Benin, the dry biomass (g/m^2) of entire crop plants (inclusive main roots which remained on the plant after pulling it from the soil), dry biomass (g/m^2) of weeds and the weed coverage (%) were recorded at the 8-leaf, 10-leaf and flowering stage of the crop. The weed coverage of single weeds was determined according to the scale of Braun-Blanquet at the 10-leaf stage. There are six levels of weed cover classes used in this method: 0-1 %, 1-5 %, 5-25 %, 25-50 %, 50-75 % and above 75 % weed cover. In the experiment at Ihinger Hof in 2009, dry above-ground biomass of the maize plants at the 4-leaf, 8-leaf and 10-leaf stage of the crop and weed density or weed coverage at the 4-leaf stage of the crop were determined. In the experiment at Ihinger Hof in 2010, dry biomass of maize and weeds was determined at the 4-leaf, 8-leaf, 10-leaf and flowering stage of the crop. Weed coverages were determined at the 4-leaf stage. Occurring weed species were monitored on all sites. Dry grain yield was recorded in Germany using a plot combine harvester. Only the inner two rows were harvested to avoid border effects. In Benin, harvest was done by hand and grain yield was determined at 14 % humidity thereafter. For Benin, weather data was acquired from the closest weather station

(Natitingou, 653190 DBBN, 10°19' North, 1°23' East). For Germany, weather data was provided by the weather station of the Ihinger Hof.

2.4 Statistical Analysis

In the field trial in 2010 in Germany, four plots had to be omitted from analyses due to high infestation of thistles (*Cirsium arvense*) and damage by mice. In Djougou, two plots had to be dropped from analyses due to improper use of the scale by the farmer. The statistical analyses were performed using the MIXED procedure from SAS 9.2, using F-tests to test for the effect of the varying periods of weed interference ($\alpha = 0.05$) and a multiple t-test for comparing least square means. The block effect was assumed to be fixed. Non-linear regression was performed with R (R DEVELOPMENT CORE TEAM, 2009) to derive the critical period for weed control for the two sites in Benin. Growing degree days (GDD) were summed from planting until the day weed competition was removed ('weedy until' treatments). For the 'weed-free until' treatments, GDD were summed from planting until the day weed removal stopped. GDD were calculated as the difference between the average temperature of T_{MIN} and T_{MAX} of the day and the base temperature (T_{BASE}). As a base temperature, 10 °C were set (MCMASTER and WILHELM, 1997). Below this base temperature, the growth of a plant is restrained. The same weather data were used for both field trials in Benin as temperature is very similar within the region and as the data acquired was from the closest weather station for both field trials. The use of GDD allows transforming the factor treatment to a quantitative dimension, which can then serve as the independent variable for the non-linear regression. After determining the critical period on this scale, recommendations can also be given in terms of leaf stage which is easier to communicate to farmers. We used GDD as explanatory variable for non-linear regression as it is believed to be a more meaningful measure of time for plant growth than for example the number of days after crop emergence. Furthermore, crop development is well correlated with thermal time (GDD) (KNEZEVIC, 2002). The yields of the treatments were calculated relative to the weed-free treatment in the analyses. The Gompertz curve was fitted to the 'weed-free until' treatments (Equation 1). The logistic curve was fitted to the 'weedy until' treatments (Equation 2) (KNEZEVIC, 2002).

$$Y = a \times \exp\left(-b \times \exp\left(-k \times T\right)\right) \quad \text{(Equation 1)}$$

$$Y = 100\left[\left(1/\left\{\exp\left[c \times \left(T - d\right)\right] + f\right\}\right) + \left[\left(f - 1\right)/f\right]\right] \quad \text{(Equation 2)}$$

For Equation 1, *Y* denotes the yield relative to the weed-free yield in percent, *a* is the yield asymptote, *T* is the time expressed in GDD, *b* and *k* are constants. For Equation 2, *d* is the point of inflection in GDD, *c* and *f* are constants (KNEZEVIC, 2002). Yield and GDD are the input variables for the analyses. Parameters are: *a, b, k, d, c* and *f*. The parameters of each equation and thus the relationship between GDD and relative yield are determined in the non-linear regression analysis by minimisation of the residual sums of squares.

3. Results

3.1 Weed distribution and weed biomass

In Djougou, the five main weeds (coverage of 5 to 25 % each at 10-leaf stage) were *Setaria pumila*, *Bulbostylis hyspidula*, *Brachiaria villosa*, *Tridax procumbens* and *Spermacoce stachydea* (Tab. 2).

Tab. 2 Coverage range of the five main weeds in the weedy treatment (control) at 10-leaf stage of maize in Benin for Djougou. In brackets: M = monocotyledonous, D = dicotyledonous, A = annual, P = perennial).

Tab. 2 *Bereich der Bedeckung der fünf Hauptunkräuter in der ständig verunkrauteten Variante (Kontrolle) zum Zeitpunkt des 10-Blattstadiums von Mais in Benin für Djougou. In Klammern: M = einkeimblättrige, D = zweikeimblättrige, A = einjährige, P = mehrjährige.*

Main weeds	Coverage (%)
Setaria pumila (M, A)	5–25
Bulbostylis hyspidula (M, A)	5–25
Brachiaria villosa (M, A)	5–25
Tridax procumbens (D, A)	5–25
Spermacoce stachydea (D, A)	5–25

In Natitingou, the five main weeds were *Stachytarpheta indica*, *Mitracarpus villosus* and *Oldenlandia herbacea, Schwenckia americana* and *Digitario argillacea* (Tab. 3). In Djougou, grass weeds and broadleaved weeds were relevant, whereas in Natitingou four of the five main weeds were grass weeds.

Tab. 3 Coverage range of the five main weeds in the weedy treatment (control) at 10-leaf stage of maize in Benin for Natitingou. In brackets: M = monocotyledonous, D = dicotyledonous, A = annual, P = perennial.

Tab. 3 *Bereich der Bedeckung der fünf Hauptunkräuter in der ständig verunkrauteten Variante (Kontrolle) zum Zeitpunkt des 10-Blattstadiums von Mais in Benin für Natitingou. In Klammern: M = einkeimblättrige, D = zweikeimblättrige, A = einjährige, P = mehrjährige.*

Main weeds	Coverage (%)
Stachytarpheta indica (D, A)	5–25
Mitracarpus villosus (D, A)	5–25
Oldenlandia herbacea (D, P)	5–25
Schwenckia americana (D, A)	1–5
Digitario argillacea (M, A)	1–5

At Ihinger Hof 2009, the main weeds were Chenopodium album, Galium aparine, Alopecurus myosuroides, Stellaria media and Lamium purpureum (Tab. 4), whereas in 2010, Stellaria media, Capsella bursa-pastoris, Galium aparine, Lamium purpureum and Chenopodium album were the most abundant weeds (Tab. 5).

Tab. 4 Average weed density of the five main weeds in the weedy treatment (control) in Germany Ihinger Hof 2009 weed density (plants/m^2). In brackets: M = monocotyledonous, D = dicotyledonous, A = annual, P = perennial.

Tab. 4 *Durchschnittliche Unkrautdichten (Pflanzen/m^2) der fünf Hauptunkräuter in der ständig verun-krauteten Variante (Kontrolle) Ihinger Hof 2009. In Klammern: M = einkeimblättrige, D = zweikeimblättrige, A = einjährige, P = mehrjährige.*

Main weeds	Weed density (plants/m^2)
Chenopodium album (D, A)	46
Galium aparine (D, A)	34
Alopecurus myosuroides (M, A)	16
Stellaria media (D, A)	11
Lamium purpureum (D, A)	11

Tab. 5 Average weed coverage in % of the five main weeds in the weedy treatment (control) at Ihinger Hof 2010. In brackets: M = monocotyledonous, D = dicotyledonous, A = annual, P = perennial.

Tab. 5 *Durchschnittlicher Unkrautbedeckungsgrad der fünf Hauptunkräuter in der ständig verunkrauteten Variante (Kontrolle) Ihinger Hof 2010. In Klammern: M = einkeimblättrige, D = zweikeimblättrige, A = einjährige, P = mehrjährige.*

Main weeds	**Coverage (%)**
Stellaria media (D, A)	4.25
Capsella bursa-pastoris (D, A)	1.00
Galium aparine (D, A)	0.75
Lamium purpureum (D, A)	0.75
Chenopodium album (D, A)	0.75

Dicotyledons prevailed in Germany and all weed species were annuals. In the untreated control, i.e. in the weedy treatment (W), the ratio of weed biomass to total plant biomass (weeds and maize plants) was large, ranging from 90 % (4-leaf stage) to 76 % (flowering) (Ihinger Hof 2010). In Djougou, it was about 35 % (8-leaf stage to flowering), whereas in Natitingou the ratio was much lower: 23 % and 9 % (10-leaf, flowering), respectively. For the Ihinger Hof 2009 trial, no weed biomass data were recorded.

3.2 Maize biomass

In Benin, the maize biomass determined at different growth stages of maize (8-leaf stage, 10-leaf stage and flowering) was not affected by the treatment neither in Djougou nor in Natitingou (data not shown), apart from the maize biomass taken in Natitingou at flowering. This was partly due to high variation within the data. In the two trials at the Ihinger Hof, the maize biomass was significantly affected by the duration of weed interference at the 10-leaf stage (Ihinger Hof 2009) and at the 8-leaf, 10-leaf stage and flowering (Ihinger Hof 2010). Treatments with weed interference until the 8-leaf stage, 10-leaf stage and flowering had produced significantly less biomass than the WF and the WU4L treatment (data not shown).

3.3 Yield and yield loss

As expected, the yield levels were much lower in Benin compared to Germany (Tab. 6 and Tab. 7). The yield of the weed-free treatment in the Ihinger Hof trial 2009 was higher (about 10.3 t/ha) than in the Ihinger Hof trial 2010 (about 8.5 t/ha).

Tab. 6 The effect of duration of weed interference on yield in Germany (Ihinger Hof 2009 and 2010). Within columns, least square means estimates followed by the same letter are not significantly different ($p < 0.05$) by multiple t-tests. Weed-free (WF), weedy until 4-leaf stage (WU4L), weedy until 8-leaf stage (WU8L), weedy until 10-leaf stage (WU10L), weedy until flowering (WUF), untreated control/weedy (W).

Tab. 6 *Effekt der Dauer der Unkrautkonkurrenz auf den Ertrag in Deutschland (Ihinger Hof 2009 und 2010. Kleinste-Quadrate Mittelwert Schätzungen gefolgt von den gleichen Buchstaben innerhalb der Spalten sind nicht signifikant verschieden (p < 0.05) multiple t-Tests. Unkrautfrei (WF), verunkrautet bis 4-Blattstadium (WU4L), verunkrautet bis 8-Blattstadium (WU8L), verunkrautet bis 10-Blattstadium (WU10L), verunkrautet bis zur Blüte (WUF), unbehandelte Kontrolle/ständig verunkrautet (W).*

	Ihinger Hof	
Treatment	**2009**	**2010**
	Grain yield in t/ha	
WF	10.309 a	8.467 a
WU4L	9.957 a	5.219 b
WU8L	7.915 ab	3.090 c
WU10L	6.642 b	3.342 bc
WUF	-[1)]	1.740 c
W	5.236 b	1.153 c
P-value	0.0239	0.0001

1) This treatment was not included in 2009

In Benin, the yield potential seems to be similar for Djougou and Natitingou (Tab. 7). In all four field trials the duration of weed infestation had a significant effect on yield. At Ihinger Hof in 2009, the WU4L and WU8L treatment were not significantly different from the weed-free treatment, whereas at Ihinger Hof in 2010 and Natitingou, none of the 'weedy' treatment achieved a similar yield compared with the weed-free treatment. For Djougou, the treatment differences were not that large. The WF and the WFUF treatments had the highest yield, the untreated control (W), the weed infested until 10-leaf stage (WU10L) treatment and the weed infested until flowering treatment (WUF) had the lowest yield and the other treatments' yields were intermediate. In the control plots (W), yield loss reached 38 % (Natitingou), 49 % (Ihinger Hof 2009), 58 % (Djougou) and 86 % (Ihinger Hof 2010).

Tab. 7 The effect of duration of weed interference on yield in Benin 2010 (Djougou and Natitingou). Within columns, least square means estimates followed by the same letter are not significantly different (p<0.05) by multiple t-tests. Additional treatments: Weedy-free until 4-leaf stage (WFU4L), weed-free until 8-leaf stage (WFU8L), weed-free until 10-leaf stage (WFU10L), weed-free until flowering (WFUF).

Tab. 7 *Effekt der Dauer der Unkrautkonkurrenz auf den Ertrag in Benin 2010 (Djougou and Natitingou). Kleinste-Quadrate Mittelwert Schätzungen gefolgt von den gleichen Buchstaben innerhalb der Spalten sind nicht signifikant verschieden (p<0.05) multiple t-Tests. Zusätzliche Varianten: Unkrautfrei bis 4-Blattstadium (WFU4L), unkrautfrei bis 8-Blattstadium (WFU8L), unkrautfrei bis 10-Blattstadium (WFU10L), unkrautfrei bis Blüte (WFUF).*

	Benin 2010	
Treatment	**Djougou**	**Natitingou**
	Grain yield in t/ha	
WF	3.396 a	3.322 a
WU4L	2.565 bcd	2.379 b
WU8L	2.536 bcde	2.250 b
WU10L	1.842 def	1.955 b
WUF	1.731 ef	1.783 b
W	1.427 f	2.070 b
WFU4L	1.977 cdef	1.689 b
WFU8L	2.610 bc	2.006 b
WFU10L	2.260 bcde	2.444 b
WFUF	2.733 ab	1.938 b
P-value	0.0007	0.0099

3.4 Critical period for weed control

The logistic and Gompertz model were fitted to the data to determine the critical period for weed control (Fig. 1) (KNEZEVIC, 2002). For an acceptable yield loss, a threshold of 20 % was chosen. In practice, the average yield loss is estimated to be about 40 % in Benin and therefore half of this yield loss would improve the situation dramatically. Neither T_{max} nor T_{min} were ever below the T_{base}. For Djougou, the critical period for weed control with these assumptions was from 4-leaf stage/ 8-leaf stage until 10-leaf stage/ flowering. For Natitingou, only the beginning of the critical period for weed control could be determined and was the same as for Djougou (data not shown). For the end of the critical period the curve could not be fitted due to the high variance in the data. For Germany an acceptable yield loss of 2 % was assumed. For Ihinger Hof in 2009, the begin of the critical period was about the 4-leaf stage, whereas for Ihinger Hof 2010 it would have been even earlier between crop emergence and 4-leaf stage (data not shown).

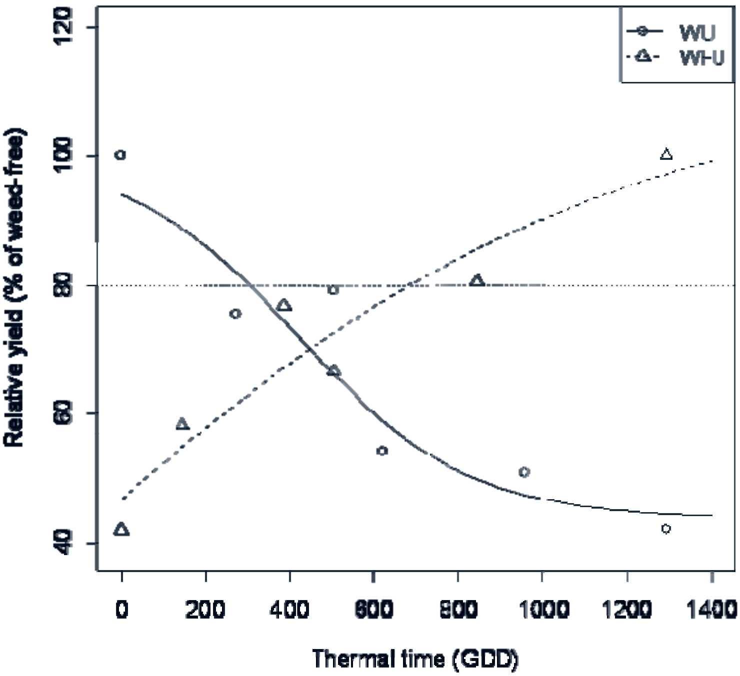

Fig. 1 Critical period for weed control for Djougou 2010. WU: logistic model fitted to the treatments „weedy until"; representing an increasing duration of weed interference. WFU: Gompertz model fitted to the data of the „weed-free until" treatments. The horizontal line at 80 % represents the acceptable relative yield (i.e. the acceptable yield loss of 20 %). The interception of this line with the WU curve is the critical timing/beginning for weed removal. The interception of the line with WFU determines the end of the critical period for weed control.

Abb. 1 *Die zeitbezogene Schadschwelle für Djougou 2010. WU: das logistische Model wurde an die Daten „verunkrautet bis" angepasst; dies repräsentiert die zunehmende Dauer der Verunkrautung. WFU: Das Gompertz Model wurde an die Daten „unkrautfrei bis" angepasst. Die horizontale Linie bei 80 % entspricht dem akzeptablen relativen Ertrag bzw. Ertragsverlust von 20 %. Die kritische Periode ergibt sich aus den Schnittpunkten der Geraden mit WU (Beginn) und WF (Ende).*

4. Discussion

The trials clearly showed the well-known yield effect of weed interference in maize. Uncontrolled weeds caused between 38 and 78 % yield loss which is well in accordance with practical experience. In addition, the results showed high variability depending on the site (Djougou and Natitingou) and the year (Ihinger Hof 2009 and Ihinger Hof 2010). The variability between years in Germany shows that the weed infestation and crop status have to be carefully considered for the application decision. The maize biomass recorded during the season showed high variation within the treatments in the trials of Djougou and Natitingou and therefore almost no significant differences could be found. For Germany and for Benin, the weed species found in the trials were characteristic for the region. In Germany, the yield of the weed-free plots for both years and for Ihinger Hof 2009 also the WU4L treatment corresponded to the average achieved grain yield in the country and of the year (2009: 9.75 t/ha, 2010: 8.79 t/ha) (ANONYMOUS, 2011b). At Ihinger Hof in 2010, maize yield was generally lower than in 2009 due to dry and cold weather at early growth stages. In contrast, the yield of the weed-free treatment in Benin was much higher than the average grain yield of 1.4 t/ha achieved in this region (ANONYMOUS, 2010b). This clearly proves that there is high potential to increase the yield by further weed control. The determined critical period for weed control in Djougou started between the

4-leaf and 8-leaf stage and ended between the 10-leaf stage and flowering, accepting 20 % of yield loss. The current recommendation of the extension service in Benin is to weed twice, one time at about the 4-leaf stage (two weeks after emergence) and the second time at the 10-leaf stage (35-40 days after emergence). Our results suggest that the second weeding should be done earlier. The critical period for weed control determined for Djougou is rather long compared to the one determined for example for Baden-Württemberg, Germany (2-leaf/ 4-leaf stage until 6-leaf stage/ 8-leaf stage) (AMMON, 2002). This could be ascribed to the highly competitive weeds in the Djougou field trials and possibly to the low fertilizer level. For Natitingou, the Gompertz curve could not be fitted due to high variation within the data and thus the end of the critical period for weed control could not be determined. However, the beginning was the same as for Djougou. The results of the German trials confirmed that the critical period of weed control in this region begins at 2-leaf/ 4-leaf stage. For Benin, more field trials are planned to determine the critical period for weed control at several sites and in several years and thus to verify the findings under different environmental conditions. The inclusion of more treatments would improve the quality of the fitted curves and thus the precision of the determined critical period for weed control. As stated in the introduction, weed control is mainly done by hand and thus recommendations about the timing of weeding can improve the weed control efficiency and therefore increase the yield. However, the critical period for weed control determined in this single trial shows also the constraints. The period during which the crop has to be kept weed-free is rather long and this is difficult to achieve with manual weeding, as it has to be done several times and often various other crops have to be taken care of at the same time. Family labor is limited and costs for hired labor are relatively high. The labor saving use of herbicides in maize is prohibitive in Benin due to the high costs and due to lacking availability of maize herbicides in the villages.

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