Critical Periods of Weed Control for Naked Crabgrass (*Digitaria nuda*), a Grass Weed in Corn in South Africa

Elbé Hugo, Liesl Morey, Anna E. J. Saayman-Du Toit, and Carl F. Reinhardt*

Difficulties in chemically controlling large crabgrass in corn in South Africa have recently been attributed to the occurrence of naked crabgrass. In contrast to large crabgrass, naked crabgrass is not easily controlled with acetanilide herbicides. Critical periods of weed control (CPWC) for naked crabgrass in corn was determined in field studies during the 2009/2010 and 2010/2011 growing seasons at two separate localities for an early and late planting date of corn. Weed-free and weed–crop interference treatments of increasing duration were maintained at various crop growth stages in the presence of naked crabgrass. Biomass of naked crabgrass was determined as dry weight per square meter quadrant, which yielded 428 g m^{-2} at Potchefstroom and 594 g m^{-2} at Wesselsbron. An exponential regression model was used to determine the CPWC expressed as growing degree days after crop emergence, on the basis of an estimated 10% relative yield loss in corn. The onset and ending, as well as the duration of the CPWC, differed between seasons and localities. At 10% relative yield loss, the onset of the CPWC ranged between the two-leaf (V2) and six-leaf (V6) stages, and the ending between the 12-leaf (V12) stage and 2 wk after tasseling (T + 2). The duration of the CPWC ranged between 22 and 80 d for the respective planting dates, years, and localities. Yield losses ranged from 28 to 82% in the season-long weedy plots. The shifting of planting dates alone did not reduce yield losses since the effect of late infestations of naked crabgrass is significant. Naked crabgrass control from crop emergence is essential, followed by POST herbicide application during the critical period of weed control to lower the risk of corn yield losses.

Nomenclature: Naked crabgrass, *Digitaria nuda* Schumach. DIGNU; large crabgrass, *Digitaria sanguinalis* (L) Scop. DIGSA; corn, *Zea mays* L.
Key words: Critical period duration, grass weeds, weed control, yield loss.

An increase in *Digitaria* species infestations reported by producers in the main corn-producing region of South Africa recently led to the identification of naked crabgrass, a relative unknown *Digitaria* species in this region. Annual grass weeds that are recognized as difficult to control in most corn-producing areas of South Africa include large crabgrass, finger millet (*Eleusine coracana* (L.) Gaertn.), guineagass (*Urochloa maxima* (Jacq.) R. Webster), African liverseed grass (*Urochloa mosambicensis* (Hack.) Dandy), and panic liverseed grass (*Urochloa panicoides* P. Beauv.) (Botha 2010; Bromilow 2010). Although several *Digitaria* species occur in most corn-producing areas in South Africa, the weed status of the more uncommon *Digitaria* spp. such as southern crabgrass (*Digitaria ciliaris* (Retz.) Koel.), velvet fingergrass (*Digitaria velutina* (Forsk.) Beauv.), and naked crabgrass is unknown. The growth cycle of these grasses coincides with corn production and their seeds germinate throughout the growing season of the crop (Saayman-Du Toit and Le Court De Billot 1991). The importance and impact of large crabgrass has been studied worldwide in a variety of crops (Holm et al. 1991; Kim et al. 2002; Mitich 1988). Naked crabgrass has been reported to be a grass weed in corn by several authors (Botha 2010, Bromilow 2010, Van Oudtshoorn 2009), but the impact or competition on corn yields has not been reported, although it is recognized to be of importance in sugarcane in Brazil (Dias et al. 2005, Vieira et al. 2010) and is a serious grass weed in West Africa (Chikoye et al. 2000).

Typical grass control in corn production includes the application of PRE herbicides such as acetochlor, *s*-metolachlor, and dimethenamid followed by cultivation 4 to 6 wk after crop emergence. The planting of glyphosate-tolerant corn cultivars validates the POST application by corn producers. A decrease in effective control with soil-applied, PRE acetanilide herbicides such as acetochlor and *s*-metolachlor has, however, been reported where

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severe infestations of naked crabgrass occurred (Hugo 2014). This is partly due to the incorrect identification of species and prevailing misconceptions that acetanilide herbicides will control all *Digitaria* spp. equally well. Competition due to grass infestations in corn, predominantly large crabgrass and African liverseed grass, resulted in significant yield losses if left uncontrolled. Jooste and Van Biljon (1980) reported that infestations of large crabgrass in corn is even more severe than that caused by yellow nutsedge (*Cyperus esculentus* L.), and can result in corn yield losses of up to 70%. Control of grass weed species is therefore essential during the first 6 wk after crop emergence to prevent yield losses (Ghosheh et al. 1996; Hellwig et al. 2002).

The optimal timing of herbicide application is crucial to ensure effective control of grass species. The CPWC is defined as the necessary duration of weed control to prevent yield reduction due to weed interference (Hall et al. 1992; Norsworthy and Oliveira 2004; Page et al. 2009). CPWC is an estimation of the period during which crop growth and yields are negatively influenced by weed interference, to predict onset, and critical and end point of CPWC (Singh et al. 1996). Two components are necessary to determine CPWC. These include the maximum period of time a crop can be exposed to early-season weed competition before a yield-loss threshold is reached, and the minimum duration of a weed-free period required after planting to prevent yield loss above an arbitrarily chosen threshold (Singh et al. 1996). Effective weed control during this period of crop development prevents serious yield losses and is the optimal time for herbicide applications (Evans et al. 2003; Norsworthy and Oliveira 2004; Williams 2006).

Several studies on various weed species have been conducted to determine the CPWC for corn, but results vary and are often contradictory (Evans et al. 2003; Gantoli et al. 2013; Ghosheh et al. 1996; Halford et al. 2001; Hall et al. 1992; Isik et al. 2006; Knezevic et al. 2002; Norsworthy and Oliveira 2004; Page et al. 2009; Williams 2006). The duration and especially the final stages of the CPWC in corn are greatly influenced by weed densities and spectrum, as well as variation in environmental factors (Evans et al. 2003; Halford et al. 2001; Norsworthy and Oliveira 2006). The beginning of CPWC in a no-till field experiment was found to show less variability than CPWC in conventionally tilled soil (Halford et al. 2004; Hall et al. 1992). Evans et al. (2003) concluded that the CPWC for corn started between crop emergence and the seven-leaf (V7) stage and ended with anthesis. Isik et al. (2006) determined CPWC for corn in Turkey at 2.5, 5, and 10% yield-loss thresholds and estimated the duration of the period to be 5 wk at a 5% yield-loss level. They found that the CPWC started at the one-leaf (V1) stage and ended at the eight-leaf (V8) stage, and that the CPWC increased to 9 wk when only a 2.5% yield-loss level was predicted. When a yield loss of only 10% was predicted, the CPWC was only 2 wk long. Williams (2006) reported that there was a significant interaction between planting date and CPWC of corn and that this could be used to optimize weed-control programs. The duration of the CPWC increased for corn planted early and fields should be kept weed-free until the V8 stage, whereas the weed-free period was only up to the three-leaf (V3) stage for corn planted later. This significant effect was due to lower weed densities later in the season, influencing corn yield less than 5%. Norsworthy and Oliveira (2004) reported great variation in the duration of the CPWC for corn between localities. The beginning of the CPWC for one locality started from the V1 stage (5 to 9 d after emergence) and ended between V8 to 10-leaf (V10) stages, whereas a CPWC of only 4 d (ending at V5 and V6) was recorded at another locality.

Most of the aforementioned critical periods of weed control were determined in cases where broadleaf weeds dominated the weed spectrum. Fewer studies have been done on the interference of grass species on corn yield (Anderson 2000; Ghosheh et al. 1996). Weed interference by barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.] had a greater effect on corn planted early in the season when weed densities were highest compared with corn planted later in the season (Williams 2006). Mickelson and Harvey (1999) determined that the density and time of emergence of woolly cupgrass (*Eriochloa villosa* (Thumb.) Kunth) had a significant effect on grass biomass and seed production. When the emergence of woolly cupgrass in corn was delayed, vegetative biomass and seed production of the weed grass declined rapidly, indicating that late-emerging grass may not be important for crop competition. Although grass species can germinate throughout a crop growth season, the incidence, densities, and interference of grass weeds also vary greatly over different localities and seasons (Hartzler et al. 1999). Since naked crabgrass is a relatively unknown grass weed in corn production in South Africa, the effect of early and late interference on crop yield is not known. This study was conducted to determine the CPWC and the effect on corn yields in those areas of South Africa where severe naked crabgrass infestations are experienced.

Materials and Methods

Three field trials in which different CPWC were evaluated for naked crabgrass were conducted at two sites in the main corn-producing regions of South Africa. A typical growing season for corn production in South Africa commences in November and December with planting in one year and concluded in May and June the following year with harvesting when corn is physiologically matured.

Experimental Site 1. One field trial, consisting of an early and a late planting date, were established at the Agricultural Research Council's Institute for Grain Crops experimental farm situated in the Northwest Province at Potchefstroom (−26.73607, 27.07553) during 2009/2010 and 2010/2011 growing seasons. The soil was a sandy clay loam (59% sand, 5% silt, 36% clay) with a pH of 6.58. Naked crabgrass seed used to infest the CPWC trial was hand harvested during May 2008, threshed from mature digitate panicles, and left to dry before it was placed in polyethylene containers and stored for 1 yr at 15 C. Before establishing homogenous infestation levels of naked crabgrass, experimental fields were conventionally tilled early in spring (September 2009) with a moldboard plow to a depth of 25 cm, followed by disc cultivation to prepare a smooth seedbed in accordance with corn production practices used in the Northwest Province. Before sowing grass or corn seed, atrazine/terbuthylazine (Gesaprim® Super 291/291 ai g L^{-1}, Syngenta South Africa [Pty Limited], Thornhill Office Park, 94 Bekker Street, Midrand, South Africa) was PRE applied to soil at a dosage of 4 L ha^{-1} for the control of broadleaf weeds. Naked crabgrass seed was hand sown on the soil surface, followed by 20-mm overhead irrigation 1 wk before planting corn. A glyphosate-tolerant corn hybrid 'DKC78-35R' was planted at an early planting (November 25, 2009) and late (December 17, 2009) planting date. This trial was repeated with the same corn hybrid in the same field during the following season, with the early planting on December 2, 2010 and the late planting on December 22, 2010. During both seasons corn was planted with a Monosem air-pressured, four-row planter (Monosem Inc., Edwardsville, KS) calibrated to plant a density of 20,000 plants ha^{-1}. Row spacing was 0.9 m and seeding depth was 6 cm, standard to local corn production practices.

The experimental design was a split plot with planting date as main factor and treatments (12 weed-interference periods) as subplots. Two control treatments were included, a season-long weed-free and a season-long weedy. The duration of weed interference and weed-free treatments were based on specific corn growth stages. Crop growth stages for corn were determined according to the system of Ritchie et al. (2003), where fully unfolded leaves were counted on corn plants when a visible collar was present in the season-long weed-free plots (e.g., V1 growth stage is where the first leaf has fully unfolded). For weed interference period treatments, naked crabgrass was allowed to grow from crop planting up to the appropriate crop growth stage of V4, V6, V8, V10, and tassel. The weed-free treatments consisted of weed-free periods up to V4, V6, V8, V10, and tassel corn growth stages. Weeds were eliminated from the different interference treatments by spraying a 2% glyphosate dosage rate (Roundup® Ready Plus 540 g ae L^{-1}, Monsanto South Africa, Monsanto House, Fourways Office Park, Fourways, South Africa) with an IRREMEC knapsack sprayer (25 L) delivering 200 L ha^{-1}. To protect corn plants from any adverse effects of glyphosate, directed spray applications were done using special spray covers over nozzles (shields) after the V8 stage. In the weed-free period treatments, naked crabgrass was removed weekly by hand or by means of glyphosate until the appropriate duration of weed control was reached for the respective crop growth stages. Individual plot dimensions were six rows, 5.4 m in width by 5.5 m in length. Plots were randomized completely, with three replications for each treatment in both early and late planting dates.

For the six weed-interference treatments, naked crabgrass plants were sampled in 1 m^2 surface areas within the central four rows of each respective treatment plot before glyphosate application. Biomass of grasses was determined after drying aboveground leaves and stems in an oven at 60 C for 24 h. The only other grass species present at the trial sites were Bushveld herringbone grass and African liverseed grass, which could be clearly distinguished from *Digitaria* spp., and thus were hand hoed to ensure homogenous infestation of naked crabgrass.

Crop and grass emergence in most treatments occurred simultaneously or within 1 wk apart. Plant stand of corn was determined 7 d after planting for each planting date during both seasons and expressed as percentage emergence. Emergence in all trials was commercially acceptable (> 95%). Corn plants were harvested at physiological maturity and kernel moisture content was adjusted to 12.5%. The number of corn plants in the central four rows of each plot was counted and hand harvested. Ears were dehusked and shredded, after which total kernel mass and 1,000 seed weight were determined. Yield (t ha^{-1}) from the season-long weed-free plots was used to determine relative yield (%) and was regressed against growing degree days (GDD). The GDD was calculated using a simple model of the average daily maximum (T_{max}) and minimum (T_{min}) air temperatures minus the base temperature of corn (T_b = 10 C) between November and May for each growing season (Williams 2006). Planting date was used as the reference point for accumulation of GDD and the beginning and end of the CPWC for each locality were expressed in GDD and corresponding crop growth stage (Evans et al. 2003).

Experimental Site 2. Another field trial consisting of an early and late planting date was established during 2010/2011 growing season on a farm near Wesselsbron (−27.69109, 26.44187) in the Free State Province. This site was characterized by severe natural infestation of naked crabgrass and no extra naked crabgrass seed were sown in at this locality. The soil was a sandy soil (84% sand, 6% silt, 10% clay) with a pH of 5.62. Conventional tillage practices for this corn production region were followed, i.e., rip cultivation (45 cm deep) during mid-October 2010.

The experimental design at this site was identical to that described above. However, at this site, each plot consisted of six corn rows, planted at wider interrow widths of 1.5 m, 5.5 m in length. The wider interrow width is standard practice to conserve soil moisture and may be unusually wide for producers in corn-producing regions in the United States and Europe, but because of the low annual rainfall of between 450 to 500 mm, wider interrow spacing is warranted for some corn-producing areas in South Africa. Early planting of the corn hybrid 'DKC78-45BR' was done on November 18, 2010 and the late planting on December 7, 2010. Corn and naked crabgrass emergence was recorded 7 d after planting in both early and late planting dates. Data collected were the same as for the trial described above. Corn yield was determined by harvesting the middle four rows of each plot.

Statistical Procedures. The data were analyzed separately for each season and locality. The actual and relative yield data for early and late planting dates were subjected to an ANOVA, with planting date as main plot factor and weed interference or weed-free treatments as subplot factor. The residuals were tested for deviation from normality and no evidence against normality was found; therefore, data were considered as reliable. The means of significant source effects were compared using Fisher's Protected LSD at the 5% significance level. A nonlinear exponential (or asymptotic) regression model was fitted to the relative yield data to determine the effect of weed interference and weed-free periods to estimate the CPWC, the beginning (critical time of weed removal = CTWR) and end (critical weed-free period = CWFP) of the period using the equation,

$$Y = A + BR^x \qquad [1]$$

where Y = relative yield (%), $A + B$ = initial relative yield in weedy or weed-free plots, R = rate of yield loss, and x = duration of interference measured in GDD. This model represents a curve rising or falling from an asymptote (A) on the left of the graph if $R > 1$, and if $0 < R < 1$ the curve rises or falls to an asymptote (A) on the right of the graph. The parameters of the regression model are listed in Table 1. The arbitrary threshold levels of 5 and 10% yield loss were used to determine the CPWC (Knezevic et al. 2002). All data were analyzed using Genstat® for Windows 13th edn. Version 14 (Payne 2011).

Results and Discussion

Yield Responses. Cumulative rainfall at Potchefstroom was similar for early and late planting dates during 2009 (541 and 503 mm, respectively), whereas the late planting date during 2010 received 21% less rainfall (400 mm) compared with the early planting date (509 mm) (Figure 1). Although total rainfall between seasons at Potchefstroom differed, the distribution of rain affected corn yields more in the weed-free corn plots. Corn in weed-free plots yielded 31% less during 2010 compared with 2009 (5.59 and 8.16 t ha^{-1}, respectively) (Figure 2). At Wesselsbron cumulative rainfall was similar between

Table 1. Exponential equations for relative yield (Y) in the function of growing degree days (GDD) measured after crop emergence with interference of naked crabgrass in corn used to determine critical periods of weed control (CPWC) in Figures 2 and 3. The beginning and end of the period were determined using the equation $Y = A + BR^x$ (Equation 1). Standard error of the means is indicated in brackets.

Locality (season)	Planting date	Parameter	Weedy	Weed-free
Potchefstroom (2009)	Early	A	25.4 (29.9)	112.0 (19.2)
		B	76.3 (27.8)	−65.5 (17.9)
		R	0.998 (0.001)	0.998 (0.001)
		R^2	0.92	0.93
	Late	A	178.0 (482.0)	35.4 (70.30)
		B	−78.0 (476.0)	22.2 (65.0)
		R	1.000 (0.001)	1.001 (0.001)
		R^2	0.79	0.83
Potchefstroom (2010)	Early	A	33.4 (41.0)	63.4 (6.57)
		B	67.1 (39.5)	1.5 (3.0)
		R	0.999 (0.0005)	1.002 (0.001)
		R^2	0.96	0.89
	Late	A	61.8 (18.6)	116.4 (17.3)
		B	38.6 (17.1)	−50.2 (15.8)
		R	0.999 (0.001)	0.999 (0.001)
		R^2	0.89	0.93
Wesselsbron (2010)	Early	A	62.6 (14.3)	92.8 (2.43)
		B	34.9 (13.8)	−29.6 (5.22)
		R	0.998 (0.001)	0.995 (0.001)
		R^2	0.77	0.89
	Late	A	−208.0 (548.0)	97.1 (4.52)
		B	307.0 (544)	−79.6 (7.94)
		R	0.999 (0.001)	0.996 (0.001)
		R^2	0.96	0.97

early and late planting dates, but yield in weed-free plots differed between planting dates. Corn planted early yielded 22% more compared with corn planted later (5.19 and 4.07 t ha^{-1}, respectively) (Figure 3). Yield loss of corn increased with the increased duration of grass interference and ranged between 28 and 55% for Potchefstroom and 37 and 82% for Wesselsbron in the season-long weedy plots. Yield was only influenced by the planting date at Potchefstroom during 2009 where the late planting yielded on average 1 t ha^{-1} more. At Wesselsbron the early planting date yielded 1.5 t ha^{-1} more than the late planting date during 2010.

Weed Growth and Biomass. Naked crabgrass emergence and growth was slower at Potchefstroom during 2009 as indicated by the dry biomass, which yielded only 183 and 169 g m^{-2} for the early and late planting dates, respectively. During 2010 biomass of naked crabgrass was 21 and 60% higher for the early and late planting dates, respectively (Figure 4) and can be ascribed to higher reinfestation after seed shedding during May 2010. Naked crabgrass biomass was much higher at Wesselsbron compared with Potchefstroom and yielded 418 and 594 g m^{-2} in the early and late planting dates, respectively and can be ascribed to the increase in the naturalized population. The highest biomass at Wesselsbron was recorded 78 d after crop emergence, which corresponded with tasseling of corn plants (Figure 4). This could be explained by the morphological growth patterns of naked crabgrass tufts that formed a thick carpet of dense growth within weeks after crop emergence at Wesselsbron, unlike grass growth at Potchefstroom where dense mat-forming growth started later and was limited because of canopy formation of corn. The difference in population density of naked crabgrass between the two localities may be attributed to various factors such as seed bank density, climatic conditions, soil type, and tillage practices (Knezevic et al. 2002). The wider interrow spacing at Wesselsbron allowed grass to grow vigorously from early in the season without competing for light since corn plants did not form a canopy between rows. Norsworthy and Oliviera (2004) found that the CPWC and corn competitiveness are not affected by row widths, but that canopy formation is needed to reduce emergence and regrowth when weed species tend to exhibit continuous emergence patterns. If resources such as light, nutrients, and soil moisture are not limited, naked crabgrass could emerge until late in

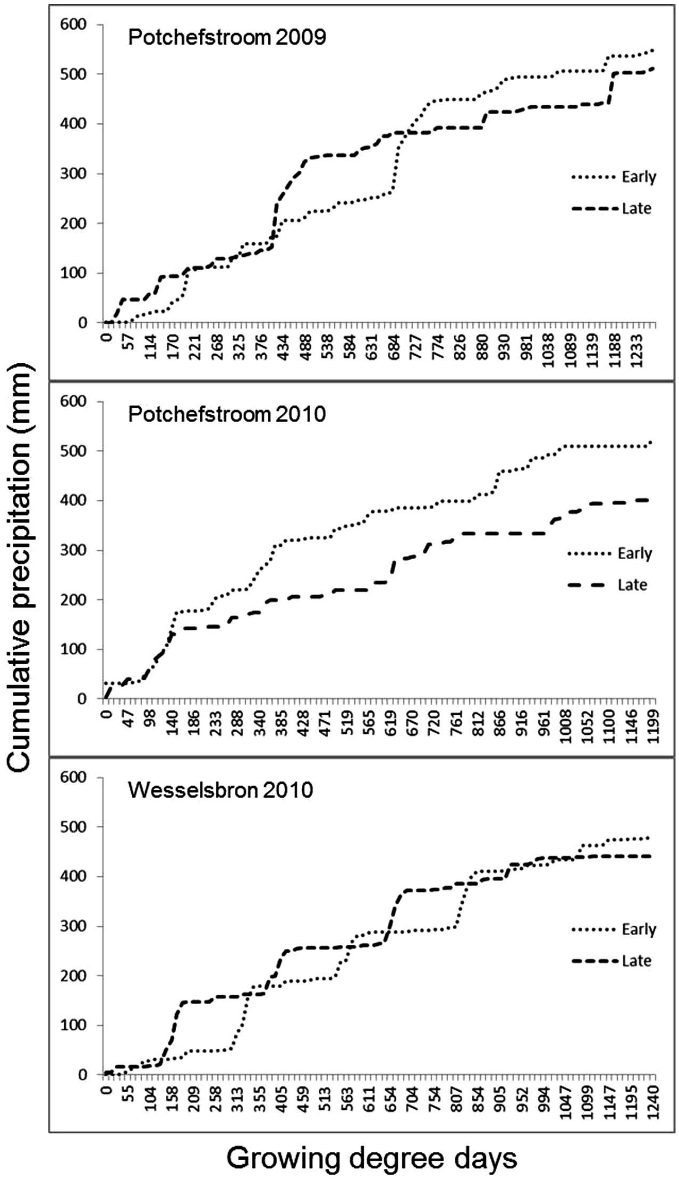

Figure 1. Cumulative rainfall plotted against growing degree days after planting of corn for two planting dates (early and late) at Potchefstroom and Wesselsbron during 2009/2010 and 2010/2011 growing seasons.

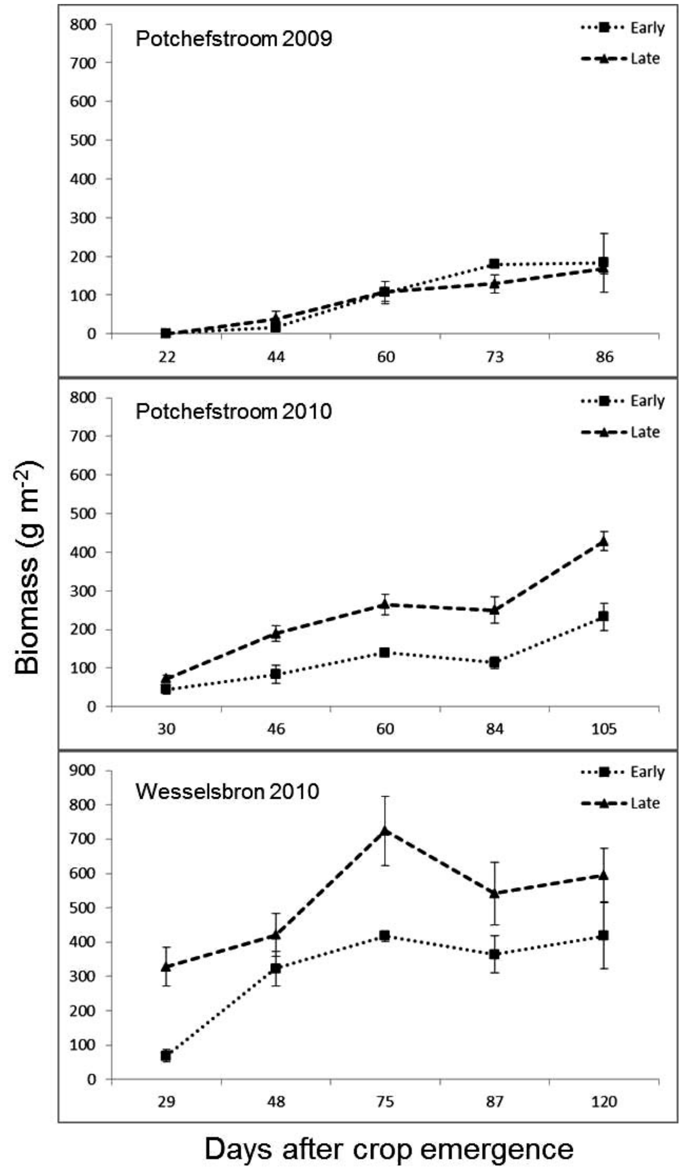

Figure 2. Critical periods of weed control (CPWC = vertical lines) of naked crabgrass in corn estimated for a yield loss of 10% during (A) early and (B) late planting at Potchefstroom for the 2009/2010 and 2010/2011 growing seasons. CTWR = critical time of weed removal; CWFP = critical weed-free period. Relative yield losses were calculated and were fitted to the following exponential response equation: $Y = A + BR^x$. Equation parameters (A, B, R) and adjusted R^2 for each site year were as follows: 2009 $\text{early}_{(\text{weedy})}$ (25.4, 76.3, 0.9, 0.92), $\text{late}_{(\text{weedy})}$ (178.0, −78.0, 1, 0.79); $\text{early}_{(\text{weed-free})}$ (112.0, −65.5, 0.9, 0.93), $\text{late}_{(\text{weed-free})}$ (35.4, 22.2, 1, 0.83); 2010 $\text{early}_{(\text{weedy})}$ (33.4, 67.1, 0.9, 0.96), $\text{late}_{(\text{weedy})}$ (61.8, 38.6, 0.9, 0.89); $\text{early}_{(\text{weed-free})}$ (63.4, 1.53, 1, 0.89), $\text{late}_{(\text{weed-free})}$ (116.4, −50.2, 0.9, 0.93).

the crop growth season, indicating that season-long weed control is needed. However, such long periods of effective weed control is in most cases not practical and very costly. Late emergence of certain grass species such as woolly cupgrass has little to no effect on corn yield (Mickelson and Harvey 1999). Similarly, Bosnic and Swanton (1997) established that barnyardgrass infestation early in the season is more detrimental to corn yield, but concluded that it is rather time of emergence than weed density that is more critical to corn yield. Grass emergence can also be greatly influenced by soil tillage, and some grass species were found to be more prevalent under no-till conditions where increased densities of foxtail species (*Setaria* spp.) and barnyardgrass were observed and showed longer periods of emergence when compared with conventionally tilled soil (Buhler 1992; Halford et al. 2001).

Critical Periods of Weed Control. Because of significant main effects between seasons and

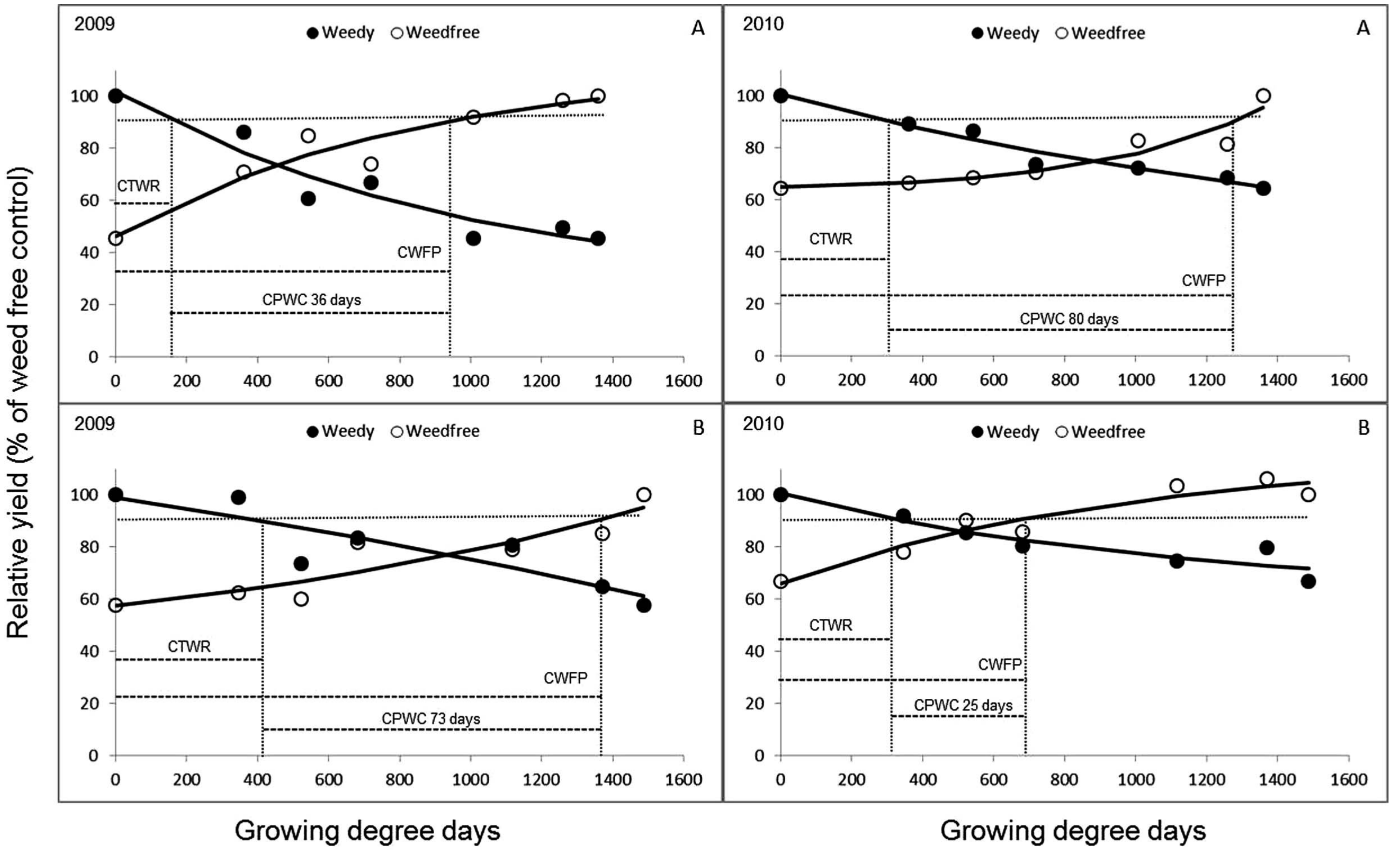

Figure 3. Critical periods of weed control (CPWC = vertical lines) of naked crabgrass in corn estimated for a yield loss of 10% during (A) early and (B) late planting at Wesselsbron for the 2010/2011 growing season. CTWR = critical time of weed removal; CWFP = critical weed free period. Relative yield losses were calculated and were fitted to the following exponential response equation: $Y = A + BR^x$. Equation parameters (A, B, R) and adjusted R^2 for each site year were as follows: 2010 early$_{(weedy)}$ (62.6, 34.9, 0.9, 0.77), late$_{(weedy)}$ (−208.0, 307.0, 0.9, 0.96); early$_{(weed\text{-}free)}$ (92.8, −29.6, 0.9, 0.89), late$_{(weed\text{-}free)}$ (97.1, −79.6, 0.9, 0.97).

planting dates observed for yield data, relative yield data were not pooled over seasons or planting dates. Both periods of weedy and weed-free curves fitted to relative yield had high coefficients of determination (R^2) and were significant at the 5% level for both localities and all seasons (Table 1). The exponential curve (asymptotic regression model) that overlapped in all cases could be used to determine both the critical time of weed removal and critical weed-free period, indicating the CPWC for naked crabgrass control in corn. The acceptable level of yield loss is an arbitrary decision that should be made considering the cost of weed control and possible incomes from crop harvests (Knezevic et al. 2002). Input costs for corn production and grain price in South Africa vary greatly between seasons and chemical weed control is estimated to comprise 11% of input costs (Grain South Africa 2013). The relative yield loss regressed to GDD for a 10% threshold level where a definite CPWC could be determined for corn at both localities and at different planting dates (Figures 2 and 3). The corresponding crop growth stage has, however, been determined for both the 5 and 10% threshold levels (Table 2). The duration of the CPWC varied considerably between planting dates and seasons and no concomitant CPWC could be determined for either planting dates or localities. During 2009, the CPWC for the late planting date (73 d) was twice as long as observed for the early planting date (36 d) (Figures 2A and 2B). This tendency was also observed between the early and late planting dates for Wesselsbron during 2010 (22 d compared with 42 d) (Figures 3A and 3B). During 2010 the duration of the CPWC for the late planting date at Potchefstroom was, however, considerably shorter at 25 d compared with the early planting date, where it was 80 d. At a 5% threshold level the duration of CPWC for naked crabgrass in corn increased for all trials (Table 2). Reported durations for most CPWC in corn are, however, relatively short when yield losses of greater than 5% were expected and are reported to range between 12 and 44 d (Isik et al. 2006; Norsworthy and Oliveira 2004).

The CPWC for Potchefstroom during 2009 commenced at the V2 and V6 stages for the early

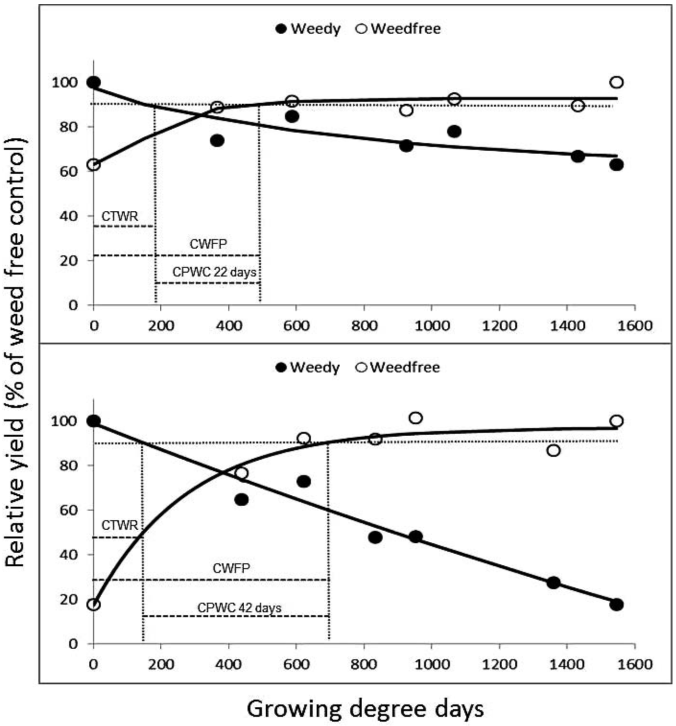

Figure 4. Naked crabgrass biomass for two planting dates (early and late) measured in weedy interference plots in 1 m^2 quadrants at Potchefstroom and Wesselsbron during 2009/2010 and 2010/2011 growing seasons. Bars indicated standard deviation of the means.

and late planting dates, respectively (Table 2). During 2010, the beginning of the CPWC was more stable than the ending of the CPWC periods at both Potchefstroom and Wesselsbron and started at the V4 and the V2 stages for the early and late planting dates (Figures 2 and 3). The end of the CPWC showed, however, more variation and range

Table 2. Critical period of weed control (CPWC) for corn at two planting dates and two localities during 2009/2010 and 2010/2011 growing seasons expressed in crop growth stage (CGS) at a 5 and 10% yield loss level.

			CGS	
Locality	Planting date	CPWC	5%	10%
Potchefstroom 2009/2010	Early	Beginning	V1	V2
		End	V14	V12
	Late	Beginning	V3	V6
		End	R1	T+2
Potchefstroom 2010/2011	Early	Beginning	V2	V4
		End	T + 4	T + 2
	Late	Beginning	V2	V4
		End	V10	V8
Wesselsbron 2010/2011	Early	Beginning	VE	V2
		End	-	V6
	Late	Beginning	VE	V2
		End	V12	V8

from the V6 stage to 2 wk after tasseling (T + 2) of corn between the localities and years. This is in contrast to the findings of Hall et al. (1992), which concluded that the beginning of the CPWC is often more variable compared with the ending. They found that the beginning of the CPWC varied between the V3 and V14 stages, whereas the ending was usually at the V14 stage of corn. Early onset of the CPWC has been reported for corn in several studies, indicating the need for weed control from crop emergence onward (Evans et al. 2003; Isik et al. 2006; Norsworthy and Oliveira, 2004). Norsworthy and Oliveira (2004) reported the onset of CPWC for corn to be as early as 5 d after crop emergence, despite different row widths. In a study done by Williams (2006) the planting date of corn significantly influenced the start and ending of CPWC period and it was concluded that corn planted early showed higher yield losses than corn planted later. This was evident due to higher weed infestation levels early in the season. All the above-mentioned studies estimated the periods of critical weed control for a weed spectrum that was dominated by broadleaf weeds where numbers started to decline later in the season. On the basis of our own observations, naked crabgrass can, however, germinate and emerge throughout the growing season if favorable growing conditions prevail, emphasizing the lengthy critical period of weed removal observed at both localities.

On the basis of the 5 and 10% estimated yield loss levels, the beginning (CTWR) and end (CWFP) of the CPWC differed among seasons and localities. These periods were, however, found to be in the same range of critical periods recorded in other CPWC studies in corn (Gantoli et al. 2013; Hall et al. 1992; Isik et al. 2006; Williams 2006). Early control of naked crabgrass in the corn growing season is crucial when heavy infestation levels of grass species are anticipated and season-long control is the safest option, despite deviation in planting date. However, the methods used to achieve season-long control may not be economical. Integrated weed management practices, such as the application of PRE and POST herbicides together with soil tillage to bury seed, will likely be more effective than herbicides alone to reduce germination of viable naked crabgrass seed. Season-long germination was experienced at both localities and late infestations can still cause severe yield reductions ranging between 28 and 82%. Corn producers should be made aware of the consequences of incorrect identification of *Digitaria* species as it appears that naked crabgrass grows more vigorously than large crabgrass and has the potential to cause severe yield losses. Although corn producers rely heavily on POST herbicide applications when minimum or no tillage is practiced, high naked crabgrass infestations can conceivably be significantly reduced with deep soil tillage to decrease viable seed in the seedbank (Buhler 1995; Halford et al. 2001). The timing of POST herbicides is furthermore crucial for significant weed control (Knezevic et al. 2009). Many common grass weeds are C_4 plants, which enhances the competitiveness of these weeds with corn. The period of corn development during tasseling and silking is critical for ear and grain development, and therefore, weed competition during these periods should be kept to a minimum. The CPWC values determined in this study showed that season-long weed control is essential to prevent yield loss, which makes POST herbicides applied at the CPWC a logical choice for prolonged grass control.

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