THE CRITICAL PERIOD OF WEED CONTROL IN
CHICKPEA AND LENTIL

By

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the requirements for the degree of

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On a more personal level, I would like to thank my parents for their endless support of my education as well as my brothers and sister who set high standards for me during my undergraduate years. Great thanks go to my many friends, who have become my family here at WSU. I have been blessed by the many nonbiological brothers and sisters that I have.
THE CRITICAL PERIOD OF WEED CONTROL IN
CHICKPEA AND LENTIL

Abstract

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Four studies were conducted near Pullman, WA in 2008 and 2009 to determine the critical period of weed control (CPWC) in chickpea and lentil. Field trials were kept free of weeds for periods of 0, 14, 25, 35, 45, 60, 75, or ~90 days after emergence (DAE), or weeds were allowed to grow before removal for periods of 0, 14, 25, 35, 45, 60, 75, or ~90 DAE.

Averaged across two varieties, weedy control treatments of lentil had 29.5% and 32% less seed yield than weed-free treatments during 2008 and 2009, respectively. When measured at crop maturity, 5.68 g/m² of dry weed biomass resulted in 1% loss in lentil seed yield. Based on a 5% yield loss threshold, the CPWC for lentil was estimated to be 270 to 999 growing degree days (GDD) (base 1.5°C, max 30°C), 22 to 57 DAE, and crop growth stage V7 to the early pod stage during 2008. In 2009, a very short CPWC (624 to 650 GDD) was observed. Weed populations were composed mainly of mayweed chamomile, prickly lettuce, and spiny sowthistle. Spiny sowthistle emerged and competed with the lentil crop up to 2 weeks later than mayweed chamomile, indicating that mayweed chamomile may be an earlier and stronger competitor than spiny sowthistle.
Full season weed interference with ‘Sierra’ chickpea caused yield reductions of 45%. A 1% reduction in chickpea seed yield was caused for every 3.16 g/m² of dry weed biomass. Crop yield, crop biomass, pod number, and 100 seed weight for ‘Sierra’ chickpeas were significantly different between years, but there was no year by treatment interaction. Therefore, data were combined over years. Based on a 5% yield loss threshold, the CPWC for the ‘Sierra’ chickpea was 16 to 26 DAE. Alternatively, the CPWC could be expressed as 162 to 256 GDD or the 9 to 13 node stage in terms of crop development. Crop yield, crop biomass, and 100 seed weight declined with an increasing duration of weed competition.
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Dedication

This thesis is dedicated to my parents and the many people who mentored me during my college career.
**Introduction**

Lentil (*Lens culinaris* Medik) is grown in rotation with wheat in the inland Pacific Northwest. In comparison to wheat, lentil is short in stature, shallowly rooted, slow to emerge, and has an open growth habit that often allows emergence and establishment of weeds (Al Thahabi et al. 1994; Basler 1981; Elkoca et al. 2005; Erman et al. 2008; Knot and Halila 1986). As a result, lentil is often the least competitive crop grown in rotation with wheat in the inland Pacific Northwest and elsewhere. Early establishing weeds, particularly those emerging prior to the crop, have a competitive advantage over lentil and severely reduce crop yield if not controlled (Kropff et al. 1992; Knott and Halila 1986). Later emerging weeds compete with lentil during pod and seed development, directly reducing seed size and quality. As lentil is a minor crop, produced on only ~26,000 and ~18,000 hectares in Washington and Idaho, respectively (NASS 2009), there has been no interest or research on the part of industry for herbicide development in lentil.

Typical weed control inputs in lentil may involve the application of a preemergence or preplant herbicide such as dimethenamid, imazethapyr, metolachlor, pendimethalin, triallate, or trifluralin for annual grass or broadleaf weed control followed by postemergence clethodim, quizalofop, or sethoxydim for annual grass control. Broadleaf weeds have impacted lentil production in the inland Pacific Northwest as metribuzin is the only selective postemergence broadleaf herbicide available. However, metribuzin often causes crop injury when applied postemergence, particularly during moist soil conditions (Yenish 2009a). Preemergence herbicides must provide effective weed control long enough to reduce or prevent the impact of broadleaf weeds on lentil yield. Yield losses due to weeds in lentil are estimated to range from 20 to 84% (Yenish et al. 2009b). Yield loss varies due to intensity of infestations and species of
weeds (Knott and Halila 1986). Yield loss due to weed competition could also differ between large and small seeded lentil cultivars due to differing amounts of carbohydrates and nutrients available to the seedling that affect early seedling vigor and competitiveness (Gulluoglu and Arioglu 2009).

The critical period of weed control (CPWC) is defined as the period of crop growth when the crop must be kept free of weeds to prevent yield loss due to weed interference (Van Acker et al. 1993). It is determined independently from two components (1) the critical timing of weed removal (CTWR), the maximum period of time a crop can be exposed to early season weed competition before a yield loss threshold is reached, and (2) the critical weed-free period (CWFP), the minimum duration of a weed-free period required following planting to prevent yield losses above a threshold, generally defined as 5%. The CTWR and the CWFP delineate the beginning and end of the CPWC, respectively. Results of CPWC studies in lentil have been quite variable (Al-Thahabi et al. 1994; Erman et al. 2008; Mohamed et al. 1997; Singh et al. 1996). Moreover, all of the work defining the CPWC in lentil has been conducted in Asia, where lentils are more commonly produced (Hawtin et al. 1980). No previous work on the CPWC has been done on lentil in North America. There is a need to determine the CPWC for lentils in the Pacific Northwest’s production system, weed spectra, and environment.

The CPWC in lentil has been estimated to be between 30 and 60 days after emergence (DAE) in India. In Syria, the CPWC has been estimated to be between 60 and 90 DAE (Hawtin et al. 1980). Al-Thahabi et al. (1994) estimated a CPWC between 49 and 56 DAE in Jordan. No base thresholds were reported in these studies. Singh et al. (1996) estimated a CPWC between 38 and 92 DAE in Jordan based on a 10% yield loss threshold. Based on a 5% yield loss threshold, Mohamed et al. (1997) in Iran estimated a CPWC between 2 and 4 or 4 and 6 weeks after
emergence depending on location. Erman et al. (2008) in India estimated a CPWC beginning prior to crop emergence lasting until eight weeks after emergence based on a 5% yield loss threshold. The average CPWC for lentil reported over the last two decades is between 25.7 and 54.8 DAE.

Chickpea (Cicer arietinum L.) is a crop in the pulse family that is grown in the same way as lentil in the inland Pacific Northwest. Chickpea is the third most important pulse crop in the world, grown widely across Asia and the Middle East (Mohammadi et al. 2005). In dryland cropping systems in Washington and Idaho, chickpea is a minor crop that has become more important over the past two decades. Production of chickpea in Washington and Idaho averaged ~ 4,000 hectares during the 1990’s, but current production is ~25,000 hectares (NASS 2009) due to increased producer acceptance and market demand. Other dryland regions in North America have had similar trends.

Although ACCase inhibitors such as clethodim or quizalofop p-ethyl offer postemergence control of grass weeds (Yenish 2009a), the complete lack of labeled postemergence broadleaf herbicides for chickpea allows broadleaf weeds to greatly impact chickpea production in the Palouse. Thus, preplant or preemergence herbicides must provide effective weed control long enough to reduce or eliminate the impact of weeds on chickpea yield. Typical broadleaf weed control measures involve the application of flumioxazin or sulfentrazone preplant or preemergence or dimethanamid or metribuzin preemergence (Yenish 2009a).

Chickpea is often the least competitive crop in a dryland crop rotation (Yenish 2007). Several characteristics of chickpea, such as slow plant emergence, short plant height, and chickpea morphology allow weeds to compete effectively. In Canada, spring wheat canopy closure was observed 16 days before chickpea canopy closure (Moes and Domitruk 1995). Slow crop
emergence and slow canopy closure allow weeds to gain a foothold without significant suppression by the crop. Early establishing weeds, particularly those emerging before the crop, have a competitive advantage over emerging crops and will severely reduce crop yields if not controlled (Hock et al. 2006; Kropff et al. 1992). Late emerging weeds compete with the chickpea crop as seeds develop, reducing seed size and quality. Yield losses due to weeds in chickpeas have been estimated at 40 to 87% in India, 41 to 42% in the former USSR, and 23 to 54% in West Asia. Variations in yield losses among different regions of Asia are due to differences in intensity of infestation and species of weeds present (Bhan and Kukula 1987). Mohammadi et al. (2005) estimated a 1% reduction in chickpea seed yield for every additional 3.85 g/m² of weed dry weight. Additional losses from weeds include added cost for harvest and reduced crop quality (McKay et al. 2002).

While the CPWC in chickpea has been studied, the results have been variable. In one location in Iran, Mohammadi et al. (2005) estimated a CPWC of 17 to 49 DAE or between the four leaf and beginning of flowering stages, but in a second location the CPWC was between 24 and 48 DAE or between the five leaf and the full flowering stages. In western Iran Mashhadi and Ahmadi (1998) estimated a CPWC of 27 to 44 DAE, between the 6 and 14 leaf stage, and 205 to 385 GDD. Al-Thahabi et al. (1994) in Jordan estimated 35 to 49 DAE; Masood-Ali (1993) in India estimated 0 to 56 DAE; Ahlawat et al (1981) in India estimated 28 to 56 DAE; and Saxena et al. (1976) in India estimated that handweedings at 30 and 60 DAE would prevent unacceptable yield loss from weeds. The average of these estimates is 23 to 52 DAE, but the estimates for the lower and upper limit ranged from 0 to 35 and 42 to 60 DAE, respectively (Yenish 2007). All of this research defining the CPWC in chickpea has been conducted in Asia and the Middle East where >70% of the world’s chickpeas are grown (Yadav et al. 2007).
The CPWC for a given crop species varies greatly and depends on the density of weed infestation, crop species characteristics, climatic conditions, and environment (Knott and Halila 1986). Environmental conditions can affect crop emergence time and the onset of weed competition. The CPWC can also differ with differing planting densities (Ahmadvand et al. 2009), and the length of the CPWC can be affected by weed densities and weed emergence time (Knott and Halila 1986; Mohammadi et al. 2005). The CPWC concept typically assumes that weed emergence, species composition, and density are spatially homogenous across an environment (Knezevic et al. 2002). Variability in environment, crop characteristics, and other factors results in CPWC estimates specific to a crop only within a given region.

The objective of these experiments was to determine the CPWC for lentil and chickpea in the inland Pacific Northwest. Defining the CPWC will allow growers to make better decisions regarding timing of planting, application timing of preemergence herbicides, and timing of postemergence herbicides. An additional objective was to determine if seed size resulted in differences in competitive ability between the relatively small seeded ‘Pardina’ and the larger seeded ‘Brewer’ lentil varieties.

**Outline**

This thesis is a compilation of an introduction and two journal articles in lieu of chapters. The articles were formatted for submission to *Weed Technology*. Additional authors were involved with regards to experimental design, statistical analysis, and editing.
Literature Cited


The Critical Period of Weed Control in Lentil (*Lens culinaris*)

Jamin A. Smitchger, Ian C. Burke, and Joseph P. Yenish

Abstract

The critical period of weed control (CPWC) for ‘Pardina’ and ‘Brewer’ lentil was determined in field experiments near Pullman, WA in 2008 and 2009. Field trial treatments were kept free of weeds for periods of 0, 14, 25, 35, 45, 60, 75, or ~90 days after emergence (DAE), or weeds were allowed to grow before removal for periods of 0, 14, 25, 35, 45, 60, 75, or ~90 DAE. Averaged across varieties, nonweeded treatments of lentil had 29.5% and 32% seed yield reduction compared to weed free lentils in 2008 and 2009, respectively. When measured at crop maturity, a 1% loss in lentil seed yield resulted from each 5.68 g/m² of dry weed biomass. Based on a 5% yield loss threshold, the CPWC for lentil was estimated to be from 270 to 999 growing degree days (GDD), 22 to 57 DAE, or crop growth stage (CGS) 7 to the early pod stage during 2008. In 2009, the CPWC was 624 to 650 GDD, with no occurrence of a CPWC when estimated using DAE and CGS. Weed populations were composed mainly of mayweed chamomile, prickly lettuce, and spiny sowthistle. Spiny sowthistle emerged and competed with the lentil crop later in the growing season than mayweed chamomile, indicating that mayweed chamomile may be an earlier and stronger competitor than spiny sowthistle.

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1 Graduate Student, Assistant Professor, Associate Professor, Department of Crop and Soil Sciences, Johnson Hall 201, Washington State University, Pullman, WA 99164; study was conducted in 2008-2009.

**Key Words:** Critical period of weed removal, critical time of weed removal, critical weed free period, weed competition, weed interference.

Lentil is grown in rotation with wheat in the inland Pacific Northwest. In comparison to wheat, it is short in stature, shallow rooted, slow to emerge, and has an open growth habit that often allows emergence and establishment of weeds (Al Thahabi et al. 1994; Basler 1981; Elkoca et al. 2005; Erman et al. 2008; Knot and Halila 1986). As a result, lentil is often the least competitive crop grown in rotation in the Palouse and elsewhere (Yenish 2009b). Early establishing weeds, particularly those emerging prior to or with the crop, have a competitive advantage over lentil and severely reduce yield if not controlled (Knott and Halila 1986; Kropff et al. 1992). Later emerging weeds compete with lentil during pod and seed development and directly reduce seed size and quality. Lentil is a minor crop produced on only ~26,000 and ~18,000 hectares in Washington and Idaho, respectively (NASS 2009). There has been limited development of herbicides for use in lentils.

Typical weed control measures in lentil may involve the application of a preemergence or preplant herbicide such as dimethenamid, imazethapyr, metolachlor, pendimethalin, triallate, or trifluralin for annual grass or broadleaf weed control followed by postemergence applications of clethodim, quizalofop, or sethoxydim for annual grass control. Broadleaf weeds have greatly impacted lentil production in the inland Pacific Northwest as metribuzin is the only selective postemergence broadleaf herbicide available. However, metribuzin often causes crop injury when applied postemergence, particularly during moist soil conditions (Yenish 2009a).
Preemergence herbicides must control weeds long enough to reduce or prevent the impact of broadleaf weeds on lentil yield. Yield losses due to weeds in lentil are estimated to range from 20-84% (Yenish et al. 2009b), but they vary with intensity of infestations and species of weeds (Knott and Halila 1986).

The critical period of weed control (CPWC) is defined as the period of crop growth when the crop must be kept weed-free to prevent yield loss due to weed interference (Van Acker et al. 1993). The CPWC is determined from two components (1) the critical timing of weed removal (CTWR), the maximum period of time a crop can be exposed to early season weed competition before a yield loss threshold is reached, and (2) the critical weed-free period (CWFP), the minimum duration of a weed-free period required following planting to prevent yield losses above a threshold, generally defined as 5%. The CTWR and the CWFP delineate the beginning and end of the CPWC, respectively. Results of CPWC studies in lentil have been quite variable (Al-Thahabi et al. 1994; Erman et al. 2008; Mohamed et al. 1997; Singh et al. 1996). Moreover, all of the work defining the CPWC in lentil has been conducted in Asia, where lentils are more commonly produced (Hawtin et al. 1980). No previous work on the CPWC has been done on lentil in North America. There is a need to determine the CPWC for lentils in the Pacific Northwest’s production systems, weed spectra, and environments.

The CPWC in lentil has been estimated to be between 30 and 60 days after emergence (DAE) in India. In Syria, the CPWC has been estimated to be between 60 and 90 DAE (Hawtin et al. 1980). Al-Thahabi et al. (1994) estimated a CPWC between 49 and 56 DAE in Jordan. No yield loss thresholds were reported in these studies. Singh et al. (1996) estimated a CPWC between 38 and 92 DAE in Jordan based on a 10% yield loss threshold. Based on a 5% yield loss threshold, Mohamed et al. (1997) in Iran estimated a CPWC between 2 and 4 or 4 and 6 weeks after
emergence depending on location. Erman et al. (2008) in India estimated a CPWC beginning prior to crop emergence and lasting until eight weeks after emergence based on a 5% yield loss threshold. The average CPWC for lentil reported over the last two decades is between 25.7 to 54.8 DAE.

Generally, the CPWC for a given crop species varies greatly and depends on the density of weed infestation, weed species characteristics, crop species characteristics, climatic conditions, and environment (Knott and Halila 1986). The CPWC can also differ with differing planting densities (Ahmadvand et al. 2009), and the duration of the CPWC can be affected by weed densities (Knott and Halila 1986). Because most weed species germinate discontinuously, weed emergence is not as predictable as crop emergence. Typically, the CPWC concept typically assumes that weed emergence, species composition, and density are spatially homogenous across an environment (Knezevic et al. 2002). Variability in environment, crop characteristics, and other factors causes CPWC estimates to be specific to a crop within a given region.

Seed size often differs among lentil cultivars. Yield loss due to weed competition could potentially differ between large and small seeded lentil cultivars (seeded at the same density) due to differing amounts of carbohydrates and nutrients available to the seedling from the cotyledons of the seed, which influences early seedling vigor and competitiveness (Gulluoglu and Arioglu 2009). Differences in seed size also could lead to differences in seed quality due to the greater amount of resources required to produce a larger vs. smaller seed.

The objective of this experiment was to determine the CPWC for lentil in the inland Pacific Northwest, primarily in the higher rainfall dryland regions of Washington and Idaho. Defining the CPWC will allow growers to make better decisions regarding timing of planting, application timing of preemergence herbicides, and timing of postemergence herbicides. An additional
objective was to determine if seed size results in differences in competitive ability between the relatively small seeded ‘Pardina’ and the larger seeded ‘Brewer’ varieties.

**Materials and Methods**

Field studies were established near Pullman, WA at Washington State University’s Cook Agronomy Farm (46.78791 Lat., -117.09171 Long., 2600’ elevation) in 2008 and 2009 with a small seeded (3.58 g. ±SD .67 /100 seed) lentil cultivar ‘Pardina’ and a large seeded (5.64 g. ±SD .38 g/100 seed) lentil cultivar ‘Brewer’ to determine the CPWC and losses due to weed competition. These cultivars were chosen because they were well adapted to the region and the different seed sizes could influence competitive ability or the CPWC. Soil types were classified as Palouse silt loam (fine, silty, mixed, mesic, Pachic Ultic Haploxerolls) in 2008 and Thatuna silt loam (fine, silty, mixed, mesic Xeric Argialbolls) in 2009. Soil pH was 5.2, and organic matter was 3.5%. In both years, the respective trial areas were prepared by fall chisel plowing followed by late-April cultivation and harrowing prior to planting. In accordance with production practices in the inland Pacific Northwest, no fertilizer was applied, but the seeds were inoculated with the appropriate strain of *Rhizobium* sp. prior to planting. Plots were planted on May 1 2008 and April 26 in 2009, respectively, and 50% of seedling emergence was measured on May 16 and May 10 during the same respective years. Seeding was done using a double disk grain drill calibrated to plant 1,050,000 seeds/ha (~56 kg/ha for Brewer lentils and ~40 kg/ha for Pardina lentils), a low commercial seeding rate (Eriksmoen et al. 2005). Seed were treated with fludioxonil (Maxim), matalaxyl (Apron), thiamethoxam (Cruiser), and the micronutrient molybdenum. Row spacing was 18 cm, and seeding depth was 4 cm. Individual plot dimensions were 3 by 5.5 meters, and they were arranged in a randomized complete block design with four
replications. Varieties were in separate trials. For analysis, variety and trial were treated synonymously. As the lentil crop emerged, the number of seedlings was determined by daily counts along random 2-meter lengths of row in each of two locations within one random plot for each of the four replications per trial. Once maximum emergence occurred, four representative plants in each plot were marked for the duration of the study with a ring made of colored electrical wire and a flag. The flag and electrical wire ring were moved to another representative plant if seedling mortality occurred. Height and growth stage of tagged plants were recorded 14, 25, 35, 45, 60, and 75 DAE and at crop maturity. Plant height was measured by gently stretching the main stem of the plant to its full length and measuring the height in cm. Vegetative growth stage was determined by counting the number of nodes on the main stem (Meicenheimer and Muehlbauer 1982). A node was defined as a portion of the stem from which a leaf or branch develops. A node was considered to be developed and, thus, counted if the leaflets in the node above it had unrolled to the point where the edges were not in contact with one another. Reproductive stages of lentil were determined according to the method described by Erskine et al. (1990). Days to 50% flowering and physiological maturity were estimated by visual observation of flowering and crop senescence.

Treatments consisted of weed interference periods of 0 (season long weed-free), 14, 25, 35, 45, 60, 75 DAE, and until crop maturity or weed-free periods of 0 (full season weedy), 14, 25, 35, 45, 60, 75 DAE, and until crop maturity. For weed interference period treatments, ambient weed populations were allowed to grow from crop planting until the appropriate number of days following crop emergence followed by weekly hand-weeding until harvest. In weed-free period treatments, weeds were removed weekly by hand until the appropriate duration of weed control was reached after which, no additional hand weeding was performed. For the 7 weed interference
treatments, weed biomass was sampled from four 0.25 m$^2$ quadrats per plot prior to the initial hand-weeding for each respective treatment. The density per species was recorded for each sample, and the weed dry weight was determined by drying the weed biomass at 40ºC for 1 to 3 days.

In order to prevent losses due to lentil seed shattering, sampling in each individual plot occurred slightly prior to crop senescence. Therefore, harvest of each plot generally occurred on separate dates due to the natural variation in lentil senescence. At harvest, crop biomass was harvested from two 0.25 m$^2$ quadrats/plot. Lentil plant density, aboveground weight, pod number, seed number, yield, and 100 seed weight were determined from these quadrats in addition to the density of each weed species and the dry weight per weed species. The number of pods per plant was determined by selecting 2 to 5 representative plants from each of the two quadrat samples and counting the number of pods per plant. Seed number, yield, and 100 seed weight were determined by threshing each of the samples and recording the dry weight and number of seeds. The number of seeds in each sample was determined via an electronic seed counter$^2$ after thoroughly cleaning the threshed seed. The yield per treatment was regressed against DAE and growing degree days (GDD). The GDD were calculated using a simple model of GDD where

\[
\text{GDD} = \frac{(\text{daily high temperature} < 30^\circ C + \text{daily low temperature})}{2} - \text{base temperature} \quad [1]
\]

The base temperature was set at 1.5 C and the maximum temperature was set at 30 C since lentil growth does not increase above that temperature (Ellis and Barrett 1994).

**Statistical Analysis.** Data were tested for homogeneity of variance by plotting residuals. All data were log transformed, which did not improve homogeneity. Therefore, nontransformed data were used in the analysis. ANOVA was conducted using the MIXED procedure in SAS$^2$ with sums of
squares partitioned to reflect variety and year effects. Sums of squares were partitioned to evaluate variety (considered fixed) and linear, quadratic, and higher order polynomial effects of treatment effects on yield (Draper and Smith 1981). Main effects and interactions were tested by the appropriate mean square associated with the fixed and random variables (McIntosh 1983). ANOVA indicated significant year main effects but no significant variety by year interactions, so data were pooled over variety (or trial) within year for analysis.

The ANOVA indicated higher order polynomial effects on yield reduction were more significant than linear or quadratic estimates. Therefore nonlinear models were used. Estimation used the Marquardt algorithm, a nonlinear least squares technique that is a compromise between the Gauss-Newton and steepest descent methods.

Thus, yield and yield parameters for CTWR and CWFP treatments in 2008 were modeled using the Gompertz function:

\[ y = AeB\text{e}^{KT} \]  \[\text{[2]}\]

where \( y \) is yield or yield parameters, \( A \) is the upper asymptote for yield or yield parameters, \( B \) and \( K \) are constants, \( e \) is the base of natural logarithms, and \( T \) is GDD. In 2009 yield and yield determining parameters for CTWR and CWFP treatments were modeled using the logistic function:

\[ y = \frac{B}{A + (x / YR_{50})^d} \]  \[\text{[3]}\]

where \( y \) is the response at weed competition duration \( x \), \( B \) is the upper limit for \( y \), \( A \) is the lower limit for \( y \), \( d \) is the slope, and the \( YR_{50} \) is the duration reducing yield or yield parameters by 50%. The Gompertz and logistic models were chosen because they provided the best fit for the data and are recommended in current literature. A 5% yield loss threshold was chosen as it is the most widely utilized threshold in CPWC studies (Knezevic et al. 2002). Percent total yield loss was
determined by subtracting the point of maximum yield along the CTWR and CWFP curves (the weed-free all season treatment) from the point of lowest yield along the same curves (the weedy all season treatment) to determine total yield loss. Season end weed biomass was averaged and divided by the percent total yield loss to determine the amount of weed biomass resulting in a 1% yield loss.

Results and Discussion

Weed populations were comprised predominantly of Italian ryegrass (*Lolium multiflorum* Lam.), volunteer wheat (*Triticum aestivum* L.), mayweed chamomile, prickly lettuce, and spiny sowthistle. These species composed over 99% of the end of season weed biomass in both years. In 2008, these 5 species comprised 23, 37, 22, 7, and 10% of total weed biomass, respectively. Mayweed chamomile, prickly lettuce, and spiny sowthistle combined to compose 92% of the total sampled biomass in 2009 with the individual species comprising 44, 34, and 14% of total weed biomass, respectively. Grassy weed species were small components of the weed population in 2009 at the location used for the two trials. In these experiments, mayweed chamomile produced the greatest total dry weed biomass.

Maximum density of mayweed chamomile peaked at 14 DAE or earlier in 2008 and 2009 and then declined during the growing season in contrast to the density of spiny sowthistle, which increased in density after 14 DAE (Figure 1). Seedling mortality up to 48% was observed for mayweed chamomile. Spiny sowthistle emerged later in the growing season and at lower densities than mayweed chamomile. Early emerging weeds such as mayweed chamomile can cause greater yield losses than later emerging weeds because a small competitive advantage during the beginning of the growing season can translate to a large advantage at the end of the
The relative competitive ability of different weed species affects the time of the CPWC (Everman et al. 2008; Knezevic et al. 2002). The CPWC estimate was based on the average yield for both lentil varieties for 2008. In 2008, the CPWC was estimated to be 22 to 57 DAE or 270 to 999 GDD (Figure 2). Expressed in terms of crop development, the CPWC was estimated to be from the 7 node stage to the early pod stage. Maximum yield loss estimates were 27% for CTWR treatments and 32% for CWFP treatments. The CPWC estimate based on crop biomass was 251 to 1220 GDD, which was longer than the CPWC estimate based on lentil seed yield. Maximum crop biomass reduction was 30% for CTWR treatments and 27% for CWFP treatments which were very similar to seed yield losses. The statement made earlier that early weed competition is more important than late season competition (Hock et al. 2006) is supported by these results. Weed competition was not severe during the pod filling stages. Early season weed competition tends to reduce both biomass and yield while late season competition reduces mainly seed yield (Zimdahl 1980).

In 2009, the CPWC was 624 to 650 GDD on a crop yield basis (Figure 3) and 584 to 681 GDD on a crop biomass basis. Rainfall was negligible for the 23 days between May 14, 2009 and June 7, 2009 (Figure 4). The dry conditions delayed weed emergence. As a result, initial treatments on the CTWR were similar to the season long weed-free, causing a short CPWC. Since the CTWR and the CWFP, the two components that determine the beginning and end of the CPWC, are determined independently, these components may not overlap to define a discrete CPWC (Martin et al. 2001; Van Acker et al. 1993). No CPWC occurred based on crop development or DAE in 2009. The relatively short CPWC indicates a single weed removal at 45 DAE, the first flowering stage of crop development, or 624-650 GDD after 50% emergence would have limited yield loss to 5% or less of the weed-free treatment in 2009. Estimated growing season (Bosnic and Swanton 1997).
maximum yield loss was 28% for CTWR treatments or 36% for CWFP treatments in 2009. Crop biomass reduction was 15% for CTWR treatments and 29% for CWFP treatments.

The two varieties had a different response to weed competition when measured by 100 seed weight. Averaged over both years there was a variety by treatment interaction for 100 seed weight (P<.05). The large-seeded ‘Brewer’ lentil variety had a higher seed weight than the small-seeded ‘Pardina’ lentil variety. However, the 100 seed weight of the large-seeded ‘Brewer’ lentil declined with an increasing duration of weed interference (Figure 5), while the 100 seed weight was not significantly affected for the small seeded ‘Pardina’ variety.

Knowledge of the CPWC in lentil is essential to formulate weed management strategies. The CPWC is the time interval when it is crucial to maintain a weed-free environment to prevent unacceptable yield loss. Several studies in Asia indicate the critical period in lentil is 26 to 55 DAE, but weed species, climate, and other factors in the areas where these experiments were conducted differ from those in the inland Pacific Northwest. Mayweed chamomile emerged earlier and competed longer during the growing season than spiny sowthistle. Knowledge of this information may be useful to plan weed management strategies. The large seeded ‘Brewer’ lentil variety showed a decline in 100 seed weight as weed competition increased, but the same effect was not seen in the small seeded ‘Pardina’ variety. The data presented here indicate a CPWC varies by year and was 270 to 999 GDD and 22 to 57 DAE after emergence in 2008. In 2009 the CPWC was 624 to 650 GDD. Because the CPWC can vary by year and environment, weed management practitioners should use the CPWC as a guideline for recommendations (Knezevic et al. 2002; Everman et al. 2008). On average, weed management in lentil should be initiated by 447 GDD after emergence and maintained until 825 GDD after emergence to avoid 31% yield losses.
Acknowledgements

Appreciation is extended to the Cool Season Food Legume Council for funding and Randy Stevens, Rod Rood, and Dennis Pittmann for technical assistance.

Sources of Materials

1. Model 850-2 Counter, Old Mill Company, Savage Industrial Center, Savage, MD 20763.
2. SAS 9.1. SAS Institute, 100 SAS Campus Drive, Cary NC 57513-2414.
Literature Cited


Figure 1. Mayweed chamomile (A) and spiny sowthistle (B) density over time, by variety of lentil averaged over year.
Figure 2. Critical period of weed control (CPWC) in lentil in 2008 pooled over varieties determined using a 5% yield loss threshold and based on the critical timing of weed removal (CTWR) and the critical weed-free period (CWFP).
Figure 3. Critical period of weed control (CPWC) in lentil in 2009 pooled over varieties determined using a 5% yield loss threshold and based on the critical timing of weed removal (CTWR), and the critical weed-free period (CWFP).
Figure 4. Daily Precipitation during May and June of 2008 and 2009.
Figure 5. The critical timing of weed removal (CTWR) and the critical weed free period based on the 100 seed weight of the large seeded ‘Brewer’ lentil variety.
The Critical Period of Weed Control in Chickpea (*Cicer arietinum*)

Jamin A. Smitchger, Joseph P. Yenish, and Ian C. Burke

Abstract

The critical period of weed control (CPWC) for ‘Sierra’ chickpea was determined in field experiments near Pullman, Washington in 2008 and 2009. Based on a 5% yield loss threshold, the CPWC for the ‘Sierra’ chickpea was 16 to 26 DAE. Alternatively, the CPWC could be expressed as 162 to 256 GDD or the 9 to 13 node stage in terms of crop development. The season long weedy treatment of ‘Sierra’ chickpea had yield reductions of 45% compared to the season long weed-free treatment. Weed biomass in the season long weedy treatment was 142.2 g/m² at the end of the growing season. A 1% reduction in chickpea seed yield resulted from every 3.16 g/m² of dry weed biomass. Crop yield, crop biomass, and 100 seed weight declined steadily as the duration of weed competition increased, indicating crop yield as well as quality decrease as the weed interference period increases.


Key Words: critical period of weed removal, critical time of weed removal, critical weed-free period, weed competition, weed interference.

Graduate Student, Associate Professor, Assistant Professor, Department of Crop and Soil Sciences, Johnson Hall 201, Washington State University, Pullman, WA 99164; study was conducted in 2008-2009.
Chickpea is the third most important pulse crop in the world, grown widely in parts of Asia and the Middle East (Mohammadi et al. 2005). In the inland Pacific Northwest, chickpea is a minor crop that has developed in importance in the past two decades. Production of chickpea in Washington and Idaho averaged ~4,000 hectares per year during the 1990’s, but production was estimated at 25,000 hectares in 2009 (NASS 2009) due to increased producer acceptance and market demand. Increasing production of chickpea has also been observed in the Northern Great Plains dryland region of the United States.

As chickpea is a minor crop, herbicide development has not been emphasized. Although herbicides such as clethodim or quizalofop p-ethyl offer postemergence control of grass weeds (Yenish 2009), absence of labeled postemergence broadleaf herbicides for chickpea allows broadleaf weeds to impact chickpea production. Thus, preplant or preemergence herbicides must provide effective control long enough to reduce or eliminate the impact of weeds on chickpea yield. Typical broadleaf weed control measures involve the application of flumioxazin or sulfentrazone preplant or preemergence or dimethanamid or metribuzin preemergence (Yenish 2009).

Chickpea is the least competitive crop in a winter wheat, spring wheat, and legume crop rotation (Yenish 2007). Several characteristics of chickpea, such as slow plant emergence, short plant height, and chickpea morphology allow weeds to compete effectively. In Canada, spring wheat canopy closure was observed 16 days before chickpea canopy closure (Moes and Domitruk 1995). Slow crop emergence and canopy closure allow weeds to establish without significant suppression by the crop. Early establishing weeds have a competitive advantage over chickpea and will severely reduce crop yields if not controlled (Hock et al. 2006; Jeschke et al. 2009; Kropff et al. 1992). Additional losses include added cost for harvest aid herbicide
applications and reduced quality (McKay et al. 2002). Yield losses due to weeds in chickpea have been estimated to be 40 to 87% in India, 41 to 42% in the former USSR, and 23 to 54% in West Asia. Variations in yield losses among different regions of Asia are due to differences in intensity of infestation and species of weeds present (Bhan and Kukula 1987). Mohammadi et al. (2005) estimated a 1% reduction in chickpea seed yield for every additional 3.85 g/m² of weed dry weight.

The critical period of weed control (CPWC) is defined as the period of crop growth when the crop must be kept weed-free to prevent yield loss due to weed interference (Van Acker et al. 1993). It is determined independently from two components (1) the critical timing of weed removal (CTWR), the maximum period of time a crop can endure weed competition before a yield loss threshold is reached, and (2) the critical weed-free period (CWFP), the minimum weed-free period required from the time of planting to prevent yield losses above a threshold, which is generally fixed at a 5% yield loss. The CTWR and the CWFP delineate the beginning and end of the CPWC respectively.

Generally, the CPWC for a given crop species varies greatly and depends on the density of weed infestation, crop species characteristics, climatic conditions, and environment (Knott and Halila 1986). Environmental conditions can affect time of crop emergence and the onset of weed competition. The CPWC can also differ with differing planting densities (Ahmadvand et al. 2009), and the length of the CPWC can be affected by weed densities and weed emergence time (Knott and Halila 1986; Mohammadi et al. 2005). The CPWC concept typically assumes that weed emergence, species composition, and density are spatially homogenous across an environment (Knezevic et al. 2002). Variability in environment, crop characteristics, and other factors causes CPWC estimates to be specific to a crop in a given region.
The objective of this experiment was to determine the CPWC for chickpea in the inland Pacific Northwest. Defining the CPWC will allow growers to make better decisions regarding timing of planting, application timing of preemergence herbicides, and timing of postemergence herbicides if any become available.

Materials and Methods

Field studies were established near Pullman, WA at Washington State University’s Cook Agronomy Farm (-117.09171 Longitude, 46.78791 Latitude, 2600’ elevation) in 2008 and 2009 with a simple leaf chickpea cultivar ‘Sierra’ and a pinnately compound-leaf chickpea cultivar ‘Dylan’ to determine the CPWC and the effect of resource competition in chickpea. Both varieties are kabuli type chickpeas. The cultivars were chosen because they are well adapted to the inland Pacific Northwest and resistant to *Ascochyta rabiei* (Muehlbauer and Chen 2004; Muehlbauer and Temple 2006). Soil types were classified as Palouse silt loam (fine, silty, mixed, mesic, Pachic Ultic Haploxerolls) and Thatuna silt loam (fine, silty, mixed, mesic, Xeric Argialbolls) in 2008 and 2009, respectively. Soil pH and organic matter were 5.2 and 3.5% respectively. Trial areas were prepared each year by fall chisel plowing wheat stubble followed by late-April cultivation and harrowing prior to planting. In accordance with production practices in the inland Pacific Northwest no fertilizer was applied, but the seeds were inoculated with the appropriate strain of *Rhizobium* sp. prior to planting. Trials were planted on May 6, 2008 and May 10, 2009. Seeding was done with a conventional disk grain drill calibrated to plant 430,000 seed per hectare (~220 kg/ha). Row spacing was 18 cm, and seeding depth was 4 cm. Seed were treated with matalaxyl (Apron), thiabendazole (Mertect), thiamethoxam (Cruiser), and the micronutrient molybdenum.
Trial design was a randomized complete block with four replications. Individual plots were 3.0 m wide and 5.5 m long. The number of emerged seedlings was determined by daily counts along 2 meters of row in each of two locations within one random plot in each of the four replications per trial. Once maximum emergence occurred, four representative plants in each plot were marked for the duration of the study with a flag and a ring made of colored electrical wire. The flag and ring were moved to another representative plant if seedling mortality occurred.

Height and growth stage of tagged plants were recorded 14, 25, 35, 45, 60, and 75 DAE and at crop maturity. Plant height was measured by gently stretching the main stem of the plant to its full length and measuring the height in cm. Vegetative crop growth stage was determined by counting the number of nodes on the main stem (Gan et al. 2006). The reproductive crop growth stage was recorded using the method developed by Meicenheimer and Muehlbauer (1982) for pea, with the exception that no flat pod stages were recorded as this stage is not present in chickpea. The stages that were recorded were the sepal, closed petal, anthesis, early round pod, late round pod, and dry pod phases. Chickpea reproductive growth is indeterminate and often most reproductive stages can be found on the same plant. A chickpea plant was considered to be in a stage when one or more of the pods or flowers on a plant reached a particular growth stage. Days to 50% flowering and physiological maturity were estimated by visual observation of flowering and crop senescence.

Treatments were weed interference periods of 0 (season long weed-free), 14, 25, 35, 45, 60, 75 DAE, and until crop maturity or weed-free periods of 0 (full season weedy), 14, 25, 35, 45, 60, 75 DAE, and until crop maturity. For weed interference period treatments, weed populations were allowed to establish and grow following crop emergence until the treatment date. After the treatment date, hand-weeding was done weekly until harvest. In weed-free period treatments,
weeds were removed weekly by hand until the correct duration of weed control was reached. No additional hand-weeding was performed. For the 7 weed interference period treatments, weed biomass was sampled from four 0.25 m² quadrats per plot prior to the initial hand-weeding for each respective treatment. The density per species was recorded for each quadrat and the weed dry weight was determined by drying the weed biomass at 40°C for 1 to 3 days.

At harvest in 2008 and 2009, chickpea plants in two 0.25 m² quadrats were sampled from each plot. Plant density, aboveground weight, pod number, seed number, yield, and 100 seed weight were determined. In addition to the density of each weed species and the dry weight per weed species. The number of pods per plant was determined by selecting 2 to 5 representative plants from each of the two quadrats and counting the number of pods per plant. Seed density per area, yield, and 100 seed weight were determined by threshing each of the samples and recording the dry weight and number of seeds. The number of seeds in each sample was determined using an electronic seed counter after thoroughly cleaning the threshed seed by hand. In 2009, the same procedure was repeated except plots were machine harvested to determine yield parameters. Seed density per area and 100 seed weight were determined from samples of the total seed yield per plot. In order to prevent variation between whole plot harvested and quadrat harvested data, harvested samples were converted to yield/m length of row and then converted to yield/m². The yield per treatment was plotted vs. days after emergence and growing degree days (GDD). The GDD were calculated using a simple model of GDD where

\[
\text{GDD} = \frac{(\text{daily high temperature} < 30^\circ \text{C} + \text{daily low temperature})}{2} - \text{base temperature} = GDD \quad [1]
\]

The base temperature was set at 4.5°C (Soltani et al. 2006) and the maximum temperature was capped at 30°C because chickpea growth does not increase significantly above 30°C.
**Statistical Analysis.** Data were tested for homogeneity of variance by plotting residuals. All data were log transformed, which did not improve data homogeneity. Therefore nontransformed data were used in the analysis. ANOVA was conducted using the MIXED procedure in SAS\(^2\) with sums of squares partitioned to reflect year and treatment effects. Sums of squares were partitioned to evaluate study location effects (considered random) and linear, quadratic, and higher order polynomial effects of yield over treatments (Draper and Smith 1981). Main effects and blocking effects were tested by the appropriate mean square associated with the fixed variables (McIntosh 1983). ANOVA indicated significant year main effects, indicating that yield was different between years, but no year by treatment interaction occurred, indicating that the treatment effect was the same over both years. The magnitude of the year main effect was one tenth of the magnitude of the treatment main effect. Therefore, data were pooled over years for analysis.

The ANOVA indicated higher order polynomial effects were more significant than linear or quadratic estimates for yield and yield parameters in response to different durations and timings of weed infestations. Therefore nonlinear regression models were used. Estimation of yield parameters used the Marquardt algorithm, an iterative nonlinear least squares technique that is a compromise between the Gauss-Newton and steepest descent methods.

Yield and yield parameters for CTWR treatments combined over years were modeled using the Gompertz function:

\[
y = a x e^{e^{-(x-k)/b}}
\]  \[2\]

where \(y\) is yield or yield parameters, \(a\) is the upper asymptote for yield or yield parameters, \(e\) is the base of natural logarithms, \(x\) is the point along the horizontal axis, \(k\) is the point of inflection,
and b is the slope of the curve at greatest inflection. Yield and yield parameters for CWFP treatments were modeled using the logistic function:

\[ y = y_0 + \left( \frac{a}{1 + (x/x_0)^b} \right) \]  

where \( y \) is the response at weed competition duration \( x \), \( y_0 \) is the minimum yield, \( a \) is the total yield loss along the curve, \( x \) is the point along the horizontal axis, \( x_0 \) is the point equaling 50% of the total yield loss, and \( b \) is the slope at that point. The Gompertz and logistic models were chosen because they provided the best fit for the data and are recommended in current literature (Knezevic et al. 2002). Each model was tested to determine if it was the best fit for the regression line.

Thresholds were established along the CTWR and CWFP. A 5% yield loss threshold was chosen as it is the most widely utilized threshold (Knezevic et al. 2002). The CTWR and CWFP were established independently from the yield data. Percent total yield loss was determined by subtracting the point of maximum yield along the CTWR and CWFP curves (the weed-free all season treatment) from the point of lowest yield along the same curves (the weedy all season treatment) to determine total yield loss. The average end of season weed biomass was divided by the percent total yield loss to determine the amount of weed biomass required to cause a 1% yield loss.

Results and Discussion

The CPWC provides a guideline for timing applications of postemergence herbicides (Knezevic et al. 2002). Previous estimations for the CPWC in chickpea have been variable, and all of the CPWC studies in chickpea were conducted in Asia and the Middle East where >70% of
the world’s chickpeas are grown (Yadav et al. 2007). No information is available on the CPWC for chickpea in North America.

In one location in Iran, Mohammadi et al. (2005) estimated a CPWC of 17 to 49 days after emergence (DAE) or from the four-leaf to the beginning of flowering stages, but in another location in Iran the CPWC was estimated to be between 24 and 48 DAE or between the five-leaf to the full flowering stages. In western Iran, Mashhadi and Ahmadi (1998) estimated a CPWC of 27 to 44 DAE, between the 6 to 14 leaf stage, and 205 to 385 GDD. Al-Thahabi et al. (1994) in Jordan estimated a CPWC from 35 to 49 DAE; Masood-Ali (1993) in India estimated a CPWC from 0 to 56 DAE; Ahlawat et al. (1981) in India estimated a CPWC from 28 to 56 DAE. Saxena et al. (1976) in India estimated that handweedings at 30 and 60 DAE would prevent unacceptable yield losses from weeds. The average of these estimates is 23 to 52 DAE, but the range of estimates for the lower and upper limits were 0 to 35 and 42 to 60 days after emergence, respectively (Yenish 2007). The CPWC estimate for this experiment was based on the pooled yield data for ‘Sierra’ chickpea. The data from the ‘Dylan’ chickpea was not used due to poor crop emergence in 2008 and lack of a competitive weed population in 2009. Based on a 5% yield loss threshold, the CPWC for the ‘Sierra’ chickpea was 16 to 26 DAE (Figure 1). Averaged over years the critical period can be expressed as 162 to 256 GDD or the 9 to 13 node stage in terms of crop development. According to the regression equations used to determine the CPWC, 45% yield loss was observed.

Based on crop biomass rather than crop yield, the CPWC for ‘Sierra’ chickpea was 21 to 46 DAE. Alternatively the CPWC could be expressed as node 14 to the closed petal phase or from 200 to 410 GDD. The difference between the CPWC based on crop yield compared crop biomass
could indicate that crop biomass is affected less than crop yield. Reductions in crop biomass averaged 38% indicating seed yield is more susceptible to weed competition than biomass yield.

Total end of season dry weed biomass averaged 142.2 g/m², indicating 1% yield loss for each 3.16 g/m² of weed biomass. The composition of weed biomass combined over years was 60.1% mayweed chamomile, 12.0% Italian ryegrass (Lolium multiflorum Lam), 11.7% prickly lettuce, 8.9% spiny sowthistle, and 7.3% other weed species.

Yield, crop biomass, pod number, and 100 seed weight were different between years (Table 1), but there was no year by treatment interaction, indicating treatment effects were similar in each year. Therefore data were pooled over years. Yield and crop biomass declined as the weed competition period increased. A decline in pod number was not observed, but the 100 seed weight for the CTWR treatments declined as the weed competition period increased indicating that weed competition reduces crop quality, which was not taken into account for this study.

Knowledge of the CPWC in chickpea is essential to formulate weed management strategies. The CPWC is the time interval when it is crucial to maintain a weed-free environment to prevent unacceptable yield loss. Because no postemergence broadleaf herbicides are registered in chickpea, broadleaf weed control relies on preplant and preemergence herbicides to control weeds through the CPWC. Several studies in Asia indicate the CPWC in chickpea is 23-52 DAE, but weed species, climate, and other factors in the area where these experiments were conducted differ from those in the Pacific Northwest. As the CPWC can vary by year and environment, weed management practitioners should use the CPWC as a guideline for recommendations (Knezevic et al. 2002; Everman et al. 2008). According to this experiment, weed management in chickpea should be initiated by 2 weeks after emergence and maintained until 4 weeks after emergence to avoid appreciable yield losses.
Acknowledgements

Appreciation is extended to the Cool Season Food Legume Council for funding and Randy Stevens, Roddard Rood, and Dennis Pittmann for technical assistance.

Sources of Materials

1. Model 850-2 Counter, Old Mill Company, Savage Industrial Center, Savage, MD 20763.
2. SAS 9.2. SAS Institute, 100 SAS Campus Drive, Cary NC 57513-2414.
Literature Cited


Table 1. Average number of pods per plant and average 100 seed wt. for critical timing of weed removal (CTWR) and critical weed-free period (CWFP) treatments in ‘Sierra’ chickpea during 2008 and 2009.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Pod #</th>
<th>100 seed weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2008</td>
<td>2009</td>
</tr>
<tr>
<td>CTWR</td>
<td>12.703</td>
<td>18.811</td>
</tr>
<tr>
<td>CWFP</td>
<td>14.242</td>
<td>21.901</td>
</tr>
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</table>
Figure 1. Critical period of weed control (CPWC) for seed yield in ‘Sierra’ chickpea pooled over years determined using a 5% yield loss threshold and based on the critical timing of weed removal (CTWR) and the critical weed-free period (CWFP).
Figure 2. Critical period of weed control (CPWC) for biomass yield in ‘Sierra’ chickpea pooled over years determined using a 5% yield loss threshold and based on the critical timing of weed removal (CTWR) and the critical weed-free period (CWFP).
Figure 3. The critical timing of weed removal (CTWR) and the critical weed-free period (CWFP) based on the 100 seed weight of ‘Sierra’ chickpea.
The Critical Period of Weed Control in ‘Dylan’ Chickpea

Jamin Smitchger, Ian C. Burke, and Joseph P. Yenish

APPENDIX

Abstract

Field studies were established near Pullman, WA in 2008 and 2009 using a ‘Dylan’ chickpea cultivar with the objective to determine the critical period of weed control (CPWC) in chickpea. Emergence of the ‘Dylan’ chickpeas in 2008 was only 27% of expected emergence. Poor stand establishment allowed weeds to establish and compete with the chickpea crop without competition from the crop, which resulted in yield losses up to 85%. The CPWC was 22 to 62 DAE. Alternatively this can be expressed as 181 to 711 GDD, or 9 nodes to anthesis in terms of crop development. In 2009 weed populations were very low, resulting in only 9% yield loss. Therefore, no CPWC was found.

3 Graduate Student, Associate Professor, Assistant Professor, Department of Crop and Soil Sciences, Johnson Hall 201, Washington State University, Pullman, WA 99164; study was conducted in 2008-2009.
**Materials and Methods**

Field studies were established near Pullman, WA at Washington State University’s Cook Agronomy Farm (-117.09171 Longitude, 46.78791 Latitude, 2600’ elevation) in 2008 and 2009 with a pinnately compound-leaf chickpea cultivar ‘Dylan’ to determine the CPWC and the effect of resource competition in chickpea. ‘Dylan’ was chosen because it is well adapted to the region and resistant to *Ascochyta rabiei* (Muehlbauer and Temple 2006). Soil types were classified as Palouse silt loam (fine, silty, mixed, mesic, Pachic Ultic Haploxerolls) and Thatuna silt loam (fine, silty, mixed, mesic Xeric Argialbolls) in 2008 and 2009, respectively. Soil pH and organic matter were 5.2 and 3.5% respectively. Trial areas were prepared each year by fall chisel plowing wheat stubble followed by late-April cultivation and harrowing prior to planting. In accordance with production practices in the inland Pacific Northwest no fertilizer was applied, but the seeds were inoculated with the appropriate strain of *Rhizobium* sp. prior to planting. Trials were planted on May 6 and May 10 in 2008 and 2009, respectively. Seeding was done with a conventional disk grain drill calibrated to plant 430,000 seed per hectare (~220 kg/ha). Row spacing was 18 cm, and seeding depth was 4 cm. Seed were treated with matalaxyl (Apron), thiabendazole (Mertect), thiamethoxam (Cruiser), and the micronutrient molybdenum. The trial design was a randomized complete block with four replications. Individual plots were 3.0 m wide and 5.5 m long. The number of emerged seedlings was determined by daily counts along 2 meters of row in each of two locations within one random plot in each of the four replications per trial. Once maximum emergence occurred, four representative plants in each plot were marked for the duration of the study with a flag and a ring made of colored electrical wire. The flag and ring were moved to another representative plant if seedling mortality occurred. Height and growth stage of tagged plants were recorded 14, 25, 35, 45, 60, and 75 DAE and at
crop maturity. Plant height was measured by gently stretching the main stem of the plant to its full length and measuring the height in cm. Vegetative crop growth stage was determined by counting the number of nodes on the main stem (Gan et al. 2006). The reproductive crop growth stage was recorded using the method developed by Meicenheimer and Muehlbauer (1982) for pea, with the exception that no flat pod stage was recorded as this stage is not present in chickpea. A chickpea plant was considered to be in a stage when one or more of the pods or flowers on a plant reached a particular growth stage. Days to 50% flowering and physiological maturity were estimated by visual observation of flowering and crop senescence.

Treatments were weed interference periods of 0 (season long weed-free), 14, 25, 35, 45, 60, 75 DAE, and until crop maturity or weed-free periods of 0 (full season weedy), 14, 25, 35, 45, 60, 75 DAE, and until crop maturity. For weed interference period treatments, weed populations were allowed to establish and grow following crop emergence until the treatment date. After the treatment date, hand-weeding was done weekly until harvest. In weed-free period treatments, weeds were removed weekly by hand until the correct duration of weed control was reached. No additional hand-weeding was performed. For the 7 weed interference period treatments, weed biomass was sampled from four 0.25 m² quadrats per plot prior to the initial hand-weeding for each respective treatment. The density per species was recorded for each quadrat and the weed dry weight was determined by drying the weed biomass at 40°C for 1 to 3 days.

At harvest in 2008 and 2009, chickpea plants in two 0.25 m² quadrats were sampled from each plot. Plant density, aboveground weight, pod number, seed number, yield, and 100 seed weight were determined in addition to the density of each weed species and the dry weight per weed species. The number of pods per plant was determined by selecting 2 to 5 representative plants from each of the two quadrats and counting the number of pods per plant. Seed density per
area, yield, and 100 seed weight were determined by threshing each of the samples and recording
the dry weight and number of seeds. The number of seeds in each sample was determined using
an electronic seed counter\(^1\) after thoroughly cleaning the threshed seed by hand. In 2009, the
same procedure was repeated except plots were machine harvested to determine yield
parameters. Seed density per area and 100 seed weight were determined from samples of the
total seed yield per plot. In order to prevent variation between whole plot harvested and quadrat
harvested data, harvested samples were converted to yield/m length of row and then converted to
yield/m\(^2\). The yield per treatment was plotted vs. days after emergence and growing degree days
(GDD). The GDD were calculated using a simple model of GDD where

\[
\text{GDD} = \frac{\text{Maximum temperature} + \text{minimum temperature}}{2} - \text{base temperature} \quad [1]
\]

The base temperature was set at 4.5º C (Soltani et al. 2006) and the maximum temperature was
capped at 30ºC because chickpea growth does not increase significantly above 30ºC.

**Statistical Analysis.** Data were tested for homogeneity of variance by plotting residuals. All data
were log transformed, which did not improve data homogeneity. Therefore the transformed data
was not used. ANOVA was conducted using the MIXED procedure in SAS\(^2\) with sums of
squares partitioned to reflect year and treatment effects. Sums of squares were partitioned to
evaluate study location effects (considered random) and linear, quadratic, and higher order
polynomial effects of yield over treatments (Draper and Smith 1981). Main effects and blocking
effects were tested by the appropriate mean square associated with the fixed variables (McIntosh
1983). ANOVA indicated significant year main effects, and a year by treatment interaction.

. The ANOVA indicated higher order polynomial effects were more significant than linear or
quadratic estimates for yield and yield parameters in response to different durations and timings
of weed infestations. Therefore nonlinear regression models were used. Estimation of yield
parameters used the Marquardt algorithm, an iterative nonlinear least squares technique that is a compromise between the Gauss-Newton and steepest descent methods.

Yield and yield parameters for CTWR treatments were modeled using the logistic function:

\[ y = y_0 + \frac{a}{1 + (x/x_0)^b} \]  

where \( y \) is the response at weed competition duration \( x \), \( y_0 \) is the minimum yield, \( a \) is the total yield loss along the curve, \( x \) is the point along the horizontal axis, \( x_0 \) is the point equaling 50% of the total yield loss, and \( b \) is the slope at that point. Yield and yield parameters for CWFP treatments combined over years were modeled using the sigmoid function:

\[ y = y_0 + \frac{a}{1 + e^{-((x-x_0)/b)}} \]  

where \( y \) is yield or yield parameters, \( y_0 \) is minimum yield, \( a \) is the upper asymptote for yield or yield parameters, \( e \) is the base of natural logarithms, \( x \) is the point along the horizontal axis, \( x_0 \) is the point of inflection, and \( b \) is the slope of the curve at greatest inflection. The logistic and sigmoid models were chosen because they provided the best fit for the data and are recommended in the current literature. Each model was tested to determine if it was the best fit for the regression line.

Thresholds were established along the CTWR and CWFP. A 5% yield loss threshold was chosen as it is the most widely utilized threshold (Knezevic et al. 2002). The CTWR and CWFP were established independently from the yield data. Percent total yield loss was determined by subtracting the point of maximum yield along the CTWR and CWFP curves (the weed-free all season treatment) from the point of lowest yield along the same curves (the weedy all season treatment) to determine total yield loss. The average end of season weed biomass was divided by the percent total yield loss to determine the amount of weed biomass required to cause a 1% yield loss.
Results and Discussion

For ‘Dylan’ chickpea, crop yield, crop biomass, pod number, and 100 seed weight were significantly different between years. Based on a 5% yield loss threshold, the CPWC in the 2008 ‘Dylan’ chickpea was 22 to 62 DAE (Figure 1). Alternatively this can be expressed as 181 to 711 GDD, or 9 nodes to anthesis in terms of crop development. The average weed biomass in the trial at crop maturity was 67% mayweed, 24% Italian ryegrass, and 9% other weed species. Non-treated weedy controls of ‘Dylan’ chickpeas had an 85% yield reduction compared to weed-free controls in 2008. The high level of yield loss in this trial and the relatively long CPWC was probably a result of poor crop emergence and stand establishment. The plots contained an average of 538 g of dry weed biomass/m$^2$ in the season long weedy treatment, compared to 479 g of dry crop biomass in the season long weed-free treatment. Approximately, 6.33 g/m$^2$ of weed biomass was enough to reduce yield by 1%.

No CPWC was found in ‘Dylan’ chickpeas in 2009 due to low weed populations. None of the treatments in the 2009 ‘Dylan’ trial were significantly different. Therefore the data for the 2009 study was not used.

Sources of Materials

1. Model 850-2 Counter. Old Mill Company. Savage Industrial Center, Savage, MD 20763
2. SAS 9.2. SAS Institute, 100 SAS Campus Drive, Cary NC 57513-2414.
Literature Cited


Figure 4. Critical period of weed control (CPWC) in ‘Dylan’ chickpea in 2008 determined using a 5% yield loss threshold and based on the critical timing of weed removal (CTWR) and the critical weed-free period (CWFP).