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SPINY AMARANTH CONTROL AND AMINOPYRALID PERSISTENCE IN KENTUCKY PASTURES

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ABSTRACT OF THESIS

SPINY AMARANTH CONTROL AND AMINOPYRALID PERSISTENCE IN KENTUCKY PASTURES

Spiny amaranth is a problematic weed of heavily grazed pastures in Kentucky and surrounding states. The first objective was to evaluate spiny amaranth control when herbicides are applied before and after emergence. Spiny amaranth seed collected in 2008 were seeded in rows in the fall (November) and the following spring (March) in fields located near Lexington and Princeton, KY. Treatments consisted of five application dates and five herbicides plus an untreated control arranged in a split-split plot design. The following parameters were measured: fresh weight, plant height and percent visual control. At both locations pendimethalin applied in November, March and April before spiny amaranth emergence gave the greatest control and significantly reduced fresh weight biomass compared to other treatments. June applications of 2,4-D reduced plant height and provided 80 control. Fresh weight biomass and height were also reduced with dicamba, aminopyralid and aminocyclopyrachlor applied in June compared to pendimethalin and the untreated control.

A soybean bioassay was conducted to measure soil dissipation of aminopyralid, a common pasture herbicide active ingredient. Soil samples were collected from two sites in Lexington and Princeton. During a season of above average rainfall aminopyralid had dissipated from the soil within 16 weeks at Lexington and by 4 weeks at Princeton.

KEYWORDS: Amaranthus spinosus, spiny amaranth, spiny amaranth control, aminopyralid, aminopyralid persistence

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SPINY AMARANTH CONTROL AND AMINOPYRALID PERSISTENCE IN KENTUCKY PASTURES

THESIS

A thesis submitted in partial fulfillment of the
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By

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Chapter 1: Literature Review

Introduction

Spiny amaranth (*Amaranthus spinosus* L.) is a common weed of grazed pastures and hayfields in Kentucky. Spiny amaranth is most prevalent in high traffic and bareground areas, such as feeding and watering areas, but can quickly move throughout the pasture if not controlled (Ferrell and Sellers, 2007). Spiny amaranth is problematic in pastures because animals will not eat this weedy plant or graze around it due to spines on the plant (Fritz and Hartwig, 1986 and Ferrell and Sellers, 2007). To a lesser extent, spiny amaranth is also a weed of agronomic crops, such as corn and soybeans (Virginia Tech Weed Identification Guide and King et al., 2009). Compared to other weedy pigweed species such as Palmer amaranth (*Amaranthus palmeri* S. Wats.), smooth pigweed (*Amaranthus hybridus* L.), common waterhemp (*Amaranthus rudis* Sauer), and tall waterhemp (*Amaranthus tuberulatus* Sauer), spiny amaranth is less competitive in row crops (Steckel, 2004). In a survey of Kentucky County Agriculture and Natural Resources Extension Agents spiny amaranth was listed as one of the top ten most problematic weeds in pastures (Green, 2007).

Amaranthus Species

Amaranthus is the genus for the family of plants referred to as pigweeds. The word amaranthus is derived from the Greek word amarantus, which means ‘everlasting’. There are 865 plant members within the Amaranthacea family (Steckel, 2004). Approximately 70 species of amaranths (Pratt et al., 1999), however, not all 70 species occur in Kentucky.

Many pigweed species are problematic weeds of agronomic crops, such as Palmer amaranth, smooth pigweed, redroot pigweed (*Amaranthus retroflexus* L.) and tall waterhemp. Agricultural fields are a great habitat for annual plants like pigweeds that grow naturally in open or disturbed areas and receive full sun (Pratt et al., 1999). Pigweeds reduce crop yields and interfere with harvest (Horak et al., 1994). Pigweeds are difficult to control due to a long germination period, rapid and large growth, prolific seed production, long seed viability and difficulty in proper identification (Sellers et al., 2003). Although, proper identification of pigweed species can be difficult it is important due to varying responses to herbicides and weed management practices (Pratt et al., 1999).

Another reason why pigweeds are so problematic is their ability to adapt quickly to new environments (Pratt et al., 1999). At least one pigweed species is reported resistant to one or more herbicide groups in twenty-nine U.S. States (Sellers et al., 2003).

Pigweeds are pollinated by wind and can produce tens of thousands to hundreds of thousands of seeds per plant (Pratt et al, 1999). Some pigweeds are dioecious (common watherhemp and Palmer amaranth) while other species are monoecious [smooth pigweed, redroot pigweed, tumble pigweed (Amaranthus albus L.) and spiny amaranth] (Pratt et al, 1999 and Steckel, 2004). The monoecious species are generally self-pollinated (Franssen et al., 2001).

The growth of common waterhemp, Palmer amaranth, redroot pigweed, smooth pigweed, spiny amaranth and tumble pigweed were compared at two sites in Missouri. Sellers et al. (2003) observed that the largest change in plant height for each species occurred 4 to 6 weeks after planting. From tallest to shortest the height ranking was Palmer amaranth, redroot pigweed, smooth pigweed, spiny amaranth, common waterhemp and tumble pigweed. Dry weight gain for each species, except tumble pigweed, increased markedly between 12 and 14 weeks after planting. At the end of the season Palmer amaranth had the greatest dry weight and tumble pigweed had the least dry weight (Sellers et al., 2003).

Spiny Amaranth

Spiny amaranth is mostly known as a problematic summer annual weed of pastures. However, spiny amaranth is not only a weed of pastures. It was been reported as a weed in 28 crops and 44 countries (Chauhan and Johnson, 2009). Spiny amaranth closely resembles other pigweed species as a seedling but becomes easily distinguishable as the plant matures. Cotyledons are long, narrow and glabrous. Leaves are glabrous, arranged alternately along glabrous stems and are approximately 3.18 cm to 6.35 cm long. Spiny amaranth can reach heights of 1.68 m and can be highly branched. The distinguishing spines are present on the plant at the base of leaf petioles and female flowering clusters. The spines, which are 5 mm to 10 mm long, are evident soon after emergence. Seedheads occur at the terminal ends of stems and in small clusters at the leaf axils (Virginia Tech Weed Identification Guide). Male flowers are occur on branches at the top of the plant and female flowers occur on branches at the middle and bottom of the plant (Pratt et al., 1999). Seeds are black, smooth, shiny and 0.7mm to 1mm in diameter (Bryson and DeFelice, 2009 and eFloras, 2008). Spiny amaranth is a prolific seed producer and can produce as many as 114,000 seeds on a single plant (Sellers et al., 2003 and Chauhan and Johnson, 2009).

Germination of small seeded annuals can sometimes be difficult. Steckel et al. (2004) reported that spiny amaranth seeds react positively under an alternating temperature regimen at 20, 25 and 30 C and adversely at 35 C and no germination occurs at 5, 10 and 15 C. When temperatures were held constant spiny amaranth seed had significant germination at 30 C and 35 C. Alternating temperatures increased spiny amaranth germination because alternating temperatures are most similar to diurnal temperature responses (Steckel et al., 2004). Santelmann and Evetts (1971) observed that spiny amaranth seed germinated in a shorter amount of time under alternating temperatures and germinated best when treated with sulfuric acid (H_2SO_4).

Spiny Amaranth Control

As a summer annual, spiny amaranth can be a difficult to control weed primarily in over grazed pastures. As with some pasture weeds, mowing is not an effective option for controlling spiny amaranth since it can also grow prostrate. Herbicide options recommended for spiny amaranth control in pastures are Cimarron® (metsulfuron), Cimarron Max® (metsulfuron + 2,4-D+ dicamba), Banvel® (dicamba), 2,4-D, Weedmaster® (dicamba + 2,4-D), Milestone® (aminopyralid) or ForeFront R&P® (aminopyralid + 2,4-D) applied from May to July (Green et al. 2006).

Fritz and Hartwig (1986) conducted a study on spiny amaranth control in permanent Kentucky bluegrass (*Poa pratensis* L.) pastures in Pennsylvania using continuous and rotational grazing and nine herbicide treatments. They observed 2,4-D and dicamba effectively controlled spiny amaranth; pendimethalin applied preemergence provided very little control, except for the rotationally grazed plots. Rotational grazing did not statistically increase spiny amaranth control; however spiny amaranth control was greater in rotationally grazed plots. Since spiny amaranth germinates throughout the summer Fritz and Hartwig (1986) concluded the best control option for spiny amaranth is two applications of 2,4-D or dicamba in combination with rotational grazing.

King et al. (2009) stated that spiny amaranth was most effectively controlled when plants are less than 5 cm in height. Eight weeks after treatment 80 percent or greater control was received with 14.03 g/ha Ally® (metsulfuron) when in combination with 1.75 L/ha of Redeem R&P® (triclopyr + clopyralid), 2.34 L/ha of 2,4-D, 2.34 L/ha of Grazon P+D® (picloram + 2,4-D), or 2.34 L/ha of PastureGard® (triclopyr + fluroxypyr). Ally® (metsulfuron) applied alone at 14.03 g/ha controlled spiny amaranth at 87 percent eight weeks after treatment and Redeem R&P® (triclopyr + clopyralid) applied alone at 2.34 L/ha per acre provided only 18 percent control (King et al., 2009).

Since spiny amaranth can continue to germinate after each rainfall event Ferrell and Sellers (2007) evaluated herbicide options that offer soil residual control. Telar® (chlorsulfuron) and Milestone® (aminopyralid) provided excellent control one month after treatment; however, new seedling plants had germinated in the treated area by three months after treatment (Ferrell and Sellers, 2007).

Research in Arkansas suggests spraying spiny amaranth before it reaches 30.5 cm. The following herbicides were listed as providing good to excellent control of spiny amaranth: Banvel® (dicamba), Cimarron® (metsulfuron), Cimarron Max® (metsulfuron + dicamba + 2,4-D), ForeFront R&P® (aminopyralid), Grazon P+D® (picloram + 2,4-D), Surmount® (picloram + fluroxypyr) and Weedmaster® (2,4-D + dicamba) (Boyd, 2008). In Tennessee, 2,4-D ester is considered to provide excellent control of spiny amaranth while 2,4-D amine and Grazon P+D® (picloram + 2,4-D) provided good control and Redeem R&P® (triclopyr + clopyralid) provided poor control (Rhodes et al, 2005).

Although spiny amaranth is not the most common pigweed species that can be problematic in row crops, it does occur. In row crops spiny amaranth can be controlled with a multitude of herbicides. Best control is achieved when a soil applied herbicide is followed by a post emergence herbicide or when a post applied herbicide is followed by another post applied herbicide that offers some residual control (Steckel, 2004). For control of spiny amaranth in corn, atrazine containing products will provide contact and residual control on small pigweeds. Dual II Magnum® (S-metolachlor), Cinch® (S-metolachlor), Degree® (acetochlor), Harness® (acetochlor), Outlook® (dimethenamid-P), Frontier® (dimethenamid-P) and FulTime® (acetachlor + atrazine) are in many premixes and also provide residual control. Spiny amaranth can be controlled post emergence in corn with plant growth regulator herbicides such as Distinct® (diflufenzopyr + dicamba), Clarity® (dicamba) and 2,4-D (Steckel, 2004). Residual control of spiny amaranth in soybeans can be achieved with Dual® (metolachlor), Prowl® (pendimethalin) and Spartan® (sulfentrazone). At 10 cm of height or smaller diphenyl ethers such as, Reflex®, Blazer® and Cobra® will control pigweeds. For conventional-till soybeans Treflan® (trifluralin) can be used to control pigweeds. Lastly, the use of Roundup Ready corn and soybeans can be used to control pigweeds, because Roundup® (glyphosate) is very effective at controlling various pigweed species (Steckel, 2004).

2,4-D

Whether used alone or in a pre-mix with other herbicide active ingredients 2,4-D is one of the most widely used herbicides for broadleaf weed control in the world (Szmedra, 1997). It is labeled for use in many agronomic crops, pastures, turf, home lawns and aquatics (Senseman et al., 2007). 2,4-D belongs to the chemical family of phenoxy herbicides and is synthetic auxin. For pastures 2,4-D is labeled at 0.28 to 2.24 kg ae/ha use rate. It is not considered a persistent herbicide because it has a relatively quick half-life of 10 days. 2,4-D is transported throughout the plant by the symplastic pathway and accumulates at the growing points of the shoots and roots (Senseman et al., 2007).

Aminocyclopyrachlor

Aminocyclopyrachlor (MAT 28) is an experimental herbicide developed by DuPont Crop Protection. It belongs to the family of herbicides known as synthetic auxins and belongs to the class of herbicides referred to as pyrimidine carboxylic acids (DuPont, 2009). Aminocyclopyrachlor has shown to be effective at controlling many broadleaf weeds and brush species at rates of 70 to 140 g ai/ha (DuPont, 2009). Proposed uses of aminocyclopyrachlor are on non-cropland areas, industrial sites, pastures and rangeland. Aminocyclopyrachlor is readily absorbed by plant leaves and roots; it is translocated in the xylem and phloem and accumulates in the meristematic areas of the plant (DuPont, 2009). Degradation of aminocyclopyrachlor is relatively slow. Bareground studies indicated the half-life ranged from 72 to 128 days (DuPont, 2009).

Aminopyralid

Aminopyralid is a recently developed herbicide registered for use in pastures, rangeland, industrial vegetation management, wheat and rice (Senseman et al., 2007). Aminopyralid is a systemic post emergence herbicide effective at controlling many broadleaf weeds at rates between 53 and 120 g ae/ha (Burch et al., 2005). Some residual control of broadleaf weeds may also be provided using aminopyralid. The Milestone® (Dow AgroSciences, 2008) herbicide label states “use a higher use rate in the rate range when residual control is desired”. Preemergence control of susceptible germinating seeds is also provided following an application of aminopylraid (Dow AgroSciences, 2008)

Aminopyralid belongs to the chemical family of pyridine carboxylic acid and has an auxinic mode of action (Masters et al., 2005 and Senseman et al., 2007). Aminopyralid is absorbed by leaves and roots and transported in the phloem and xylem where it accumulates in meristematic tissue (Senseman et al., 2007). Aminopyralid degrades in soil with a half-life of about 34 days (Masters et al., 2005 and Senseman et al., 2007). The majority of warm and cool season pastures grasses are tolerant to aminopyralid at 240 g ae/ha, which is twice the labeled use rate (Burch et al., 2005).

Aminopyralid is recommended for use on permanent grass pastures and hayfields because many desirable legumes and broadleaf crops are highly susceptible to aminopyralid. The herbicide label for Milestone® (Dow AgroSciences, 2008) also recommends not to plant a desirable broadleaf crop after treating the field with aminopyralid until an “adequately sensitive field bioassay shows that the level of aminopyralid present in the soil will not adversely affect that broadleaf crop” (Dow AgroSciences, 2008)

Witt and Blair (2007) evaluated clover tolerance to aminopyralid applied in fall or late winter. They reported that when aminopyralid was applied in September or November and clover seeded the following March, clover yield did not significantly differ from the untreated control. On the other hand, when herbicide treatments were applied in March and clovers are seeded two weeks later the aminopyralid treatment significantly reduced clover yield compared to the untreated control. Weedmaster® (2,4-D + dicamba) and 2,4-D did not significantly reduce clover yield compared to the untreated control (Witt and Blair, 2007).

Renz (2007) observed similar results to that of Witt and Blair (2007); alfalfa and white clover frequency was less in plots treated with aminopyralid compared to the other treatments. Grass establishment was not reduced when seeded the spring following a fall application of aminopyralid, conversely, enough aminopyralid persisted to reduce the establishment of legumes (Renz, 2007).

Aminopyralid is in the same family as clopyralid and picloram, which are two residual herbicides known to have herbicide carryover problems. Clopyralid is an herbicide that closely resembles aminopyralid in chemical structure. The only difference is the amine group on the fourth position of the pyridine ring (Wood, 1995 and Bukun et al., 2009). Aminopyralid is also very similar to picloram in chemical structure. The only difference in herbicide structure between aminopyralid and picloram is the third chlorine at the fifth position on the pyridine ring of picloram (Wood, 1995). Little research has been done to compare aminopyralid and picloram in the soil or plant. Picloram can persist in the soil for over a year. In a study conducted by Keys and Friesen (1968) picloram applied at rates of 73.1, 146.2 and 219.2 mL/ha retained 50 to 75 percent activity when sampled two and a half months later and 10 percent activity when sampled fifteen and a half months later. On three soils from Oklahoma, picloram had a half life greater than 100 days (Altom and Stritzke, 1973). The percent of the original concentration that remained in the soil 100 days after treatment was 63 to 77 percent (Altom and Stritzke, 1973).

One of the most important factors affecting the fate of herbicides in soils is adsorption (Bukun et al., 2010). Plant availability, efficacy and degradation rate are all correlated to an herbicides adsorption potential in soil. Bukun et al. 2010 compared the soil adsorption of aminopyralid and clopyralid and reported that aminopyralid adsorbed more tightly to six of the eight soils tested than did clopyralid. Aminopyralid Kd adsorption values ranged from 0.106 to 0.697 and 0.083 to 0.364 for clopyralid (Bukun et al., 2010). For both aminopyralid and clopyralid Pearson correlation analysis suggest that binding was highly correlated to soil organic matter and texture but not to soil pH (Bukun et al., 2010).

When comparing absorption and translocation of aminopyralid and clopyralid in Canada thistle (*Cirsium arvense* L.), clopyralid has a significantly greater foliar absorption than aminopyralid; and significantly more clopyralid translocated out of the treated leaf than aminopyralid (Bukun et al., 2009). Aminopyralid absorption was much slower than clopyralid absorption. Aminopyralid did not reach maximum absorption until 96 hours after treatment; whereas, clopyralid reached maximum absorption 24 hours after treatment. Bukun et al., 2009 noted the greater biological activity associated with aminopyralid compared to clopyralid is not due to greater absorption and translocation.

There have been some problems with herbicide carryover of picloram, clopyralid and aminopyralid in hay, manure, compost and grass clippings. The herbicide passes through the animal's digestive tract and is excreted in urine and manure without being broken down (Davis et al., 2010). If the compost containing parts of crops treated with one of these herbicides, manure of animals grazing treated pastures and hay from treated fields is moved off site there is a very good possibility broadleaf crops could be injured due to the indirect exposure of picloram, clopyralid and aminopyralid (Davis et al., 2010). Boydston (1994) observed that clopyralid persisted in spearmint hay treated in the fall at rates of 0.28 and 0.43 kg/ha to injure potato when planted in soils amended with the spent spearmint hay. Clopyralid injures potatoes at rates as low as 0.003 ppm (Boydston, 1994). There was a direct relationship between potato injury and the amount of clopyralid treated spearmint hay from 3 to 50 g/kg soil (Boydston, 1994). Soil amended with 3 g/kg soil spearmint hay had similar injury symptoms to 0.0125 ppm of clopyralid.

Dicamba

Dicamba is a synthetic auxin in the benzoic acid herbicide family; its behavior in plants is similar to that of 2,4-D (Senseman et al., 2007). In the plant dicamba is transported by the symplastic and apoplastic pathways and accumulates in the growing points. Much like that of 2,4-D, dicamba is applied as a foliar herbicide (Senseman et al., 2007). Dicamba has a half-life of less than 14 days (Senseman et al., 2007). Dicamba is a commonly used herbicide for the control of annual broadleaf weeds. In pastures dicamba has a labeled use rate of 0.28 to 2.24 kg ae/ha.

Pendimethalin

Unlike the previous herbicides discussed pendimethalin is in the dinitroaniline herbicide family. Pendimethalin primarily controls weedy grasses but can also be used to control certain broadleaf weeds such as pigweeds and lambsquarters. Pendimethalin is a soil applied herbicide that is absorbed by the roots and coleoptiles of germinating plants (Senseman et al., 2007). It can be applied pre-plant, pre-plant incorporated or early post planting. Currently, pendimethalin is not labeled for use in pastures but registered by the Environmental Protection Agency for use in turf and several agronomic crops such as corn and soybean at a use rate of 0.84 to 2.24 kg ai/ha (Senseman et al., 2007). Pendimethalin is generally used as a residual herbicide because it does persist longer in the soil with a half-life of 44 days (Senseman et al., 2007). Cultivation practices, soil temperature, soil moisture and soil type all influence the persistence of pendimethalin (Zimdahl et al., 1984). As temperature decreased and soil water content decreased pendimethalin degradation decreased. The rate of pendimethalin degradation did not vary as much between soil types, therefore it was concluded that soil temperature and moisture have a greater influence on persistence than does soil type (Zimdahl et al., 1984).

Chapter 2: Herbicide Application Timing for Control of Spiny Amaranth

Introduction

In Kentucky, spiny amaranth is most prevalent in over grazed pastures. It can be a very difficult weed to control because it has an extended germination period from April to September. Spiny amaranth seed may germinate each time it rains. Mowing is not an effective option for control because once mowed spiny amaranth starts growing prostrate and still produces viable seed. Therefore, herbicides can be a more effective option to control spiny amaranth, than mowing.

Since spiny amaranth has the ability to germinate over an extended period of time, more than one herbicide application is often needed for effective control. According to Steckel (2004), pigweed species in row crops are best managed when a pre-applied herbicide is followed by a post applied herbicide or when a post applied herbicide is followed by another post applied herbicide, which contains a residual product. Ferrell and Sellers (2007) also reported that it may be necessary to make two to three herbicide applications to effectively control spiny amaranth all season long in pastures.

This study was conducted to evaluate herbicide options for spiny amaranth control in Kentucky pastures. The herbicides used in this study were chosen based on their post-emergence and potential residual activity.

The objectives of this study were to (1) evaluate herbicide options for spiny amaranth control, (2) determine the effect of time of application on spiny amaranth control, and (3) determine if herbicides applied before spiny amaranth emergence would provide residual control.

Materials and Methods

An experiment was conducted to evaluate time of herbicide application spiny amaranth control. The experiment was initiated in the fall of 2008 at Spindletop Research Farm near Lexington, Kentucky and the West Kentucky Research and Education Center near Princeton, Kentucky.

The experimental site at Spindletop was a Maury silt loam (fine, mixed, mesic Typic Paleudult) which consisted of a long-term grass sod that was removed before planting of spiny amaranth. The experimental site at Princeton was a Crider silt loam (fine-silty, mixed, mesic Typic Paleudult). The previous crop was corn that was harvested from the site in 2007; the site was fallow until planting of spiny amaranth in November of 2008. In September of 2008 both experimental sites were prepared for planting spiny amaranth. Glyphosate was applied at a rate of 7 L/ha to control existing vegetation at both locations. Both sites were then plowed and disked to create an optimal seed bed.

Spiny amaranth seed were collected in August, September and October of 2008 on two livestock farms located in: Fayette County, Kentucky and Barren County, Kentucky. Seed were harvested by cutting the spiny amaranth at the base of the plant; and seed allowed to air dry before removal from the plant. Seeds were sieved to remove plant material and other debris. The Spindletop location was planted with spiny amaranth seed collected from the Fayette County site. The Princeton location was planted with a mixture of spiny amaranth seed from Fayette and Barren counties.

At both locations the experimental design was a split-split plot with four replications at Spindletop and three replications at Princeton. Seeding date was the main plot, herbicide application dates sub-plots, and herbicide treatments sub-sub plots. Individual plot size was 1.5 m by 4.6 m.

In November 2008 (Table 2.1) half the total plot area at each location was seeded with spiny amaranth. Spiny amaranth seeds were hand-planted in single rows for plot establishment. Remaining seed were stored in a non-heated storage building throughout the winter months until seeding in March. In March of 2009 (Table 2.1) the remaining plot area was seeded in the same manner.

Herbicides were applied in November 2008, and March, April, May and June 2009 (Table 2.1). Treatments consisted of: 2,4-D ester at 1.1 kg ae/ha (applied as Weedone LV4®), dicamba at 0.56 kg ae/ha (applied as Banvel®), pendimethalin at 1.6 kg ai/ha (applied as Prowl H_20®), aminopyralid at 120 g ae/ha (applied as Milestone®), and aminocyclopyrachlor at 70 g ae/ha (applied as MAT 28) plus an untreated control. Nonionic surfactant was added to the aminopyralid and aminocyclopyrachlor treatments at 0.25% v/v. Herbicide treatments were applied during the middle of the month for each application date (Table 2.1). All herbicides were applied using a CO_2 pressurized sprayer with a 1.5 meter boom delivering 140 L/ha.

Emergence of spiny amaranth was first noted the first week of May for Lexington and the second week of May for Princeton; therefore, spiny amaranth had not emerged before the April application date but had begun to emerge before the May application date. Spiny amaranth had reached an average height of 51 cm for Lexington by the June application date. Spiny amaranth at the June application date in Princeton ranged from 25 cm to 64 cm.

Visual control ratings were recorded and spiny amaranth height measured in July of 2009 (Table 2.1). Visual control ratings were made using a 0 to 10 scale (0 equals no visual control and 10 equals complete visual control). Spiny amaranth control was compared to the untreated control plots. Visual control ratings were made in July (Table 2.1) approximately seven weeks after the May application date and three weeks after the June application date. Visual control ratings were converted to percentages for ease of analyzing data and understanding the level of control obtained. Individual plant height measurements were taken as three subsamples at designated points along the length of each plot. Fresh weight was determined in August of 2009 (Table 2.1) using a small plot forage harvester. Before harvest 1.5 meters were removed from the end of each plot using a 4-wheeler and pull behind mower, resulting in a harvested area of 1.5 m by 3 m from each plot.

Data were initially analyzed using PROC MIXED of SAS to determine any interactions or differences among treatments of factors evaluated. There was a site x application date x treatment interaction for each of the three measured parameters; as a result, all data were analyzed by location. No interaction was detected within the November or March planting date for Princeton therefore planting dates were combined and analyzed. However, there was a significant interaction within the November and March planting dates for Lexington; therefore, planting dates were analyzed separately. An LSD mean separation test in PROC ANOVA of SAS at the 0.05 significance level was used to compare treatment means for each measured parameter. A log transformation of percent control data were made before analysis. Mean separations were determined from the transformed data but the percent visual control data are presented in the tables for ease of understanding.

Table 2.1 Dates for spiny amaranth seeding, herbicide applications and data collection for Lexington and Princeton

	Location	
	Lexington	***Princeton***
Seeding	10 November 2008 19 March 2009	20 November 2008 18 March 2009
Herbicide Application Dates	10 November 2008 19 March 2009 24 April 2009 15 May 2009 19 June 2009	20 November 2008 18 March 2009 22 April 2009 15 May 2009 17 June 2009
Spiny Amaranth Height	7 July 2009	9 July 2009
Visual Control Rating	7 July 2009	9 July 2009
Harvest	14 August 2009	21 August 2009

Results and Discussion

Lexington

An interaction was observed for planting date x application date x herbicide treatment for percent control and fresh weight. For height, there was not an interaction for planting date x application date x treatment but planting date and planting date x application date were both significant. Therefore, data were analyzed both by application date and by herbicide treatments.

Treatment was significant for percent control across both planting dates and all application dates. Pendimethalin applied in November and March provided significantly higher percent control for both planting dates (Table 2.2 and 2.3). Pendimethalin applied in April also provided 80 percent control, but did not differ from the aminocyclopyrachlor treatments for both planting dates and aminopyralid treatment for the November planting. Aminopyralid applied in May provided 88 percent control and 2,4-D provided 83 percent control, however, these were not statistically different from the aminocyclopyrachlor (78%) and dicamba (68%) treatments for the November planting date (Table 2.2). In June, 80 percent control or greater was provided by 2,4-D, aminopyralid and dicamba (Table 2.2). For the March planting date and April application date all herbicide treatments were statistically different from the untreated control, however, the greatest control was attained with pendimethalin (80%) (Table 2.3). All herbicides applied in May and June significantly differed from the untreated control but the greatest control was with 2,4-D, aminocyclopyrachlor, aminopyralid and dicamba treatments (Table 2.3).

Application date was significant across each herbicide treatment except aminocyclopyrachlor and pendimethalin for the November planting date. Application date was significant for each herbicide treatment, for the March planting date. The greatest control with dicamba and aminopyralid were the May and June applications for the November planting date (Table 2.2). Spiny amaranth control with pendimethalin applied in November, March and April did not significantly differ from each other at both planting dates for percent control (Table 2.2 and 2.3). For the March planting date pendimethalin treatments applied in November, March and April did differ from pendimethalin treatments applied in May and June for percent control (Table 2.3). Aminocyclopyrachlor and aminopyralid applied in April, May and June statistically differed from treatments applied in November and March at the March planting date (Table 2.3).

Spiny amaranth height measurements were significant for the November and March planting dates across all application dates. For the November planting date aminocyclopyrachlor, pendimethalin and the untreated control did not differ by application date but 2,4-D, dicamba and aminopyralid differed (Table 2.4). Pendimethalin applied in November and March greatly reduced spiny amaranth height compared to all other herbicide treatments for both planting dates (Table 2.4 and 2.5). In April plant height was reduced by pendimethalin and aminocyclopyrachlor compared to the untreated control. At the November planting date spiny amaranth height was reduced by all herbicide treatments in May, however, 2,4-D (10 cm), aminocyclopyrachlor (7cm) and aminopyralid (5cm) reduced spiny amaranth height the most (Table 2.4). In June the height of spiny amaranth was significantly reduced by 2,4-D (3 cm), dicamba (5 cm) and aminopyralid (7 cm) when compared to the other herbicide treatments (Table 2.4).

All herbicide treatments, except 2,4-D, reduced spiny amaranth height compared to the untreated control (63 cm) for the March planting date and April application date (Table 2.5). All herbicide treatments, except pendimethalin, reduced spiny amaranth height for the May application date (Table 2.5). In June 2,4-D (11 cm) provided the greatest reduction in spiny amaranth height followed by dicamba (21 cm) and aminopyralid (24 cm) (Table 2.5). The greatest level of stunting among the herbicides in the March planting occurred with pendimethalin applied in April.

Application date was significant for 2,4-D, dicamba and aminopyralid and not significant for aminocyclopyrachlor, pendimethalin and the untreated control for the November planting date. Spiny amaranth height for the March planting was impacted by application timing for all herbicide treatments except for the untreated control (Table 2.5). May and June applications of 2,4-D, aminopyralid or dicamba significantly limited growth of spiny amaranth compared to the November, March and April application dates for both planting dates (Table 2.4 and 2.5). Aminocyclopyrachlor reduced plant height at the May application date compared to the November and March application dates for both planting dates (Table 2.4 and 2.5).

Herbicide treatments differed for every application date across both planting dates for fresh weight. Pendimethalin applied in November, March and April provided the greatest reduction in fresh weight for both planting dates at Lexington (Table 2.6 and 2.7). The greatest reduction in fresh weight for the November planting date and May application date was aminocyclopyrachlor (10221 kg/ha) followed by 2,4-D and aminopyralid (Table 2.6). For the November planting date and June application date 2,4-D (4610 kg/ha), dicamba (3464 kg/ha) and aminopyralid (4269 kg/ha) all significantly reduced fresh weight compared to the untreated control (Table 2.2).

For the March planting date and April application date pendimethalin (9953 kg/ha) provided the greatest reduction in fresh weight followed by 2,4-D, aminocyclopyrachlor, aminopyralid and dicamba (Table 2.7). In May the greatest fresh weight reduction was provided by 2,4-D, aminocyclopyrachlor, aminopyralid and dicamba; however, pendimethalin was not statistically different from the untreated control (Table 2.3). Applied in June, 2,4-D (6659 kg/ha) and dicamba (9050 kg/ha) provided the greatest reduction in fresh weight followed by aminopyralid (Table 2.7).

Application date was significant across herbicide treatment except the untreated control for both planting dates for fresh weight. When treatments were compared across application date 2,4-D and aminopyralid significantly reduced fresh weight for the November planting date in June followed by May but there was no difference between the November, March and April application dates (Table 2.6). Aminocyclopyrachlor only differed in fresh weight for the May application date (Table 2.6). The June application of dicamba differed from all other application dates (Table 2.2). For pendimethalin, November and March did not significantly differ from each other; however, they did differ from the May and June application dates for the November planting date (Table 2.2).

For the March planting date aminopyralid treatments applied in May and June reduced fresh weight compared to treatments applied in November and March in Lexington (Table 2.7). Pendimethalin applied in November, March and April differed from pendimethalin treatments applied in May and June (Table 2.7). Spiny amaranth fresh weights for the March planting were significantly less for aminocyclopyrachlor applied in May compared with fresh weights for treatments applied in November, March or June (Table 2.7).

Table 2.2. Percent visual control of spiny amaranth planted in Lexington in November 2008

	Herbicide Application Date				
Herbicide	NOV	MAR	APR	MAY	JUN
	(%)				
2,4-D	28 BC b	5 D bc	30 C b	83 AB a	88 A a
Aminocyclopyrachlor	23 B b	25 AB b	58 AB ab	78 A a	50 AB b
Aminopyralid	25 B b	5 C bc	40 AB ab	88 A a	83 A a
Dicamba	18 B b	10 B b	8 B c	68 A a	80 A a
Pendimethalin	95 A a	73 AB a	80 A a	38 B b	40 AB b
Untreated control	0 A c	0 A c	0 A d	0 A c	0 A c

*Lower case letters represent statistical differences within columns by application date. Upper case letters represent statistical differences across rows by herbicide treatment.
**Mean with the same letter are not significantly different according to Fisher's Protected $LSD_{(0.05)}$
***Percent visual control recorded in July 2009.

Table 2.3 Percent visual control of spiny amaranth planted in Lexington in March 2009

	Herbicide Application Date				
Herbicide	NOV	MAR	APR	MAY	JUN
	---(%)---				
2,4-D	3 C b	0 C c	15 B d	65 A a	75 A a
Aminocyclopyrachlor	0 C b	15 B b	50 A ab	65 A a	43 A a
Aminopyralid	5 B b	5 B c	30 A bc	78 A a	47 A a
Dicamba	0 C b	0 C c	28 B cd	70 A a	44 AB a
Pendimethalin	50 A a	56 A a	80 A a	15 B b	8 B b
Untreated control	0 A b	0 A c	0 A e	0 A c	0 A c

*Lower case letters represent statistical differences within columns by application date. Upper case letters represent statistical differences across rows by herbicide treatment.
**Mean with the same letter are not significantly different according to Fisher's Protected $LSD_{(0.05)}$
***Percent visual control recorded in July 2009.

Table 2.4 Average height of spiny amaranth planted in Lexington in November 2008

	Herbicide Application Date				
Herbicide	NOV	MAR	APR	MAY	JUN
	----------------------------	-----------	(cm)	-----------	----------------------------
2,4-D	30 B a	50 A a	32 B ab	10 C c	3 C d
Aminocyclopyrachlor	36 A a	35 A b	20 AB b	7 B c	22 AB cb
Aminopyralid	39 AB a	48 A a	29 B ab	5 C c	7 C cd
Dicamba	44 A a	48 A a	49 A a	18 B bc	5 B d
Pendimethalin	1 B b	15 AB c	15 AB b	30 A b	23 A b
Untreated control	43 A a	35 A b	47 A a	52 A a	39 A a

*Lower case letters represent statistical differences within columns by application date. Upper case letters represent statistical differences across rows by herbicide treatment.
**Mean with the same letter are not significantly different according to Fisher's Protected $LSD_{(0.05)}$
***Spiny amaranth height measured in July 2009.

Table 2.5 Average height of spiny amaranth planted in Lexington in March 2009

	Herbicide Application Date				
Herbicide	NOV	MAR	APR	MAY	JUN
	--------------------(cm)--------------------				
2,4-D	67 A a	66 A a	57 A ab	22 B b	11 B e
Aminocyclopyrachlor	71 A a	59 A a	29 BC d	18 C b	31 B c
Aminopyralid	64 A a	63 A a	40 B cd	13 C b	24 C cd
Dicamba	69 A a	66 A a	49 B bc	16 C b	21 C d
Pendimethalin	38 AB b	29 B b	10 C e	50 A a	56 A b
Untreated control	70 A a	62 A a	63 A a	59 A a	65 A a

*Lower case letters represent statistical differences within columns by application date. Upper case letters represent statistical differences across rows by herbicide treatment.
**Mean with the same letter are not significantly different according to Fisher's Protected $LSD_{(0.05)}$
***Spiny amaranth height measured in July 2009.

Table 2.6 Fresh weight of spiny amaranth planted in Lexington in November 2008

	Herbicide Application Date				
Herbicide	NOV	MAR	APR	MAY	JUN
	----------(kg/ha)----------				
2,4-D	15466 AB b	20881 A a	18490 A ab	11050 B cd	4610 C c
Aminocyclopyrachlor	20320 A ab	18881 AB a	16197 B bc	10221 C d	17612 AB ab
Aminopyralid	20588 A ab	19173 A a	17027 A bc	11123 B cd	4269 C c
Dicamba	21857 A a	19588 A a	21808 A ab	19808 A ab	3464 B c
Pendimethalin	2366 B c	6635 B b	10855 AB c	16441 A bc	15295 A b
Untreated control	22808 AB a	17588 B a	24394 A a	25491 A a	21393 AB a

*Lower case letters represent statistical differences within columns by application date. Upper case letters represent statistical differences across rows by herbicide treatment.
**Mean with the same letter are not significantly different according to Fisher's Protected $LSD_{(0.05)}$
***Fresh weight measured in August 2009.

Table 2.7 Fresh weight of spiny amaranth planted in Lexington in March 2009

	Herbicide Application Date				
Herbicide	NOV	MAR	APR	MAY	JUN
	------------------------(kg/ha)------------------------				
2,4-D	24930 A a	20222 B a	1780 B b	13221 C c	6659 D d
Aminocyclopyrachlor	23540 A a	19173 B a	16539 BC b	13660 C c	18442 B b
Aminopyralid	20369 A a	21125 A a	17198 AB b	13807 B c	13392 B c
Dicamba	22003 A a	21418 A a	15466 B b	16636 B bc	9050 C d
Pendimethalin	13660 B b	9318 B b	9953 B c	19954 A ab	19759 A ab
Untreated control	22491 A a	19954 A a	25150 A a	23637 A a	22418 A a

*Lower case letters represent statistical differences within columns by application date. Upper case letters represent statistical differences across rows by herbicide treatment.
**Mean with the same letter are not significantly different according to Fisher's Protected $LSD_{(0.05)}$
***Fresh weight measured in August 2009.

Princeton

An interaction was not observed for percent control and fresh weight for planting date x application date x treatment. Conversely, there was an interaction for height for planting date x application date x treatment. However, planting date, planting date x application date and planting date x treatment were not significant. Therefore planting dates were combined for percent control, height and fresh weight and analyzed by application date and by treatment.

Treatment was significant across all application dates for percent control. Pendimethalin provided the greatest visual control of spiny amaranth for the November and March application dates yet the level of control did not exceed 32 percent (Table 2.8). All treatments provided less than 20 percent with the April application date. In May, aminopyralid provided 53 percent control (Table 2.8). In June, 82 percent control was achieved with 2,4-D but was not statistically different from the aminocyclopyrachlor (60%), aminopyralid (68%) or dicamba (65%) treatments (Table 2.8).

Application timing affected spiny amaranth control for all herbicides. June applications of 2,4-D, aminocyclopyrachlor and dicamba significantly differ from all other application dates (Table 2.8). May and June applications of aminopyralid significantly differed from November, March and April applications for percent visual control (Table 2.8).

Application timing of all herbicides also affected height of spiny amaranth (Table 2.9). Spiny amaranth height was reduced for pendimethalin for the November, March and May application dates compared to the June application date (Table 2.9). Aminocyclopyrachlor (69 cm) reduced spiny amaranth height the greatest in April but was not different from the pendimethalin (79 cm) treatment (Table 2.9). In May all herbicide treatments significantly reduced plant height except pendimethalin; the greatest reduction was with aminopyralid (Table 2.9). Applied in June, 2,4-D (17 cm) provided the greatest reduction in spiny amaranth height compared to all other treatments but was not statistically different from aminopyralid (27 cm) (Table 2.9).

When analyzed by treatment, application date was significant for every herbicide treatment except pendimethalin. June applications of 2,4-D, dicamba and aminocyclopyrachlor statistically differed from all other application dates. May and June applications of aminopyralid significantly differed from November, March and April applications for plant height (Table 2.9).

For fresh weight measurements herbicide treatment differed for every application date except April. Pendimethalin compared to other herbicides applied in November provided the lowest fresh weight; all other herbicide treatments except 2,4-D were not statistically different from the untreated control (Table 2.10). Pendimethalin (16885 kg/ha) applied in March reduced fresh weight the greatest but did not differ from 2,4-D (19851 kg/ha) and dicamba (21966 kg/ha) (Table 2.10). Aminopyralid, 2,4-D and dicamba reduced fresh weight when applied in April (Table 2.10). All herbicide treatments except 2,4-D and dicamba differed from the untreated control when applied in May (Table 2.10). The greatest reduction in fresh weight in June was provided by 2,4-D (11440 kg/ha) but was not statistically different from dicamba (15691 kg/ha) (Table 2.10). June applications of 2,4-D differed from all other herbicide treatments; dicamba was comparable to aminocyclopyrachlor (Table 2.10).

Application date was significant for 2,4-D and dicamba and was not significant for aminopyralid, aminocyclopyrachlor, pendimethalin and the untreated control. When applied in June, 2,4-D and dicamba were significantly different from all other application dates (Table 2.10). The March application of pendimethalin resulted in lower fresh weight compared to the June application date (Table 2.10).

Table 2.8 Percent visual control of spiny amaranth planted in Princeton combined across planting dates in November 2008 and March 2009

	Herbicide Application Date				
Herbicide	NOV	MAR	APR	MAY	JUN
	---(%)---				
2,4-D	0 D b	3 CD b	7 C b	27 B bc	82 A a
Aminocyclopyrachlor	0 C b	2 C b	17 B a	23 B ab	60 A a
Aminopyralid	0 C b	0 C b	8 B ab	53 A a	68 A a
Dicamba	0 C b	0 C b	3 C bc	23 B bc	65 A a
Pendimethalin	32 A a	28 A a	17 A a	12 AB c	3 B b
Untreated control	0 A b	0 A b	0 A c	0 A d	0 A c

*Lower case letters represent statistical differences within columns by application date. Upper case letters represent statistical differences across rows by herbicide treatment.
**Mean with the same letter are not significantly different according to Fisher's Protected $LSD_{(0.05)}$
***Percent visual control recorded in July 2009.

Table 2.9 Average height of spiny amaranth planted in Princeton combined across planting dates in November 2008 and March 2009

	Herbicide Application Date				
Herbicide	NOV	MAR	APR	MAY	JUN
	---(cm)---				
2,4-D	108 A a	99 AB a	90 B bc	65 C b	17 D c
Aminocyclopyrachlor	107 A a	102 A a	69 B d	60 B b	37 C b
Aminopyralid	101 A a	105 A a	94 A ab	33 B c	27 B bc
Dicamba	108 A a	106 A a	97 A ab	67 B b	31 C b
Pendimethalin	74 B b	68 B b	79 AB cd	77 B ab	100 A a
Untreated control	104 A a	104 A a	104 A a	93 B a	100 AB a

[*]Lower case letters represent statistical differences within columns by application date. Upper case letters represent statistical differences across rows by herbicide treatment.
[**]Mean with the same letter are not significantly different according to Fisher's Protected $LSD_{(0.05)}$
[***]Spiny amaranth height measured in July 2009.

Table 2.10 Fresh harvest weight of spiny amaranth planted in Princeton combined across planting dates in November 2008 and March 2009

	Herbicide Application Date				
Herbicide	NOV	MAR	APR	MAY	JUN
	----(kg/ha)----				
2,4-D	25048 A b	19851 A ab	21899 A b	26329 A abc	11440 B c
Aminocyclopyrachlor	27959 A ab	23006 AB a	22731 AB b	21612 AB c	19004 B b
Aminopyralid	28066 A ab	22645 A a	24606 A ab	23123 A bc	24037 A a
Dicamba	26705 AB ab	21966 B ab	25242 AB ab	28105 A ab	15691 C bc
Pendimethalin	19522 AB c	16885 B b	20935 AB b	21489 AB c	25847 A a
Untreated control	29929 A a	24449 A a	28733 A a	30630 A a	24930 A a

*Lower case letters represent statistical differences within columns by application date. Upper case letters represent statistical differences across rows by herbicide treatment.
**Mean with the same letter are not significantly different according to Fisher's Protected $LSD_{(0.05)}$
***Spiny amaranth height measured in July 2009.

Conclusions

All herbicide treatments applied before spiny amaranth emergence (November, March and April) provided very little to no control except for pendimethalin. Pendimethalin applied before spiny amaranth emergence consistently provided the greatest control and reduced spiny amaranth growth relative to other herbicides evaluated. These results differ from Fritz and Hartwig (1986), who reported pendimethalin had very little control when applied pre-emergence. After spiny amaranth had emerged, pendimethalin was inferior to other herbicide treatments.

Aminocyclopyrachlor was most effective at controlling spiny amaranth when applied soon after emergence. Aminocyclopyrachlor applied in May reduced plant height and fresh weight the greatest compared to all other application dates.

Later in the growing season spiny amaranth was best controlled with 2,4-D or dicamba. When applied in June, 2,4-D provided at least 75 % or better control of spiny amaranth. Plant height and fresh weight were statistically less with 2,4-D and dicamba treatments compared to all other herbicide treatments applied in June. These results were similar to Fritz and Hartwig (1986), who reported that 2,4-D or dicamba effectively controlled spiny amaranth. Although they believe the best control option for spiny amaranth is two applications of of 2,4-D or dicamba in combination with rotational grazing.

Aminopyralid provided little to no residual control when applied before spiny amaranth emergence. After spiny amaranth emergence aminopyralid did provide partial control and reduced plant height and fresh weight. Conversely, other herbicide treatments provided better control and were more effective at reducing spiny amaranth height and fresh weight. Ferrell and Sellers (2007) observed that aminopyralid had little residual control on spiny amaranth. To receive season long control with aminopyralid multiple applications would have to be made, as aminopyralid is most effective on small spiny amaranth plants and does not provide effective residual control.

Future research on spiny amaranth control should include evaluation of different application rates with residual herbicides such as pendimethalin. Application rates of newer herbicides such as aminocyclopyrachlor should also be evaluated to determine if greater control of spiny amaranth can be achieved.

Chapter 3: Aminopyralid Persistence

Introduction

Soil residual herbicides are generally applied before weed emergence and often used to provide weed control throughout the entire growing season of a crop. Herbicide persistence is very important from the aspect of long-term weed control; however, herbicide carryover may be problematic. Herbicide carryover is undesirable when herbicide residues persist long enough to injure sequential crops. Herbicide carryover problems are most often localized and short-term problems are usually associated with specific cropping sequences (Walker, 1987).

Herbicide persistence is not only variable among different herbicides but also varies by location with the same herbicide. Walker (1987) explained that herbicide degradation is a function of its molecular structure and is influenced by soil and weather conditions which vary from site to site and year to year. Soil factors which affect herbicide persistence are organic matter, pH and clay content and texture (Walker, 1987). Climatic factors which influence degradation rate are soil temperature and moisture content. Generally, as temperature and moisture increase, herbicide persistence decreases. Herbicide degradation tends to be more variable with changes in soil moisture than changes in soil temperature (Walker, 1987).

Aminopyralid has the ability to persist in the soil for long periods of time. The label for aminopyralid containing products (Milestone®, ForeFront R&P®) (Dow AgroSciences, 2008) clearly state "do not rotate to any crop from rangeland, permanent grass pasture or CRP acres within one year following treatment. Do not plant a broadleaf crop until an adequately sensitive field bioassay shows that the level of aminopyralid present in the soil will not adversely affect that broadleaf crop."

There have been instances in Kentucky where aminopyralid has persisted in soil and injured sensitive crops such as tobacco and soybean. The objectives of this study were 1) to examine the growth response of soybean as a bioassay crop for determining aminopyralid concentration in soil, and 2) determine the time required for aminopyralid dissipation in soil under field conditions.

Materials and Methods

In March 2009 an herbicide dissipation study was initiated, to study the rate of aminopyralid degradation from two Kentucky soils; a Maury silt loam (fine, mixed, mesic Typic Paleudult) near Lexington, KY and a Crider silt loam (fine-silty, mixed, mesic Typic Paleudult) near Princeton, KY. Aminopyralid was applied at a rate of 120 g ae/ha on March 18 and 19, 2009 for Princeton and Lexington, respectively. Individual plot size was 1.5 x 4.6 meters with four replications in Lexington and three replications in Princeton. Soil samples were collected at time 0 (the time of herbicide application in March), 1, 2, 4, 8, 16, 32 and 52 weeks after application (Table 3.1). Two sub-samples were collected from each plot in a random, pre-determined pattern and thoroughly mixed to create a composite sample of approximately 2000 g from each plot. Soil samples were taken with a 10 cm diameter probe to a depth of 10 cm. Additional soil samples were also collected from untreated control plots in the same manner. Collected samples were stored in labeled polyethylene bags and frozen until a residue analysis was conducted.

Soil samples were analyzed in the greenhouse using a plant bioassay procedure. Frozen soil samples were allowed to air dry and prepared with a soil grinder to obtain a consistent soil aggregate size. From the composite sample 1000 g of dry soil was measured and divided among four pots of 225 g each; therefore, 16 individual pots per sampling date were used at Lexington and 12 individual pots at Princeton to determine the aminopyralid concentration for each soil sample date. Soil samples taken from the untreated control plots were used to dilute soil samples from the aminopyralid treated plots to achieve an herbicide concentration within the limits of the standard curve (Table 3.2). A 1:20 dilution was made using 50 g treated soil and 950 g of untreated soil (Table 3.2). The 1:10 dilution was prepared using 100 g treated soil and 900 g untreated soil (Table 3.2).

Three soybean seeds (‘Shiloh’ S080120 LL) were planted in each pot and allowed to grow in the greenhouse for four weeks. Pots were watered daily at approximately 25 mL to maintain field capacity. Soybeans were harvested by cutting the stem at the base of each plant near the soil surface. Fresh and dried plant samples were weighed for analysis. Harvested soybean plants were oven dried for 24 hours at 60 C to measure dry weight. Since dry weight provided on overall better fit, dry weight was used to calculate the standard curve from known soil concentrations and aminopyralid concentrations in soil sampled throughout the year from field sites.

Aminopyralid concentrations of 0, 0.125, 0.25, 0.5, 1, 2 and 4 ppb (eight replications per concentration) were run for each set of soil samples (Figures 3.1 and 3.2) to develop the standard curve. The average per plant dry weight from each concentration was graphed and a line of best fit determined. A linear equation was then used to calculate the unknown herbicide concentration from the soil samples collected from the field at each location. For Lexington three standard curves were ran, the slopes ranged from -0.032 to -0.044 with R^2 values of 0.72 to 0.87 (Figure 3.1). All three Lexington standard curves were averaged to calculate the week 1 soil sample concentrations (Figure 3.1). Week 1 soil sample concentrations for Lexington were calculated from an average of all three standard curves because week 1 had to be re-run at a lower dilution. Since all soil sample dates were ran simultaneously, only one standard curve was used for the Princeton location; which had a slope of -0.078 and an R^2 of 0.89 (Figure 3.2). Half-life of herbicide concentration in the soil was determined using first-order reaction kinetics. The integrated form of the first-order reaction kinetic equation is $\ln C = \ln C_0 - kt$ where C and C_0 are herbicide concentrations at time t and time 0 and k is the rate constant (Walker 1987). The first order rate constant, k is the slope of the line resulting from the regression of the natural log (ln) herbicide concentration remaining in soil over time. When t is assumed to be the time taken for 50% disappearance, half -life is calculated from the equation $t_{1/2} = \ln 2/k$ (Walker 1987).

Table 3.1 Soil sample collection dates for Lexington and Princeton

	Collection Date	
Sample	*Lexington*	*Princeton*
Application Date / Time 0	19 March 2009	18 March 2009
1 week	27 March 2009	26 March 2009
2 weeks	3 April 2009	2 April 2009
4 weeks	24 April 2009	22 April 2009
8 weeks	15 May 2009	13 May 2009
16 weeks	8 July 2009	9 July 2009
32 weeks	30 October 2009	29 October 2009
52 weeks	17 March 2010	18 March 2010

Table 3.2 Dilutions used and planting to harvest dates for each collected soil sample

		Date from planting to harvest	
Sample	**Dilution**	Lexington	Princeton[4]
Time 0	1:20	16 Mar to 13 Apr[1]	10 May to 9 Jun
1 week	1:10	10 May to 9 Jun[*]	10 May to 9 Jun
2 weeks	1:10	31 Mar to 28 Apr[2]	10 May to 9 Jun
4 weeks	1:10	31 Mar to 28 Apr[2]	10 May to 9 Jun
8 weeks	No dilution	21 Apr to 20 May[3]	10 May to 9 Jun
16 weeks	No dilution	21 Apr to 20 May[3]	10 May to 9 Jun
32 weeks	No dilution	21 Apr to 20 May[3]	10 May to 9 Jun
52 weeks	No dilution	21 Apr to 20 May[3]	10 May to 9 Jun

[1] Ran with standard curve 1 (LEX) [2] Ran with standard curve 2 (LEX) [3] Ran with standard curve 3 (LEX) [4] Ran with standard curve 4 (PRN) [*] standard curves 1,2 and 3 combined to calculate herbicide concentrations for week 1

Figure 3.1 Slope of standard curves and correlating R^2 values for Lexington

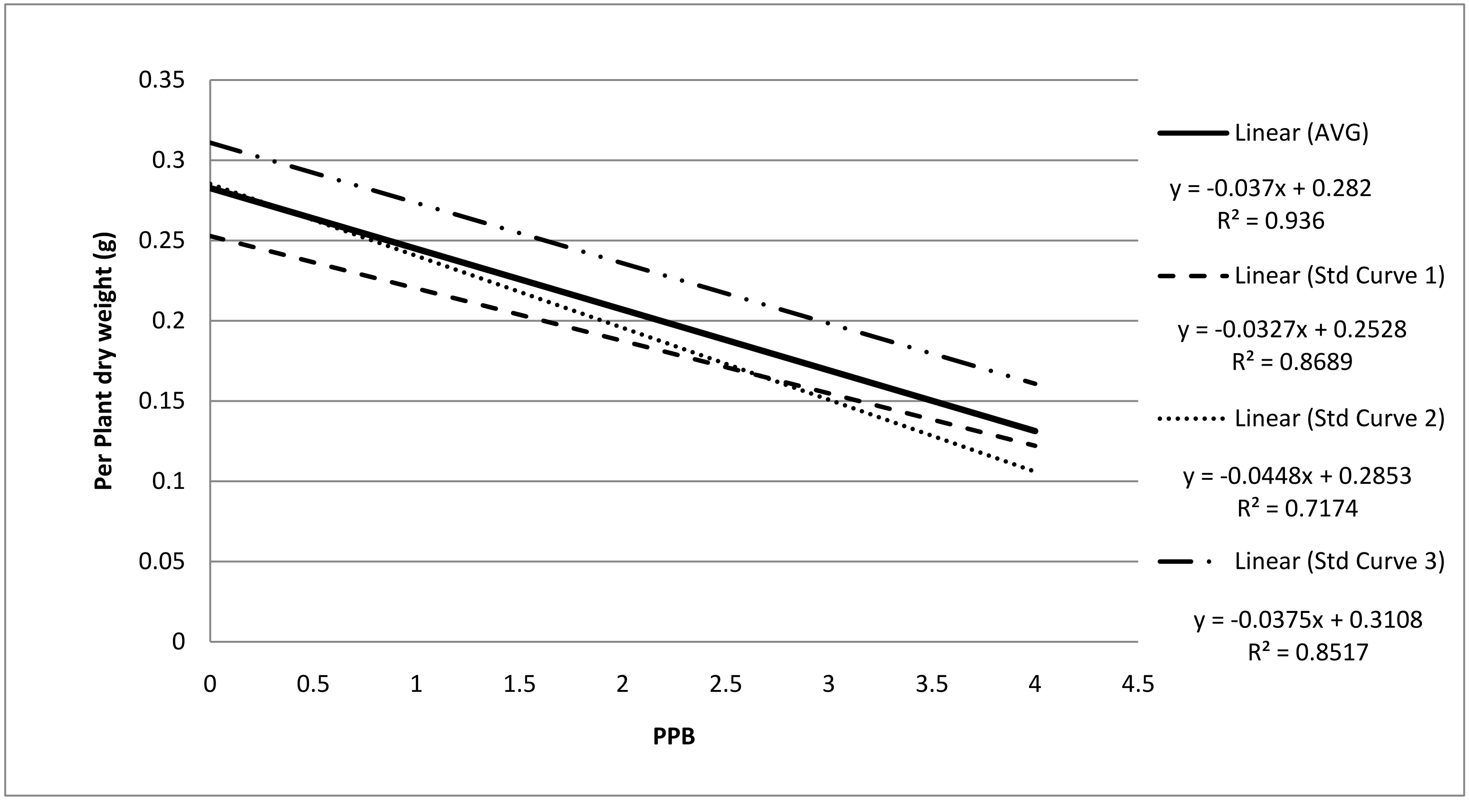
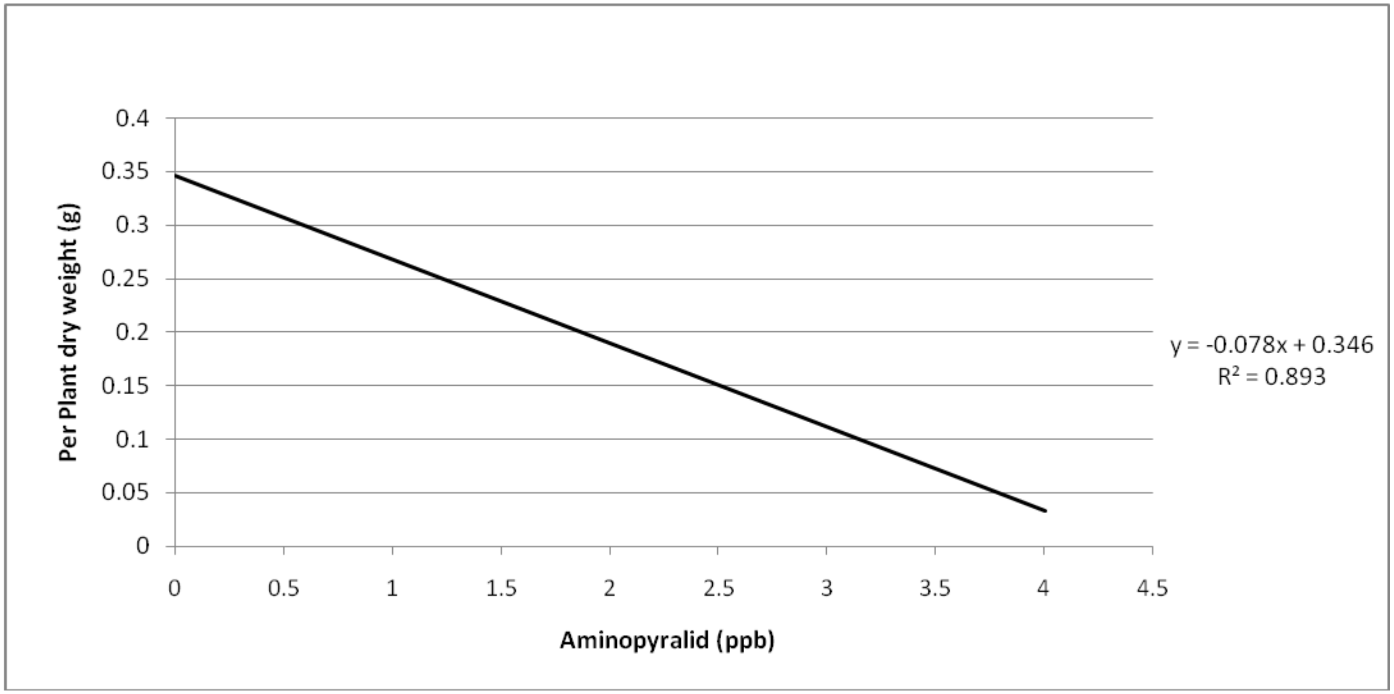


Figure 3.2 Slope of standard curve and correlating R^2 value for Princeton



Results and Discussion

Soybean was used as the plant species for conducting the plant bioassay since growth and development of soybean seedlings responded to increasing concentrations of aminopyralid in soil. Visual expression of aminopyralid on soybean growth were observed at aminopyralid concentrations as low as 0.25 ppb. However, injury could not be detected from dry weight analysis at this concentration. The herbicide symptomology observed was soybean leaf curling and puckering and thickened, misshaped growing points. Soybeans were severely injured at 1 and 2 ppb and soybean plant death occurred at 4 ppb. Preliminary studies using tobacco as an indicator species suggested that it would be more difficult to measure a correlation in plant weights relative to low aminopyralid concentrations (data not shown).

Using soybean as the plant bioassay species at time 0, the aminopyralid concentration rate was determined to be 76 and 75 ppb for Lexington and Princeton, respectively (Figure 3.3 and 3.4). Degradation over time for Lexington occurred within 16 weeks after treatment (Figure 3.3). Whereas, by week 4, aminopyralid concentration was at or below 0 ppb at Princeton (Figure 3.4).

Half -life was determined for Lexington assuming first-order reaction kinetics. Regression analysis of the natural log (ln) of aminopyralid concentrations over time (days after treatment), is best described by a linear equation with an R^2 of 0.98 (Figure 3.5). Half -life was calculated using the equation $t_{1/2} = 0.693/k$, where 0.693 is the ln of 2 and k is the slope of the line. The slope of the line was 0.06; therefore, the half -life for aminopyralid was calculated at 11.5 days at Lexington (Figure 3.5).

Using soybean as the indicator species and assuming first-order reaction kinetics, half -life could not be determined for the Princeton site. To show aminopyralid degradation at Princeton aminopyralid concentrations over time was broken into two phases. Phase one is from time 0 (herbicide application date in March 2009) to week 1 and phase two is week 1 to week 4 (Figure 3.6). Phase one and two are best described by linear equation with an R^2 of 1 and 0.98 for phase 1 and 2, respectively. When comparing the slopes of the two lines for phase 1 (60) and phase 2 (6), aminopyralid degradation was more rapid in the beginning and slower as time increased from the initial aminopyralid application (Figure 3.6). Even though half -life could not be calculated for Princeton, by week 1 aminopyralid concentration was much less at Princeton (approximately 15 ppb) than Lexington (approximately 38 ppb) when comparing figure 3.3 with figure 3.4.

Half -life can be valuable in comparing herbicide degradation under different environments; however, the complex nature of soil and the interaction between the herbicide and soil, half -life is often oversimplified (Walker, 1987). Walker (1987) further explained that not all herbicides followed first-order reaction kinetics, more often than not degradation proceeded with an order greater than 1.0.

The difference in the rate of aminopyralid disappearance in soil between the two locations could partly be explained by the amount of rainfall that occurred during the early part of the season. Princeton received more rainfall between the initial soil sample date (time 0) and the week 4 soil sample date than occurred at Lexington. During one rainfall event Princeton received over 2 inches of precipitation the day following the week 2 soil sample (Figure 3.7). Whereas, Lexington received less than 0.5 inches of rain per event during the same time frame (Figure 3.8).

Figure 3.3 Aminopyralid concentration over time for Lexington

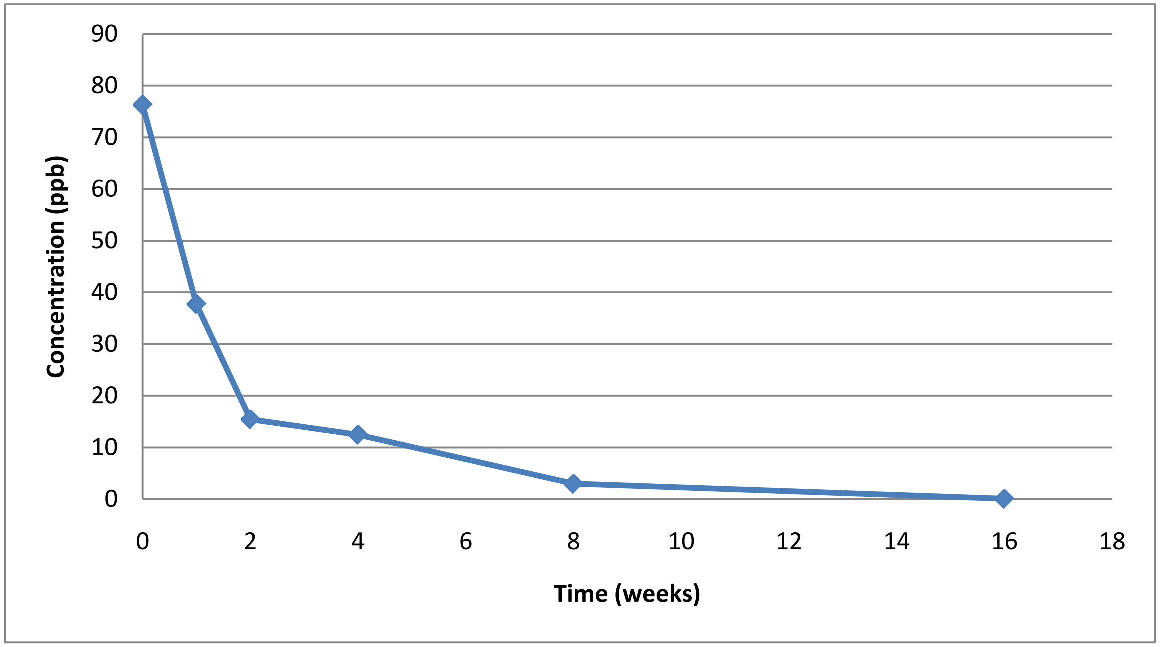


Figure 3.4 Aminopyralid concentration over time for Princeton

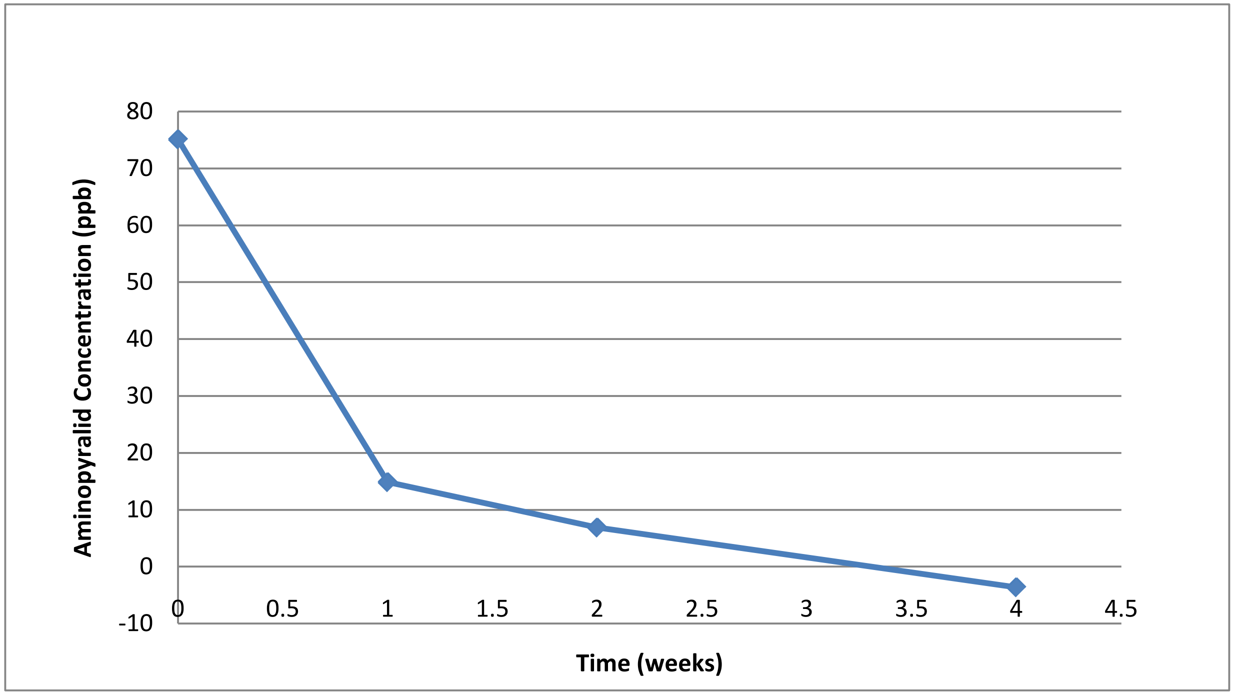


Figure 3.5 Aminopyralid degradation over time and half life for Lexington

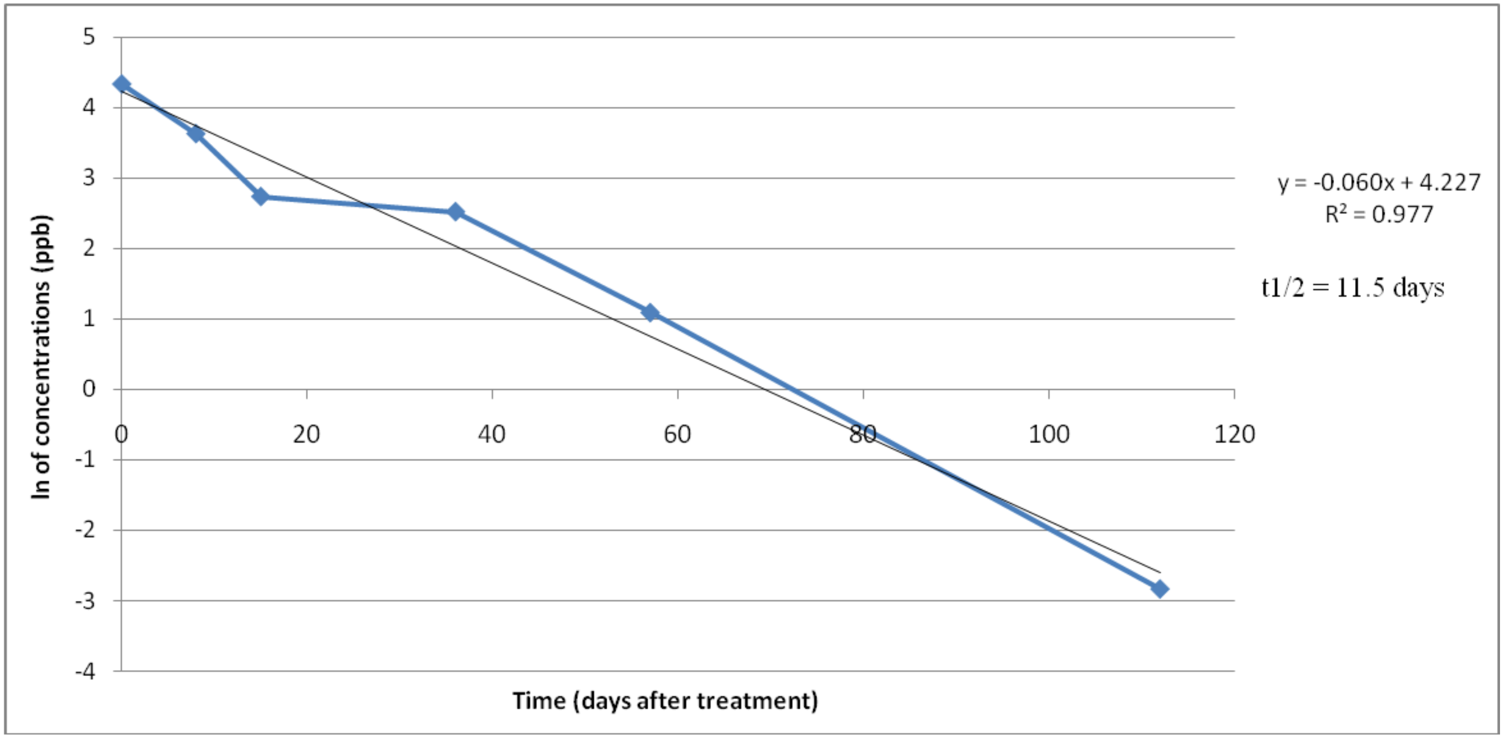


Figure 3.6 Aminopyralid degradation over time for Princeton

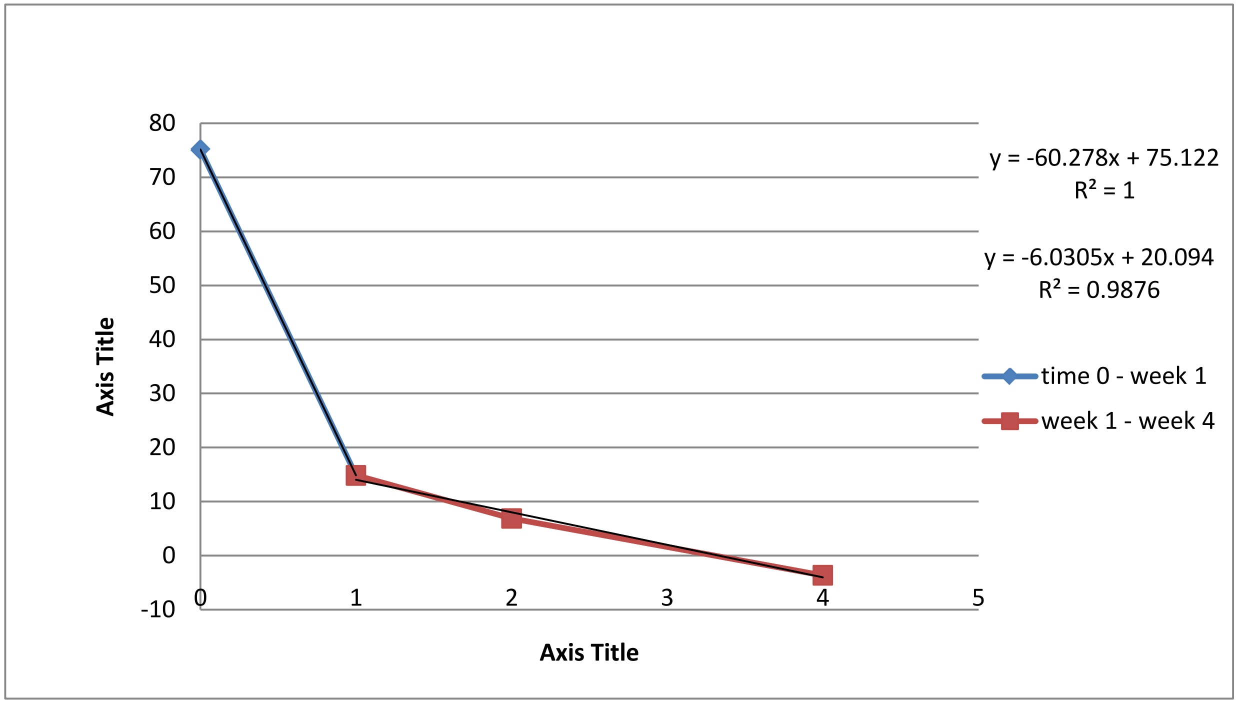


Figure 3.7 Precipitation data for Princeton from March 18, 2009 to May 19, 2009

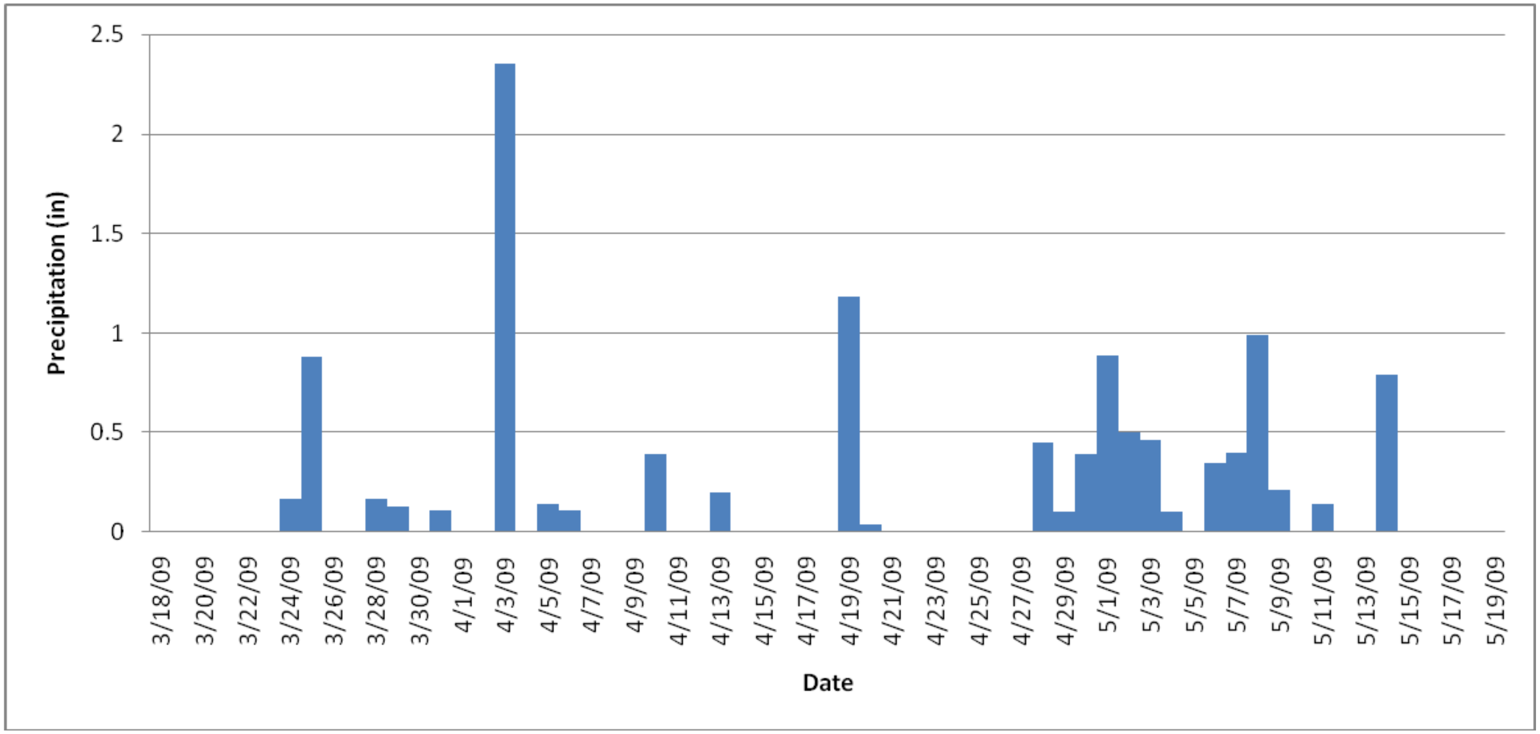
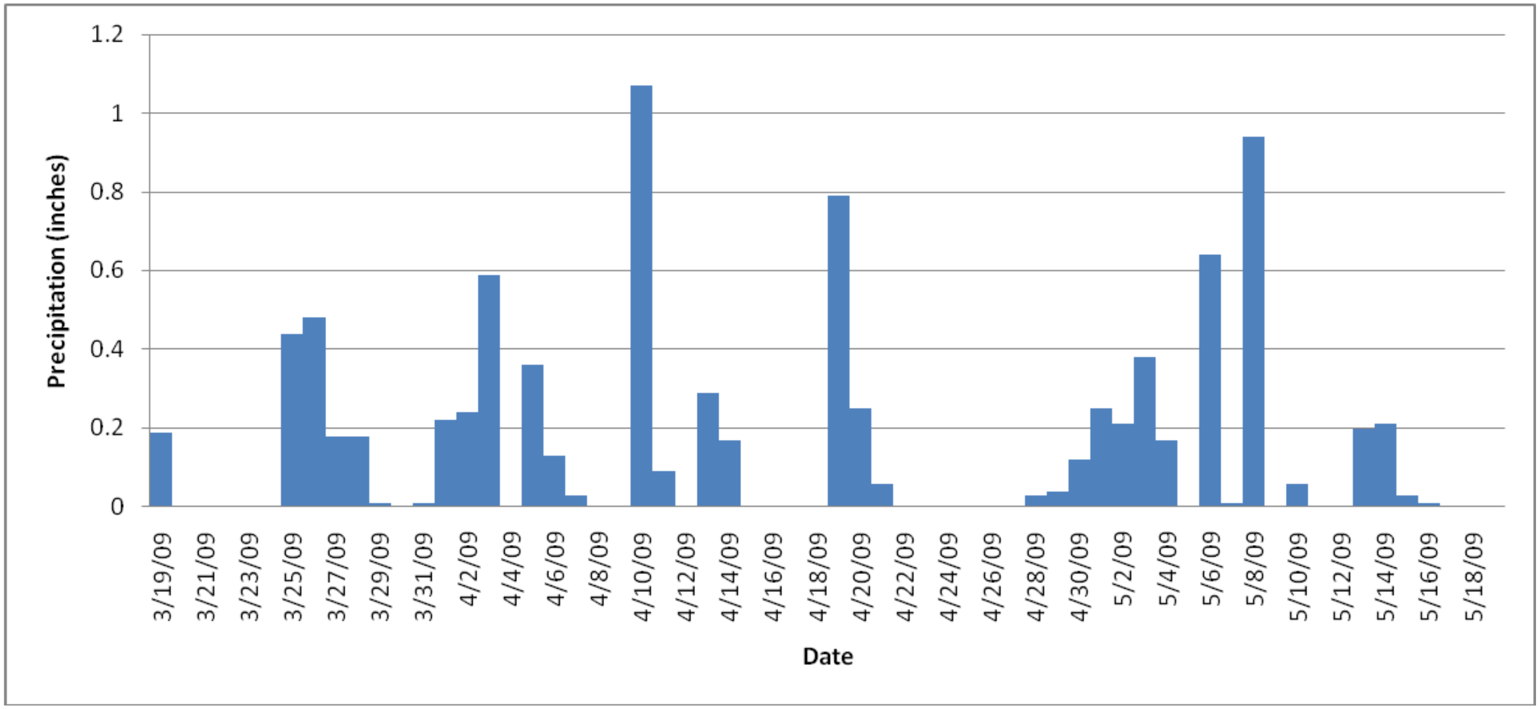


Figure 3.8 Precipitation data for Lexington from March 19, 2009 to May 18, 2009



Conclusions

The half-life of aminopyralid was calculated at 11.5 days at Lexington, but could not be determined at Princeton. These results were not similar to the aminopyralid half-life (34.5 d) in the field reported in the Herbicide Handbook published by the Weed Science Society of America [WSSA] (Senseman et al., 2007). One possible explanation for the greater degradation rate in this study could be the amount of rainfall received during the summer of 2009 (Appendix A). The summer of 2009 was characterized as above average rainfall for Kentucky. From March 2009 to July 2009 Lexington received over 1.5 inches above normal, for the same time period, Princeton received approximately 7 inches more than normal. According to the WSSA Herbicide Handbook aminopyralid rapidly degrades in water (Senseman et al., 2007).

It can be concluded from these results that aminopyralid has degraded to soil concentrations below detection levels and not harmful to soybean in 16 and 4 weeks for Lexington and Princeton, respectively. However, it cannot be concluded from these results that one year after treatment it is always safe to plant a broadleaf crop in an aminopyralid treated area. Aminopyralid persistence is very variable among climatic conditions, and under certain climatic conditions could persist longer than 16 weeks. Therefore, to be more reliable similar studies should be repeated over multiple years and a range of climatic conditions. Since aminopyralid is sometimes applied later in the summer or fall to control perennial broadleaf weeds it may also be useful to study aminopyralid persistence throughout the winter months following applications in late summer or early fall.

Appendix

A. Herbicide efficacy trial on spiny amaranth

In June 2009 an herbicide efficacy trial was conducted on spiny amaranth in Barren County, KY. The spiny amaranth site was an established stand of in a continuously grazed pasture. Experimental design was a randomized complete block with 4 replications. Individual plot size was 10 x 30 feet. Herbicide treatments were applied on June 17, 2009 with a CO_2 pressurized sprayer at a rate of 15 gal/acre. At the time of application spiny amaranth height ranged from 3 to 20 inches, but averaged about 10 inches tall. Percent control ratings were made 3 (July 10) and 6 (July 30) weeks after treatment (Table A.1). All data were analyzed using PROC ANOVA of SAS to determine any differences or interactions among treatments. An LSD test at the 0.05 significance level was used to compare treatment means. Three WAT 88 percent control or better was received with all treatments except Aim at 1.5 and 2 oz/acre (Table A.2). However, both Aim treatments were statistically different from the untreated control (Table A.2). Although, all herbicide treatments were statistically different from the untreated control; 6 WAT 93 percent control or better was obtained with Banvel at 0.5 and 1 pt/acre, Overdirve at 8 oz/acre, Milestone at 3 and 5 oz/acre, ForeFront at 1.5 oz/acre, Chaparral at 2.5 oz/acre, Cimarron at 0.02 oz/acre and Cimarron Plus at 0.125 oz/acre (Table A.2).

Table A.1 Spiny amaranth control in Barren County 3 and 6 weeks after treatment (WAT)

	Percent Control	
Treatment	*3 WAT*	*6 WAT*
2,4-D 1pt/a	87.5 A	62.5 B
2,4-D 2pt/a	95 A	72.5 B
Banvel 0.5pt/a	87.5 A	97.5 A
Banvel 1pt/a	100 A	97.5 A
Overdrive 8oz/a	97.5 A	92.5 A
Weedmaster 2pt/a	90 A	65 B
Milestone 3oz/a	87.5 A	92.5 A
Milestone 5oz/a	92.5 A	100 A
ForeFront 1.5oz/a	100 A	100 A
Chaparral 2.5oz/a	100 A	100 A
Aim 1.5oz/a	32.5 B	25 C
Aim 2oz/a	30 B	20 C
Cimarron 0.2oz/a	100 A	100 A
Cimarron Plus 0.125oz/a	100 A	100 A
Untreated Check	0 C	0 D

Table A.2 List of herbicide treatments and percent control data recorded three and six weeks after treatment. Clover was recorded as percent ground cover.

Plot	REP	TRT	Treatment	3 WAT 7-10-09	Clover 3WAT	6 WAT 7-30-09	Clover 6WAT
101	1	1	2,4-D 1pt/a	90	25	60	40
102	1	2	2,4-D 2pt/a	100	10	70	30
103	1	3	Banvel 0.5pt/a	100	0	90	5
104	1	4	Banvel 1pt/a	100	0	100	0
105	1	5	Overdrive 8oz/a	100	0	80	0
106	1	6	Weedmaster 2pt/a	100	0	70	0
107	1	7	Milestone 3oz/a	100	0	80	0
108	1	8	Milestone 5oz/a	100	0	100	0
109	1	9	ForeFront 1.5oz/a	100	0	100	0
110	1	10	Chaparral 2.5oz/a	100	0	100	0
111	1	11	Aim 1.5oz/a	80	0	60	0
112	1	12	Aim 2oz/a	50	0	40	0
113	1	13	Cimarron 0.2oz/a	100	0	100	0
114	1	14	Cimarron Plus 0.125oz/a	100	0	100	0
115	1	15	Untreated Check	0	30	0	20
201	2	15	Untreated Check	0	20	0	40
202	2	14	Cimarron Plus 0.125oz/a	100	0	100	0
203	2	9	ForeFront 1.5oz/a	100	0	100	0
204	2	7	Milestone 3oz/a	100	0	100	0
205	2	2	2,4-D 2pt/a	90	5	60	15
206	2	13	Cimarron 0.2oz/a	100	0	100	0
207	2	11	Aim 1.5oz/a	30	0	10	5
208	2	12	Aim 2oz/a	40	5	10	5
209	2	1	2,4-D 1pt/a	80	15	60	20
210	2	5	Overdrive 8oz/a	100	0	100	0
211	2	6	Weedmaster 2pt/a	90	0	70	0
212	2	4	Banvel 1pt/a	100	0	90	0
213	2	8	Milestone 5oz/a	100	0	100	0
214	2	10	Chaparral 2.5oz/a	100	0	100	0
215	2	3	Banvel 0.5pt/a	80	0	100	0
301	3	14	Cimarron Plus 0.125oz/a	100	0	100	0
302	3	8	Milestone 5oz/a	80	0	100	0
303	3	11	Aim 1.5oz/a	10	5	10	5
304	3	12	Aim 2oz/a	20	5	20	10
305	3	9	ForeFront 1.5oz/a	100	5	100	0
306	3	15	Untreated Check	0	0	0	20
307	3	6	Weedmaster 2pt/a	90	0	40	0

308	3	1	2,4-D 1pt/a	90	10	50	35
309	3	3	Banvel 0.5pt/a	90	0	100	0
310	3	2	2,4-D 2pt/a	90	15	60	25
311	3	5	Overdrive 8oz/a	100	0	90	0
312	3	10	Chaparral 2.5oz/a	100	0	100	0
313	3	13	Cimarron 0.2oz/a	100	0	100	0
314	3	4	Banvel 1pt/a	100	0	100	0
315	3	7	Milestone 3oz/a	80	0	90	0
401	4	15	Untreated Check	0	40	0	50
402	4	9	ForeFront 1.5oz/a	100	0	100	0
403	4	14	Cimarron Plus 0.125oz/a	100	0	100	0
404	4	10	Chaparral 2.5oz/a	100	0	100	0
405	4	12	Aim 2oz/a	10	15	10	15
406	4	13	Cimarron 0.2oz/a	100	0	100	0
407	4	1	2,4-D 1pt/a	90	10	80	10
408	4	8	Milestone 5oz/a	90	0	100	0
409	4	5	Overdrive 8oz/a	90	0	100	0
410	4	3	Banvel 0.5pt/a	80	0	100	0
411	4	2	2,4-D 2pt/a	100	5	100	10
412	4	4	Banvel 1pt/a	100	0	100	0
413	4	11	Aim 1.5oz/a	10	5	20	5
414	4	7	Milestone 3oz/a	70	0	100	0
415	4	6	Weedmaster 2pt/a	80	0	80	5

B. Weather data collected from Lexington and Princeton, KY from March 2009 through March 2010

The following weather data is reported from the weather station nearest the experimental sites in Lexington (Spindletop) and Princeton, KY. Data reported on a daily basis includes maximum, minimum and average air temperature, precipitation, and maximum and minimum relative humidity. Precipitation is reported in inches and amounts less than 0.01 inch are recorded as "T" (trace). An "E" next to a date denotes estimation by the NWS (National Weather Service). Following the daily weather data is a table summarizing air temperature and precipitation for each month. The following weather data was accessed at http://wwwagwx.ca.uky.edu/.

		AIR TEMPERATURE				RELATIVE HUMIDITY	
STATION	**DATE**	MX	MN	AV	**PRECIP**	MX	MN
Spindletop	3/19/09	57	41	49	0.19	97	20
Spindletop	3/20/09	49	28	38		77	41
Spindletop	3/21/09	59	28	44		78	26
Spindletop	3/22/09	65	32	48		79	26
Spindletop	3/23/09	67	45	56		57	31
Spindletop	3/24/09	72	42	57		59	31
Spindletop	3/25/09	63	57	60	0.44	98	59
Spindletop	3/26/09	58	42	50	0.48	99	73
Spindletop	3/27/09	58	43	50	0.18	98	77
Spindletop	3/28/09	65	44	54	0.18	100	75
Spindletop	3/29/09	48	38	43	0.01	88	71
Spindletop	3/30/09	58	32	45		96	41
Spindletop	3/31/09	65	40	52	0.01	77	40
Spindletop	4/1/09	62	42	52	0.22	94	29
Spindletop	4/2/09	75	41	58	0.24	94	46
Spindletop	4/3/09	57	41	49	0.59	97	67
Spindletop	4/4/09	61	35	48		96	32
Spindletop	4/5/09	75	42	58	0.36	93	40
Spindletop	4/6/09	54	34	44	0.13	96	80
Spindletop	4/7/09	42	32	37	0.03	99	45
Spindletop	4/8/09	55	33	44		74	36
Spindletop	4/9/09	63	34	48		87	31

Spindletop	4/10/09	62	50	56	1.07	99	66
Spindletop	4/11/09	58	40	49	0.09	98	34
Spindletop	4/12/09	58	33	46		76	32
Spindletop	4/13/09	68	47	58	0.29	97	40
Spindletop	4/14/09	58	44	51	0.17	99	72
Spindletop	4/15/09	47	43	45		97	83
Spindletop	4/16/09	61	44	52		99	57
Spindletop	4/17/09	71	37	54		84	33
Spindletop	4/18/09	74	43	58		89	31
Spindletop	4/19/09	62	53	58	0.79	98	47
Spindletop	4/20/09	57	43	50	0.25	98	62
Spindletop	4/21/09	51	39	45	0.06	93	53
Spindletop	4/22/09	62	38	50		84	27
Spindletop	4/23/09	70	42	56		76	38
Spindletop	4/24/09	82	60	71		73	31
Spindletop	4/25/09	83	63	73		64	31
Spindletop	4/26/09	84	62	73		69	34
Spindletop	4/27/09	82	63	72		65	30
Spindletop	4/28/09	72	63	68	0.03	96	43
Spindletop	4/29/09	78	61	70	0.04	99	53
Spindletop	4/30/09	72	63	68	0.12	93	68
Spindletop	5/1/09	73	56	64	0.25	97	68
Spindletop	5/2/09	59	51	55	0.21	98	73
Spindletop	5/3/09	59	52	56	0.38	98	80
Spindletop	5/4/09	64	52	58	0.17	99	71
Spindletop	5/5/09	71	55	63		93	56
Spindletop	5/6/09	64	56	60	0.64	98	90
Spindletop	5/7/09	73	58	66	0.01	98	67
Spindletop	5/8/09	75	57	66	0.94	98	71
Spindletop	5/9/09	72	54	63		98	48
Spindletop	5/10/09	70	47	58	0.06	96	43
Spindletop	5/11/09	69	52	60		93	47
Spindletop	5/12/09	69	42	56		92	37
Spindletop	5/13/09	73	51	62	0.2	93	60
Spindletop	5/14/09	73	59	66	0.21	98	70
Spindletop	5/15/09	81	53	67	0.03	100	53
Spindletop	5/16/09	77	58	68	0.01	91	62
Spindletop	5/17/09	61	47	54		72	34
Spindletop	5/18/09	65	40	52		75	29
Spindletop	5/19/09	73	39	56		86	29
Spindletop	5/20/09	78	47	62		84	29
Spindletop	5/21/09	83	54	68		83	35
Spindletop	5/22/09	84	61	72		85	38

Spindletop	5/23/09	86	60	73		97	39
Spindletop	5/24/09	80	64	72	T	81	56
Spindletop	5-25-2009 E	78	66	72	0.73	87	68
Spindletop	5-26-2009 E	81	66	74	0.09	90	58
Spindletop	5/27/09	81	65	73	0.25	98	60
Spindletop	5/28/09	81	65	73	0.09	98	61
Spindletop	5/29/09	75	60	68		96	52
Spindletop	5/30/09	79	58	68	0.5	95	57
Spindletop	5/31/09	78	59	68	0.28	93	43
Spindletop	6/1/09	85	56	70		88	47
Spindletop	6/2/09	89	67	78	0.26	92	45
Spindletop	6/3/09	77	60	68	0.17	96	69
Spindletop	6/4/09	59	55	57	0.43	98	95
Spindletop	6/5/09	76	51	64		96	40
Spindletop	6/6/09	78	48	63		96	32
Spindletop	6/7/09	84	58	71		90	40
Spindletop	6/8/09	84	64	74		92	49
Spindletop	6/9/09	87	70	78		85	41
Spindletop	6/10/09	78	66	72	0.7	98	72
Spindletop	6/11/09	79	66	72	0.57	99	74
Spindletop	6/12/09	73	64	68	0.06	99	79
Spindletop	6/13/09	83	58	70		100	48
Spindletop	6/14/09	84	62	73	0.31	99	48
Spindletop	6/15/09	82	65	74	0.33	99	61
Spindletop	6/16/09	82	67	74	0.11	98	68
Spindletop	6/17/09	89	66	78		95	56
Spindletop	6/18/09	83	70	76	0.17	97	63
Spindletop	6/19/09	93	72	82		94	50
Spindletop	6/20/09	89	69	79	0.3	98	53
Spindletop	6/21/09	87	68	78		95	57
Spindletop	6/22/09	85	72	78	0.19	95	65
Spindletop	6/23/09	86	66	76		98	41
Spindletop	6/24/09	88	64	76		97	46
Spindletop	6/25/09	91	68	80	1.29	98	52
Spindletop	6/26/09	88	67	78	0.52	98	60
Spindletop	6-27-09 E	90	69	80		90	40
Spindletop	6/28/09	85	68	76		94	43
Spindletop	6/29/09	83	62	72		74	38
Spindletop	6/30/09	77	65	71		81	52
Spindletop	7/1/09	72	62	67		95	62
Spindletop	7/2/09	70	60	65		91	58

Spindletop	7/3/09	80	60	70		92	56
Spindletop	7/4/09	75	60	68	0.28	98	66
Spindletop	7/5/09	72	64	68	0.44	99	85
Spindletop	7/6/09	82	59	70		100	45
Spindletop	7/7/09	83	59	71		97	45
Spindletop	7/8/09	81	62	72		91	44
Spindletop	7/9/09	86	65	76		85	44
Spindletop	7/10/09	86	67	76	0.12	94	62
Spindletop	7/11/09	83	72	78		93	69
Spindletop	7/12/09	84	70	77		98	52
Spindletop	7/13/09	82	63	72		94	42
Spindletop	7/14/09	84	60	72		95	38
Spindletop	7/15/09	80	67	74	0.09	94	64
Spindletop	7/16/09	84	72	78		96	60
Spindletop	7/17/09	77	61	69	0.36	97	51
Spindletop	7/18/09	70	57	64		93	57
Spindletop	7/19/09	75	54	64		99	51
Spindletop	7/20/09	79	54	66		99	43
Spindletop	7/21/09	81	55	68		98	45
Spindletop	7/22/09	70	65	68	0.83	98	79
Spindletop	7/23/09	78	64	71		97	61
Spindletop	7/24/09	82	61	72		98	47
Spindletop	7/25/09	83	66	74	0.83	97	64
Spindletop	7/26/09	82	67	74	0.28	99	48
Spindletop	7/27/09	84	61	72		97	46
Spindletop	7/28/09	82	65	74	0.16	95	71
Spindletop	7/29/09	81	70	76	0.2	97	66
Spindletop	7/30/09	82	68	75	0.2	98	71
Spindletop	7/31/09	82	66	74	2.1	99	54
Spindletop	8/1/09	82	63	72	0.07	99	55
Spindletop	8/2/09	78	62	70	0.4	97	53
Spindletop	8/3/09	81	58	70		99	53
Spindletop	8/4/09	73	64	68	2.1	100	79
Spindletop	8/5/09	80	65	72	0.05	99	67
Spindletop	8/6/09	83	64	74		99	49
Spindletop	8/7/09	81	57	69		97	43
Spindletop	8/8/09	88	65	76		93	55
Spindletop	8/9/09	90	73	82		86	56
Spindletop	8/10/09	89	70	80		97	60
Spindletop	8/11/09	86	68	77	0.2	98	61
Spindletop	8/12/09	84	65	74	0.1	99	54
Spindletop	8/13/09	85	62	74		99	43
Spindletop	8/14/09	86	60	73		98	40

Spindletop	8/15/09	88	64	76		96	54
Spindletop	8/16/09	89	70	80		95	46
Spindletop	8/17/09	88	70	79	0.24	95	51
Spindletop	8/18/09	83	70	76	0.4	96	70
Spindletop	8/19/09	87	71	79		98	62
Spindletop	8/20/09	84	70	77	0.3	96	68
Spindletop	8/21/09	81	67	74	1	99	48
Spindletop	8/22/09	72	59	66		98	71
Spindletop	8/23/09	74	59	66		95	59
Spindletop	8/24/09	78	54	66		99	54
Spindletop	8/25/09	86	57	72		99	55
Spindletop	8/26/09	88	64	76		99	50
Spindletop	8/27/09 E	89	67	78	0.28	97	46
Spindletop	8/28/09	80	69	74	0.17	96	71
Spindletop	8/29/09	78	62	70	0.07	98	58
Spindletop	8/30/09	75	56	66		98	41
Spindletop	8/31/09	73	51	62		95	51
Spindletop	9/1/09	75	51	63		91	47
Spindletop	9/2/09	81	57	69		95	54
Spindletop	9/3/09	80	60	70		96	39
Spindletop	9/4/09	81	59	70		93	43
Spindletop	9/5/09	83	57	70		95	37
Spindletop	9/6/09	82	60	71		98	60
Spindletop	9/7/09	79	63	71	0.47	98	62
Spindletop	9/8/09	80	63	72	0.6	99	67
Spindletop	9/9/09	82	59	70	0.01	100	50
Spindletop	9/10/09	78	62	70		100	63
Spindletop	9/11/09	81	60	70		99	56
Spindletop	9/12/09	77	55	66		95	48
Spindletop	9/13/09	78	55	66		98	51
Spindletop	9/14/09	81	55	68		99	40
Spindletop	9/15/09	80	56	68		99	56
Spindletop	9/16/09	81	61	71		99	56
Spindletop	9/17/09	77	55	66		91	64
Spindletop	9/18/09	80	64	72		89	69
Spindletop	9/19/09	78	60	69		87	58
Spindletop	9/20/09	75	63	69	0.9	99	83
Spindletop	9/21/09	76	68	72	0.66	98	81
Spindletop	9/22/09	81	67	74	0.19	97	71
Spindletop	9/23/09	79	69	74	0.06	98	76
Spindletop	9/24/09	79	67	73	1.1	99	80
Spindletop	9/25/09	74	66	70	0.38	99	89
Spindletop	9/26/09	73	61	67	1	100	79

Spindletop	9/27/09	69	59	64		99	66
Spindletop	9/28/09	70	53	62		85	40
Spindletop	9/29/09	57	48	52		86	65
Spindletop	9/30/09	60	46	53		98	62
Spindletop	10/1/09	68	43	56		100	51
Spindletop	10/2/09	68	53	60	0.29	96	40
Spindletop	10/3/09	67	47	57		83	40
Spindletop	10/4/09	61	45	53		93	56
Spindletop	10/5/09	69	42	56		100	45
Spindletop	10/6/09	66	50	58	0.04	97	80
Spindletop	10/7/09	63	45	54		91	51
Spindletop	10/8/09	63	45	54	0.47	98	60
Spindletop	10/9/09	69	55	62	0.94	99	88
Spindletop	10/10/09	56	43	50		98	70
Spindletop	10/11/09	61	39	50		100	50
Spindletop	10/12/09	68	44	56		94	69
Spindletop	10/13/09	61	49	55		92	66
Spindletop	10/14/09	49	41	45	0.75	99	79
Spindletop	10/15/09	50	45	48	0.15	100	90
Spindletop	10/16/09	48	40	44	0.02	98	77
Spindletop	10/17/09	48	34	41	0.01	93	53
Spindletop	10/18/09	54	29	42		98	38
Spindletop	10/19/09	59	35	47		81	44
Spindletop	10/20/09	67	46	56		74	39
Spindletop	10/21/09	69	45	57		86	42
Spindletop	10/22/09	70	48	59		85	55
Spindletop	10/23/09	70	55	62	0.41	98	71
Spindletop	10/24/09	56	42	49		96	57
Spindletop	10/25/09	61	38	50		97	38
Spindletop	10/26/09	68	37	52		93	39
Spindletop	10/27/09	58	45	52	0.69	99	80
Spindletop	10/28/09	59	55	57	0.04	98	81
Spindletop	10/29/09	69	48	58		98	62
Spindletop	10/30/09	79	62	70	0.26	98	56
Spindletop	10/31/09	61	40	50	0.76	98	76
Spindletop	11/1/09	57	34	46		100	46
Spindletop	11/2/09	62	32	47		99	41
Spindletop	11/3/09	55	34	44		86	28
Spindletop	11/4/09	57	31	44	0.02	91	41
Spindletop	11/5/09	53	36	44		92	51
Spindletop	11/6/09	59	30	44		98	37
Spindletop	11/7/09	70	49	60		54	36
Spindletop	11/8/09	71	51	61		68	42

Spindletop	11/9/09	68	47	58		87	40
Spindletop	11/10/09	62	49	56		90	60
Spindletop	11/11/09	59	41	50		87	33
Spindletop	11/12/09	58	35	46		81	41
Spindletop	11/13/09	62	34	48		86	50
Spindletop	11/14/09	68	45	56		75	50
Spindletop	11/15/09	68	45	56		75	50
Spindletop	11/16/09	65	43	54		100	60
Spindletop	11/17/09	55	46	50	0.3	95	69
Spindletop	11/18/09	49	44	46	0.23	99	88
Spindletop	11/19/09	49	42	46		92	70
Spindletop	11/20/09	58	33	46		100	55
Spindletop	11/21/09	59	36	48		99	57
Spindletop	11/22/09	57	36	46		92	57
Spindletop	11/23/09	51	46	48	0.01	99	81
Spindletop	11/24/09	55	47	51		99	78
Spindletop	11/25/09	52	45	48		90	62
Spindletop	11/26/09	48	35	42	0.01	95	62
Spindletop	11/27/09	42	30	36		92	61
Spindletop	11/28/09	60	29	44		90	45
Spindletop	11/29/09	58	46	52		97	53
Spindletop	11/30/09	51	31	41	0.37	99	69
Spindletop	12/1/09	51	30	40		91	44
Spindletop	12/2/09	55	35	45	0.44	99	80
Spindletop	12/3/09	46	34	40	0.01	97	74
Spindletop	12/4/09	39	26	32		84	49
Spindletop	12/5/09	35	20	28		93	48
Spindletop	12/6/09	37	17	27		90	53
Spindletop	12/7/09	37	28	32	0.02	99	80
Spindletop	12/8/09	50	33	42	1	100	86
Spindletop	12/9/09	55	28	42	0.9	97	54
Spindletop	12/10/09	27	17	22		77	37
Spindletop	12/11/09	37	17	27		73	27
Spindletop	12/12/09	45	19	32		69	24
Spindletop	12/13/09	49	36	42	0.3	100	82
Spindletop	12/14/09	60	43	52		97	72
Spindletop	12/15/09	43	25	34		90	71
Spindletop	12/16/09	37	17	27		93	39
Spindletop	12/17/09	44	21	32		86	35
Spindletop	12/18/09	40	31	36	0.32	100	61
Spindletop	12/19/09	34	32	33	0.28	100	99
Spindletop	12/20/09	33	31	32	0.09	100	50
Spindletop	12/21/09	34	31	32		98	89

Spindletop	12/22/09	46	30	38		100	75
Spindletop	12/23/09	49	34	42		96	72
Spindletop	12/24/09	50	36	43	0.05	89	61
Spindletop	12/25/09	53	34	44	0.17	96	70
Spindletop	12/26/09	43	28	36		82	38
Spindletop	12/27/09	44	25	34		95	47
Spindletop	12/28/09	29	20	24		92	71
Spindletop	12/29/09	35	19	27		89	49
Spindletop	12/30/09	45	25	35	0.04	98	43
Spindletop	12/31/09 E	63	51	57	0.24	98	55
Spindletop	1/1/10	43	14	28		90	31
Spindletop	1/2/10	20	12	16		84	63
Spindletop	1/3/10	24	6	15		88	54
Spindletop	1/4/10	28	17	22		89	59
Spindletop	1/5/10	22	13	18		89	71
Spindletop	1/6/10	22	13	18		95	77
Spindletop	1/7/10	28	9	18	0.11	95	73
Spindletop	1/8/10	16	7	12		93	72
Spindletop	1/9/10	23	15	19		94	75
Spindletop	1/10/10	23	9	16		95	67
Spindletop	1/11/10	29	15	22		96	66
Spindletop	1/12/10	32	18	25		91	56
Spindletop	1/13/10	37	15	26		95	56
Spindletop	1/14/10	48	25	36		78	41
Spindletop	1/15/10	54	39	46		83	49
Spindletop	1/16/10	55	34	44		97	59
Spindletop	1/17/10	45	38	42	0.39	100	85
Spindletop	1/18/10	43	30	36		100	80
Spindletop	1/19/10	52	33	42		99	80
Spindletop	1/20/10	40	35	38	0.5	100	99
Spindletop	1/21/10	46	35	40	0.28	100	96
Spindletop	1/22/10	48	42	45	0.01	100	96
Spindletop	1/23/10	53	43	48		100	73
Spindletop	1/24/10	51	47	49	0.93	99	67
Spindletop	1/25/10	38	32	35	0.02	96	75
Spindletop	1/26/10	34	22	28		96	67
Spindletop	1/27/10	38	19	28		91	54
Spindletop	1/28/10	40	19	30		87	36
Spindletop	1/29/10	21	15	18		77	59
Spindletop	1/30/10	26	10	18	0.16	93	63
Spindletop	1/31/10	32	3	18		93	47
Spindletop	2/1/10	38	14	26		90	40
Spindletop	2/2/10	42	27	34		84	68

Spindletop	2/3/10	41	27	34		94	57
Spindletop	2/4/10	39	26	32		96	64
Spindletop	2/5/10	40	33	36	0.69	100	84
Spindletop	2/6/10	35	22	28	0.06	100	88
Spindletop	2/7/10	29	19	24	0.01	97	72
Spindletop	2/8/10	30	14	22		96	79
Spindletop	2/9/10	36	27	32	0.51	100	91
Spindletop	2/10/10	28	12	20		92	73
Spindletop	2/11/10	27	15	21		96	72
Spindletop	2/12/10	31	8	20		95	59
Spindletop	2/13/10	27	17	22		95	71
Spindletop	2/14/10	32	17	24		94	61
Spindletop	2/15/10	32	19	26	0.07	100	84
Spindletop	2/16/10	26	18	22		91	78
Spindletop	2/17/10	32	25	28		93	64
Spindletop	2/18/10	33	22	28		92	66
Spindletop	2/19/10	43	19	31		96	33
Spindletop	2/20/10	47	27	37		87	42
Spindletop	2/21/10	63	38	50		67	30
Spindletop	2/22/10	49	37	43	0.02	97	52
Spindletop	2/23/10	36	32	34	0.01	99	86
Spindletop	2/24/10	35	22	28		92	58
Spindletop	2/25/10	30	20	25		95	74
Spindletop	2/26/10	39	20	30		90	48
Spindletop	2/27/10	31	26	28	0.01	99	68
Spindletop	2/28/10	35	30	32		99	84
Spindletop	3/1/10	39	33	36		88	65
Spindletop	3/2/10	39	30	34		96	66
Spindletop	3/3/10	37	29	33		84	62
Spindletop	3/4/10	46	25	36		94	28
Spindletop	3/5/10	48	20	34		87	26
Spindletop	3/6/10	51	21	36		90	30
Spindletop	3/7/10	57	23	40		87	22
Spindletop	3/8/10	64	38	51	0.01	88	40
Spindletop	3/9/10	69	35	52		94	33
Spindletop	3/10/10	67	50	58	0.09	89	48
Spindletop	3/11/10	63	49	56	0.01	91	68
Spindletop	3/12/10	65	46	56	0.28	99	60
Spindletop	3/13/10	49	44	46		98	72
Spindletop	3/14/10	48	40	44	0.05	97	87
Spindletop	3/15/10	46	39	42	0.01	98	77
Spindletop	3/16/10	54	42	48		95	59
Spindletop	3/17/10	61	44	52		89	46

Spindletop	3/18/10	65	38	52		75	23
Spindletop	3/19/10	66	39	52		71	34

			AIR TEMPERATURE					
			AVERAGE			EXTREME		AVG DEPART FROM NORM
STATION	**YEAR**	**MONTH**	MAX	MIN	**AVG**	MAX	MIN	
Spindletop	2009	Mar	58	38	48	76	10	+4
Spindletop	2009	Apr	65	46	55	84	32	0
Spindletop	2009	May	74	55	64	86	39	0
Spindletop	2009	Jun	83	64	74	93	48	+2
Spindletop	2009	Jul	80	63	71	86	54	-5
Spindletop	2009	Aug	83	64	73	90	51	-2
Spindletop	2009	Sep	77	59	68	83	46	0
Spindletop	2009	Oct	62	45	54	79	29	-3
Spindletop	2009	Nov	58	39	49	71	29	+4
Spindletop	2009	Dec	43	28	36	63	17	0
Spindletop	2010	Jan	36	22	29	55	3	-2
Spindletop	2010	Feb	36	23	29	63	8	-6
Spindletop	2010	Mar	57	38	47	73	20	+3

			PRECIPITATION					
					CUMULATIVE			
STATION	**YEAR**	**MONTH**	**TOTAL**	**DEPARTURE FROM NORMAL**	TOTAL	DEPARTURE	**GREATEST 24 HOUR TOTAL**	**% RAIN DAYS**
Spindletop	2009	Mar	2.19	-2.21	2.19	-2.21	0.48	32
Spindletop	2009	Apr	4.48	0.60	6.67	-1.61	1.07	53
Spindletop	2009	May	5.05	0.58	11.72	-1.03	0.94	52
Spindletop	2009	Jun	5.41	1.75	17.13	0.72	1.29	47
Spindletop	2009	Jul	5.89	0.89	23.02	1.61	2.10	39
Spindletop	2009	Aug	5.38	1.45	28.40	3.06	2.10	42
Spindletop	2009	Sep	5.37	2.17	33.77	5.23	1.10	30
Spindletop	2009	Oct	4.83	2.26	38.6	7.49	0.94	39
Spindletop	2009	Nov	0.94	-2.45	39.54	5.04	0.37	13
Spindletop	2009	Dec	3.86	-0.12	43.40	4.92	1.00	39
Spindletop	2010	Jan	2.40	-0.46	45.80	4.46	0.93	23
Spindletop	2010	Feb	1.38	-1.83	47.18	2.63	0.69	18
Spindletop	2010	Mar	1.05	-3.35	48.23	-0.72	0.28	26

		AIR TEMPERATURE				RELATIVE HUMIDITY	
STATION	**DATE**	MX	MN	AV	**PRECIP**	MX	MN
Princeton	3/18/09	72	38	55		60	40
Princeton	3/19/09	75	43	59	T	95	30
Princeton	3/20/09	59	43	51		95	30
Princeton	3/21/09	58	32	45		87	31
Princeton	3/22/09	59	33	46		85	30
Princeton	3/23/09	71	44	58		56	35
Princeton	3/24/09	78	65	72	0.17	78	38
Princeton	3/25/09	78	65	72	0.88	95	53
Princeton	3/26/09	67	47	57	T	95	40
Princeton	3/27/09	67	47	57	T	95	40
Princeton	3/28/09	60	49	54	0.17	100	87
Princeton	3/29/09	68	47	58	0.13	98	87
Princeton	3/30/09	62	29	46		97	36
Princeton	3/31/09	66	51	58	0.11	78	41
Princeton	4/1/09	65	37	51		90	26
Princeton	4/2/09	71	38	54		95	50
Princeton	4/3/09	70	43	56	2.35	98	62
Princeton	4/4/09	72	32	52		94	35
Princeton	4/5/09	66	34	50	0.14	86	37
Princeton	4/6/09	56	35	46	0.11	97	62
Princeton	4/7/09	51	34	42		97	34
Princeton	4/8/09	66	30	48		78	34
Princeton	4/9/09	66	33	50	T	90	35
Princeton	4/10/09	64	50	57	0.39	100	42
Princeton	4/11/09	61	41	51		98	41
Princeton	4/12/09	64	42	53		95	41
Princeton	4/13/09	69	42	56	0.2	84	48
Princeton	4/14/09	66	45	56	T	98	78
Princeton	4/15/09	56	44	50		98	74
Princeton	4/16/09	66	40	53		97	63
Princeton	4/17/09	76	44	60		96	35
Princeton	4/18/09	75	44	60		95	60
Princeton	4/19/09	71	46	58	1.18	90	65
Princeton	4/20/09	66	51	58	0.04	95	40
Princeton	4/21/09	66	46	56		95	40
Princeton	4/22/09	70	42	56		90	40
Princeton	4/23/09	78	43	60		95	50
Princeton	4/24/09	84	63	74		75	50

Princeton	4/25/09	85	50	68		90	40
Princeton	4/26/09	85	64	74		90	40
Princeton	4/27/09	85	65	75		95	50
Princeton	4/28/09	81	64	72	0.45	95	50
Princeton	4/29/09	79	61	70	0.1	96	65
Princeton	4/30/09	78	62	70	0.39	95	60
Princeton	5/1/09	71	61	66	0.89	100	70
Princeton	5/2/09	67	50	58	0.5	100	100
Princeton	5/3/09	60	53	56	0.46	90	70
Princeton	5/4/09	65	54	60	0.1	90	70
Princeton	5/5/09	73	55	64		90	55
Princeton	5/6/09	73	59	66	0.35	100	85
Princeton	5/7/09	80	62	71	0.4	100	55
Princeton	5/8/09	81	50	66	0.99	100	75
Princeton	5/9/09	74	64	69	0.21	95	50
Princeton	5/10/09	73	52	62		80	40
Princeton	5/11/09	71	51	61	0.14	100	50
Princeton	5/12/09	76	51	64		90	40
Princeton	5/13/09	77	50	64		95	80
Princeton	5/14/09	78	61	70	0.79	95	70
Princeton	5/15/09	85	61	73		90	70
Princeton	5/16/09	79	67	73	T	100	80
Princeton	5/17/09	71	50	60		70	40
Princeton	5/18/09	69	43	56		90	30
Princeton	5/19/09	77	40	58		95	30
Princeton	5/20/09	80	45	62		90	30
Princeton	5/21/09	85	47	66		100	46
Princeton	5/22/09	84	57	70		90	50
Princeton	5/23/09	85	49	67		90	70
Princeton	5/24/09	82	50	66	0.91	90	50
Princeton	5/25/09	80	68	74	0.05	100	70
Princeton	5/26/09	82	65	74	0.35	90	60
Princeton	5/27/09	86	65	76		100	70
Princeton	5/28/09	86	59	72		100	65
Princeton	5/29/09	86	56	71	T	100	65
Princeton	5/30/09	85	57	71		90	50
Princeton	5/31/09	87	65	76		90	40
Princeton	6/1/09	90	60	75		100	50
Princeton	6/2/09	89	65	77		95	39
Princeton	6/3/09	90	67	78	0.85	100	100
Princeton	6/4/09	67	58	62	0.32	100	100
Princeton	6/5/09	74	51	62		100	40
Princeton	6/6/09	80	51	66		100	40

Princeton	6/7/09	86	60	73		100	40
Princeton	6/8/09	83	69	76	T	95	70
Princeton	6/9/09	86	64	75	0.11	95	60
Princeton	6/10/09	85	70	78		80	68
Princeton	6/11/09	86	68	77	0.19	95	70
Princeton	6/12/09	86	65	76	1.7	95	65
Princeton	6/13/09	85	62	74	0.01	100	80
Princeton	6/14/09	83	68	76		80	70
Princeton	6/15/09	83	70	76	0.26	100	90
Princeton	6/16/09	79	65	72	0.59	100	80
Princeton	6/17/09	91	66	78		100	79
Princeton	6/18/09	92	67	80	3.91	100	69
Princeton	6/19/09	91	75	83		100	68
Princeton	6/20/09	93	77	85		100	69
Princeton	6/21/09	92	73	82		100	40
Princeton	6/22/09	95	77	86		100	60
Princeton	6/23/09	96	72	84	0.03	100	70
Princeton	6/24/09	90	69	80		100	40
Princeton	6/25/09	93	69	81		100	60
Princeton	6/26/09	93	74	84		96	68
Princeton	6/27/09	94	73	84		90	40
Princeton	6/28/09	89	74	82		96	45
Princeton	6/29/09	89	57	73		97	40
Princeton	6/30/09	90	63	76		100	50
Princeton	7/1/09	81	60	70		96	55
Princeton	7/2/09	80	63	72		97	62
Princeton	7/3/09	84	58	71		95	50
Princeton	7/4/09	80	67	74	2.14	97	56
Princeton	7/5/09	77	70	74		97	95
Princeton	7/6/09	83	65	74		95	48
Princeton	7/7/09	87	61	74		100	40
Princeton	7/8/09	89	65	77		100	40
Princeton	7/9/09	89	63	76		95	46
Princeton	7/10/09	92	68	80		100	60
Princeton	7/11/09	92	68	80		100	60
Princeton	7/12/09	85	70	78	0.95	94	56
Princeton	7/13/09	84	65	74	0.08	100	60
Princeton	7/14/09	87	62	74		100	50
Princeton	7/15/09	85	71	78		100	60
Princeton	7/16/09	87	68	78	0.6	100	80
Princeton	7/17/09	84	67	76		100	45
Princeton	7/18/09	70	59	64		97	58
Princeton	7/19/09	74	53	64		95	52

Princeton	7/20/09	80	54	67		97	49
Princeton	7/21/09	82	58	70		100	55
Princeton	7/22/09	77	63	70	1.76	100	80
Princeton	7/23/09	82	61	72		96	56
Princeton	7/24/09	85	67	76		96	64
Princeton	7/25/09	85	73	79		96	63
Princeton	7/26/09	84	69	76		96	52
Princeton	7/27/09	86	64	75		95	46
Princeton	7/28/09	85	65	75	1.16	100	95
Princeton	7/29/09	81	68	74	0.76	100	72
Princeton	7/30/09	80	71	76		96	80
Princeton	7/31/09	82	68	75		96	54
Princeton	8/1/09	82	64	73		96	57
Princeton	8/2/09	80	63	72		96	50
Princeton	8/3/09	87	63	75		85	6
Princeton	8/4/09	87	63	75		85	6
Princeton	8/5/09	92	65	78	1.5	100	60
Princeton	8/6/09	84	64	74		96	59
Princeton	8/7/09	87	65	76		100	65
Princeton	8/8/09	88	69	78		97	60
Princeton	8/9/09	89	72	80		96	60
Princeton	8/10/09	90	75	82		97	67
Princeton	8/11/09	81	69	75		96	74
Princeton	8/12/09	83	67	75		95	55
Princeton	8/13/09	87	60	74		100	50
Princeton	8/14/09	90	66	78		100	60
Princeton	8/15/09	89	66	78		100	50
Princeton	8/16/09	89	72	80		100	50
Princeton	8/17/09	91	65	78		100	60
Princeton	8/18/09	90	68	79		100	60
Princeton	8/19/09	90	68	79	0.65	100	50
Princeton	8/20/09	85	65	75	0.23	100	60
Princeton	8/21/09	82	65	74	0.03	96	49
Princeton	8/22/09	73	59	66		97	66
Princeton	8/23/09	74	54	64		97	59
Princeton	8/24/09	78	57	68		100	55
Princeton	8/25/09	87	56	72		100	50
Princeton	8/26/09	90	63	76		100	45
Princeton	8/27/09	91	64	78		100	45
Princeton	8/28/09	85	64	74		96	62
Princeton	8/29/09	81	69	75		92	48
Princeton	8/30/09	74	59	66		92	42
Princeton	8/31/09	74	53	64		100	50

Princeton	9/1/09	76	52	64		96	48
Princeton	9/2/09	80	56	68		95	60
Princeton	9/3/09	80	62	71	0.55	95	65
Princeton	9/4/09	83	61	72		100	55
Princeton	9/5/09	85	64	74		100	55
Princeton	9/6/09	80	66	73	0.19	94	52
Princeton	9/7/09	83	61	72		94	62
Princeton	9/8/09	83	66	74		100	55
Princeton	9/9/09	84	61	72		100	55
Princeton	9/10/09	85	62	74		100	55
Princeton	9/11/09	83	61	72		92	56
Princeton	9/12/09	83	65	74		92	56
Princeton	9/13/09	81	58	70		94	48
Princeton	9/14/09	84	60	72		100	60
Princeton	9/15/09	80	70	75	0.45	94	58
Princeton	9/16/09	83	68	76		93	60
Princeton	9/17/09	83	63	73		100	80
Princeton	9/18/09	82	64	73		94	78
Princeton	9/19/09	79	67	73	0.25	94	72
Princeton	9/20/09	79	71	75	0.09	94	84
Princeton	9/21/09	85	68	76		100	60
Princeton	9/22/09	84	68	76	0.01	90	70
Princeton	9/23/09	80	70	75		90	70
Princeton	9/24/09	81	71	76	1.23	100	70
Princeton	9/25/09	75	69	72	1.23	100	90
Princeton	9/26/09	77	63	70	0.61	94	84
Princeton	9/27/09	78	53	66		94	59
Princeton	9/28/09	79	59	69		100	40
Princeton	9/29/09	71	48	60		100	55
Princeton	9/30/09	68	44	56		96	57
Princeton	10/1/09	75	50	62		100	50
Princeton	10/2/09	76	55	66	0.85	100	30
Princeton	10/3/09	66	53	60		90	31
Princeton	10/4/09	58	42	50		94	40
Princeton	10/5/09	69	49	59	0.06	100	60
Princeton	10/6/09	66	60	63	0.73	94	66
Princeton	10/7/09	65	45	55		96	47
Princeton	10/8/09	74	49	62	1.45	100	75
Princeton	10/9/09	66	58	62	1.56	96	94
Princeton	10/10/09	55	48	52	0.04	94	80
Princeton	10/11/09	61	40	50		94	53
Princeton	10/12/09	72	46	59		100	55
Princeton	10/13/09	70	50	60	0.06	100	80

Princeton	10/14/09	54	50	52	0.43	96	86
Princeton	10/15/09	51	49	50	0.93	96	96
Princeton	10/16/09	50	43	46	0.02	100	85
Princeton	10/17/09	52	40	46		94	38
Princeton	10/18/09	56	30	43		94	32
Princeton	10/19/09	63	35	49		100	42
Princeton	10/20/09	70	44	57		98	44
Princeton	10/21/09	66	39	52		98	44
Princeton	10/22/09	68	54	61		100	60
Princeton	10/23/09	67	57	62	0.84	95	55
Princeton	10/24/09	58	46	52	0.01	90	46
Princeton	10/25/09	66	37	52		85	28
Princeton	10/26/09	69	39	54		86	28
Princeton	10/27/09	70	41	56	0.37	100	90
Princeton	10/28/09	58	54	56	0.27	96	90
Princeton	10/29/09	61	46	54	0.13	100	90
Princeton	10/30/09	76	56	66	1.01	98	59
Princeton	10/31/09	59	48	54	0.32	96	56
Princeton	11/1/09	58	34	46		96	43
Princeton	11/2/09	70	35	52		95	40
Princeton	11/3/09	69	45	57		90	30
Princeton	11/4/09	68	35	52		90	40
Princeton	11/5/09	68	36	52		100	35
Princeton	11/6/09	67	34	50		90	34
Princeton	11/7/09	74	52	63		53	38
Princeton	11/8/09	73	49	61		78	38
Princeton	11/9/09	73	53	63		95	60
Princeton	11/10/09	71	50	60		95	40
Princeton	11/11/09	70	45	58		95	35
Princeton	11/12/09	60	36	48		96	47
Princeton	11/13/09	66	34	50		95	45
Princeton	11/14/09	69	38	54		95	44
Princeton	11/15/09	73	52	62		96	65
Princeton	11/16/09	67	53	60	0.07	96	49
Princeton	11/17/09	59	44	52	1	96	64
Princeton	11/18/09	48	43	46	0.01	96	80
Princeton	11/19/09	58	44	51		96	70
Princeton	11/20/09	66	36	51		95	45
Princeton	11/21/09	65	38	52		96	56
Princeton	11/22/09	61	44	52		96	53
Princeton	11/23/09	63	42	52	0.04	95	40
Princeton	11/24/09	61	50	56		95	60
Princeton	11/25/09	55	41	48	0.08	96	68

Princeton	11/26/09	43	33	38		96	73
Princeton	11/27/09	49	27	38		97	48
Princeton	11/28/09	66	36	51		96	44
Princeton	11/29/09	54	46	50		94	65
Princeton	11/30/09	53	40	46	0.3	95	55
Princeton	12/1/09	49	29	39		96	44
Princeton	12/2/09	44	39	42	0.39	96	80
Princeton	12/3/09	40	36	38	0.06	95	55
Princeton	12/4/09	40	21	30		95	60
Princeton	12/5/09	37	18	28		89	44
Princeton	12/6/09	38	20	29		96	50
Princeton	12/7/09	44	34	39	0.09	96	70
Princeton	12/8/09	48	37	42	1	100	96
Princeton	12/9/09	47	32	40	0.07	98	35
Princeton	12/10/09	32	15	24		85	40
Princeton	12/11/09	40	18	29		85	40
Princeton	12/12/09	43	26	34		88	35
Princeton	12/13/09	48	41	44	0.35	96	38
Princeton	12/14/09	60	40	50		100	70
Princeton	12/15/09	44	30	37		80	70
Princeton	12/16/09	38	16	27		95	50
Princeton	12/17/09	47	21	34		96	42
Princeton	12/18/09	51	32	42	0.02	96	44
Princeton	12/19/09	36	33	34	0.03	96	44
Princeton	12/20/09	33	30	32		96	88
Princeton	12/21/09	32	25	28		92	70
Princeton	12/22/09	55	31	43		99	71
Princeton	12/23/09	56	46	51		100	36
Princeton	12/24/09	60	48	54	0.11	99	44
Princeton	12/25/09	44	31	38	0.51	99	82
Princeton	12/26/09	41	28	34		96	44
Princeton	12/27/09	36	26	31		87	43
Princeton	12/28/09	32	20	26		95	40
Princeton	12/29/09	37	26	32		96	56
Princeton	12/30/09	45	30	38	0.01	90	54
Princeton	12/31/09	43	38	40	0.09	98	55
Princeton	1/1/10	28	18	23		98	57
Princeton	1/2/10	24	12	18		93	51
Princeton	1/3/10	23	11	17		99	59
Princeton	1/4/10	26	8	17		80	25
Princeton	1/5/10	25	8	16		80	40
Princeton	1/6/10	33	7	20		80	40
Princeton	1/7/10	31	21	26	0.05	95	50

Princeton	1/8/10	16	10	13		98	76
Princeton	1/9/10	20	8	14		98	84
Princeton	1/10/10	24	2	13		97	66
Princeton	1/11/10	37	23	30	T	95	55
Princeton	1/12/10	35	15	25		90	60
Princeton	1/13/10	44	17	30		90	40
Princeton	1/14/10	53	25	39		97	39
Princeton	1/15/10	58	43	50		80	40
Princeton	1/16/10	52	35	44		99	63
Princeton	1/17/10	48	40	44	0.63	100	86
Princeton	1/18/10	53	26	40		100	98
Princeton	1/19/10	58	34	46		100	65
Princeton	1/20/10	58	50	54	0.82	100	95
Princeton	1/21/10	56	51	54	0.92	100	99
Princeton	1/22/10	42	38	40		100	99
Princeton	1/23/10	56	42	49		100	92
Princeton	1/24/10	55	48	52	0.45	100	76
Princeton	1/25/10	40	29	34		90	60
Princeton	1/26/10	37	22	30		70	50
Princeton	1/27/10	43	20	32		87	34
Princeton	1/28/10	42	28	35		80	50
Princeton	1/29/10	32	19	26	T	70	60
Princeton	1/30/10	26	20	23	0.19	99	69
Princeton	1/31/10	33	3	18		100	54
Princeton	2/1/10	42	5	24		80	40
Princeton	2/2/10	42	27	34		100	64
Princeton	2/3/10	42	34	38		80	56
Princeton	2/4/10	42	30	36		98	74
Princeton	2/5/10	43	40	42	0.62	100	78
Princeton	2/6/10	33	31	32	0.17	100	98
Princeton	2/7/10	35	21	28		100	78
Princeton	2/8/10	36	24	30		100	90
Princeton	2/9/10	31	22	26	0.37	89	23
Princeton	2/10/10	32	20	26		98	71
Princeton	2/11/10	36	10	23		90	40
Princeton	2/12/10	33	10	22		99	50
Princeton	2/13/10	33	27	30		99	81
Princeton	2/14/10	35	30	32	0.06	100	76
Princeton	2/15/10	35	21	28	0.12	100	87
Princeton	2/16/10	30	20	25		100	78
Princeton	2/17/10	37	20	28		70	48
Princeton	2/18/10	44	21	32		100	58
Princeton	2/19/10	50	21	36		100	42

Princeton	2/20/10	62	35	48		74	36
Princeton	2/21/10	65	39	52		76	39
Princeton	2/22/10	56	37	46	0.2	90	60
Princeton	2/23/10	36	32	34		100	86
Princeton	2/24/10	31	24	28		100	68
Princeton	2/25/10	39	17	28		90	50
Princeton	2/26/10	43	19	31		100	43
Princeton	2/27/10	46	21	34		100	45
Princeton	2/28/10	47	31	39		100	79
Princeton	3/1/10	43	29	36		100	81
Princeton	3/2/10	41	34	38		100	63
Princeton	3/3/10	44	27	36		100	32
Princeton	3/4/10	48	25	36		78	43
Princeton	3/5/10	51	24	38		88	34
Princeton	3/6/10	56	23	40		100	36
Princeton	3/7/10	65	27	46		100	33
Princeton	3/8/10	66	39	52		90	45
Princeton	3/9/10	64	41	52	0.02	98	49
Princeton	3/10/10	75	54	64	0.07	100	40
Princeton	3/11/10	68	53	60	0.66	100	75
Princeton	3/12/10	52	46	49	0.28	100	82
Princeton	3/13/10	49	40	44	0.02	100	86
Princeton	3/14/10	48	43	46	0.08	100	86
Princeton	3/15/10	48	42	45		100	80
Princeton	3/16/10	53	44	48		99	67
Princeton	3/17/10	56	44	50		99	53
Princeton	3/18/10	66	44	55		80	30

			AIR TEMPERATURE					
			AVERAGE			EXTREME		AVG DEPART FROM NORM
STATION	YEAR	MONTH	MAX	MIN	AVG	MAX	MIN	
Princeton	2009	Mar	64	42	53	78	16	+6
Princeton	2009	Apr	70	46	58	85	30	-1
Princeton	2009	May	78	55	67	87	40	0
Princeton	2009	Jun	87	67	77	96	51	+2
Princeton	2009	Jul	83	65	74	92	53	-4
Princeton	2009	Aug	85	64	75	92	53	-2
Princeton	2009	Sep	80	62	71	85	44	0
Princeton	2009	Oct	64	47	55	76	30	-4
Princeton	2009	Nov	63	42	52	74	27	+5
Princeton	2009	Dec	43	30	36	60	15	-3
Princeton	2010	Jan	39	24	31	58	2	-3
Princeton	2010	Feb	41	25	33	65	5	-5
Princeton	2010	Mar	58	39	48	78	23	+1

			PRECIPITATION					
					CUMULATIVE			
STATION	YEAR	MONTH	TOTAL	DEPARTURE FROM NORMAL	TOTAL	DEPARTURE	GREATEST 24 HOUR TOTAL	% RAIN DAYS
Princeton	2009	Mar	2.89	-2.05	2.89	-2.05	0.88	35
Princeton	2009	Apr	5.35	0.55	8.24	-1.50	2.35	33
Princeton	2009	May	6.14	1.18	14.38	-0.32	0.99	42
Princeton	2009	Jun	7.97	4.12	22.35	3.80	3.91	30
Princeton	2009	Jul	7.45	3.16	29.80	6.96	2.14	23
Princeton	2009	Aug	2.41	-1.60	32.21	5.36	1.5	13
Princeton	2009	Sep	4.61	1.28	36.82	6.64	1.23	27
Princeton	2009	Oct	9.08	6.03	45.90	12.67	1.56	52
Princeton	2009	Nov	1.50	-3.13	47.40	9.54	1.00	17
Princeton	2009	Dec	2.73	-2.31	50.13	7.23	1.00	35
Princeton	2010	Jan	3.06	-0.74	53.19	6.49	0.92	19
Princeton	2010	Feb	1.54	-2.89	54.73	3.60	0.62	21
Princeton	2010	Mar	3.24	-1.70	57.97	1.90	1.19	32

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Vita

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