# BIOLOGY AND DEVELOPMENT OF HOGPOTATO

# (HOFFMANSEGGIA DENSIFLORA)

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BIOLOGY AND DEVELOPMENT OF HOGPOTATO

(HOFFMANSEGGIA DENSIFLORA)

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure Page

PART I

# INTRODUCTION

Each of the three parts of this thesis is a separate manuscript to be submitted for publication in Weed Science, the journal of the Weed Science Society of America.

# PART I

## VEGETATIVE DEVELOPMENT AND ANATOMY OF HOGPOTATO (*HOFFMANSEGGIA DENSIFLORA*) PROPAGULES

# Vegetative Development and Anatomy of Hogpotato (Hoffmanseggia densiflora) Propagules

Abstract. Hogpotato (Hoffmanseggia densiflora Benth ex. Gray #[3] HOFDE) vegetative propagules planted in the field every 2 weeks from late May to late July emerged 21 to 31 days after planting. Sprouting percents for the planting dates ranged from 79 to 94%. Propagules planted in late May produced 129 and 160 secondary plants in 1984 and 1985, respectively, and spread an average of 147 cm when measurements were made in late August. Fifteen months after the establishment of the 1984 study the experimental area contained 127 above ground stems/$m^2$. Vegetative spread and secondary plant production decreased with later planting dates. In another experiment, propagules weighing 3.5 g emerged from as deep as 80 cm within 65 days after planting. Anatomical studies of the propagule indicate that it contains both stem and root tissue.

Additional index words. tuber, date of planting, spread, HOFDE, depth of planting.

## INTRODUCTION

Perennial weed species can cause significant yield reductions in several important crops. Young et al.(12) reported soybean yield reductions of 19 and 55% from quackgrass (Agropyron repens L. #[3] AGRRE) densities of 520 and 910 shoots per $m^2$, respectively.

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[3] Letters following this symbol are a WSSA-approved computer code from Composite List of Weeds, Weed Sci. 32 Suppl. 2. Available from WSSA, 309 W. Clark St., Champaign, IL 61820.

In another paper, Young et al. (13) reported corn yields were reduced 12 to 16% from quackgrass densities of 65 to 390 shoots per $m^2$. Full season competition from yellow nutsedge (Cyperus esculentus L. #3 CYPES) reduced seed cotton yields in 2 of 3 years, however, seed cotton yields were not appreciably reduced by shorter periods of interference (11). In furrow-irrigated cotton , Keely (7) noted seed cotton yield reductions of 34% from full season yellow nutsedge interference while interference for 6 to 8 weeks reduced seed cotton yields by 20%. Most problems with effective, long term control of perennial species are due to their ability to regrow from deep-rooted rootstocks. Surveys conducted by the Southern Weed Science Society indicate that perennial weeds have been considered the most troublesome to Oklahoma cotton production for many years. Combinations of three of the following five perennial species, silverleaf nightshade (Solanum elaeagnifolium Cav. #3 SOLEL), yellow nutsedge, johnsongrass (Sorghum halepense (L.)Pers. #3 SORHA), field bindweed (Convolvulus arvensis L. #3 CONAR),and horsenettle (Solanum carolinense L. #3 SOLCA), ranked as the three most troublesome weeds in cotton production in 1974, 1977, 1980, and 1983 (2,3,8,9).

Hogpotato's presence and apparent spread has become a concern to some producers. Previous research (4,5) has described seedling germination and development and documented detrimental effects on cotton lint yield and fiber quality. Also noted was the observation that only 3 or 4 seed per pod reach full maturity during a given growing season even though there is room for the development of seven or more seed. Also reported was the existence of a seed beetle that feeds on seed from members of the genus Hoffmanseggia. Hogpotato

infestations appear as irregularly shaped, isolated areas in the field. Vegetative propagules are typically found in the upper 50 cm of the soil profile but they may be found up to 1 m below the soil surface (5). Mature propagules are light brown to black in color and range in weight from 0.5 to 20 g; with a more common weight being in the 5 to 7 g range.

Two distinct ends on each propagule are discernible. Upon sprouting a single or, in some cases, multiple shoots arise from the distal end. Although reproduction by seed is possible, all infestations that we have observed were propagated vegetatively. The anatomical structure of the propagule has not been reported, however, one report (14) refers to the propagules as tubers. At one time, hogpotato propagules were considered a delicacy by Indians who roasted and ate them (10). Wiese (14) noted that the common name arose from hogs rooting the propagules out of the ground and eating them.

Since hogpotato does not produce many viable seed in a given year, we established experiments to evaluate the potential of transplanted hogpotato propagules to sprout and spread vegetatively, when planted at various dates during the cotton growing season. Additionally, anatomical studies were conducted to describe the anatomical structure of the propagule with the hope that they may aid future research concerning translocation of herbicides into the species.

## MATERIALS AND METHODS

Date of planting. Hogpotato propagules were collected from an infestation near Altus in southwestern Oklahoma. Propagules used in the experiment weighed 6.0±0.5 g. Four propagules per plot were

planted, within 24 h after collection, to a depth of 10 cm equally spaced from the center of each plot. Plots were established on the Agronomy Research Station near Stillwater, Oklahoma (Kirkland silt loam, Uderic Paleustolls).

In 1984 the plots were arranged in a completely randomized design with 7 replications. The 1985 experiment was arranged as a randomized complete block with 10 replications. Individual plots, were spaced 2 m apart in 1984 and 3 m apart in 1985. Planting dates evaluated in each year were; May 22, June 8, June 21, July 5, and July 19. No herbicides were applied in 1984, however; in 1985, a preemergence application of 2.24 kg/ha of alachlor[2-chloro-N-(2,6-diethylphenyl)-N-(methoxy-methyl)acetamide] was applied to minimize hand labor.

Data collected included the average number of days for each proagule to emerge, the number of secondary plants produced and the distance they spread, and propagule sprouting percentage. A propagule was considered as sprouted when an emerging shoot appeared above the soil surface. The number of secondary plants produced and their spread was determined on August 20, 1984 and August 25, 1985. Vegetative spread was determined by measuring the distance from the center of the plot to the 2 most distant secondary plants and taking the arithmatic average. The number of secondary plants produced was determined by counting the total number of secondary plants in each plot. On September 1, 1985 or approximately 15 months after the initiation of the 1984 experiment, the experimental area appeared as a dense mat of hogpotato. Above ground shoot counts were made using a 0.25 $m^2$ quadrat to estimate weed pressure.

All data were subjected to analysis of variance. Data were initially pooled over both years for all data collected. Analysis by individual years was conducted for those parameters having a statistically significant interaction term in the combined analysis.

Additionally, in 1984, propagules weighing approximately 7.0 g were planted in steel cylinders which were 1 m in diameter and 50 cm deep. Plants remained in the cylinders for 110 days (87 days after emergence). At that time the cylinders were lifted away from the soil and the intact underground portion of the hogpotato plant was recovered. Line drawings presented in this paper are a composite drawing from several of the plants recovered as well as observations made from a 1.5 m deep trench dug in the 1984 date of planting experiment.

Depth of planting. Hogpotato propagules weighing 3.5±0.5 g were planted at depths of 20, 40, 60, and 80 cm. The experiment was conducted in the field during 1985 as a randomized complete block design with 4 replications. A 7.6 cm i.d. soil probe was used to dig holes to the appropriate depth. One propagule per plot was placed in the bottom of each hole and the hole was backfilled with soil.

Anatomical study. In order to evaluate the anatomical structure of the hogpotato propagule studies were established involving cross sections of chemically fixed tissue. Tissues were fixed and processed using procedures described by Berlyn and Miksche (1). Ten micrometer sections were cut on a rotary microtome and fixed to glass microscope slides. To aid in tissue identification, all slides were stained using Johansen's Quadruple Stain (6). Our primary goal was to identify vascular tissue, particularly xylem, and note its position in

the tissue so that a determination could be made as to whether the propagule contains stem tissue, root tissue, or both. Once suitable slides were obtained, photomicrographs were taken of tissues magnified at 100 and 200X.

## RESULTS AND DISCUSSION

Date of planting. Data presented (Table 1) for secondary plants and their spread are on a per plot basis (4 propagules were planted per plot). Sprouting percentage and the number of days it took for each propagule to emerge are based on individual propagules (28 per planting date in 1984 and 40 per planting date in 1985). A significant interaction term prevented averaging treatment effects for days to sprout and the number of secondary plants produced. Therefore analysis by year is presented.

In 1984, propagules emerged 21 to 31 days after planting. Sprouting time for each planting date, with the exception of the June 21 date, were within 4 days of each other. In 1985, emergence time for the May 22 and June 8 planting dates were 8 to 9 days longer than in 1984. Cooler soil temperatures caused by increased precipitation may have played a role in the delayed emergence times observed. Emergence time for the other three planting dates were similar to those in 1984. The number of secondary plants produced was determined on August 20, 1984 and August 25, 1985. In 1984, the May 22 planting date had an average of 129 secondary plants per plot which were produced within 69 days after sprouting. In 1985, the May 22 planting date produced 160 secondary plants within 66 days after the propagules emerged from the soil. Propagules planted on July 5 had produced 4 secondary plants in 1984 and 7 secondary plants in 1985 within 24 days

after sprouting. Averaged over both years, spread of the secondary plants from the center of the plot ranged from 147 cm with the May 22 planting date to only 4 cm in the July 19 planting date. Sprouting percentage averaged over both years indicated that the propagules in the June 21 and July 19 planting dates sprouted significantly less than the other three dates, however; sprouting percentages for all dates were excellent. Later planting dates led to fewer secondary plants and decreased spread.

One hundred ten days after planting in the steel cylinders (87 days after emergence) the underground portion of the hogpotato plant was recovered. An average of eight propagules per plant were produced (Figure 1). The two above ground shoots shown on the left of Figure 1 represent drawings of established plants typically found in the field and are shown to give some idea of plant height in established stands. Vegetative growth varies from 20 to 30 cm in height on shoots that tend to be erect. The three above ground shoots on the right side of the figure are based on the appearance of the plants grown in the cylinder and shows hogpotato's low growing habit after sprouting. Detail drawings enclosed in circles show the bipinnately compound leaf and a propagule that formed approximately 30 cm below the soil during the experiment.

Approximately 15 months after establishment, the 1984 date of planting study appeared as a solid mat of hogpotato. It was impossible to distinguish among individual plots initiated the year before and hogpotato had spread several feet beyond boundries present in 1984. Above ground shoot counts made at this time indicated that there were 127±21 above ground shoots present per $m^2$. We also noted

that flowering was prolific, many pods were formed, but very few viable seed were present.

Depth of planting. In 1985, 75% (3 of 4) of the propagules planted at 20 cm emerged approximately 37 days after planting (Table 2). This observation seems to compare well with emergence times in the date of planting study where propagules emerged 21 to 31 days after planting at a 10 cm depth. All propagules planted at 40, 60, and 80 cm emerged 51, 57, and 65 days, respectively, after planting.

Anatomical study. Cross sections of the "upper" propagule (Figure 2) reveal xylem elements present in bundles forming a ring that surrounds pith tissue. Conversely, a section made from the lower portion of the propagule (Figure 3) shows evidence of centrally located xylem elements and no pith tissue. Based on the presence of pith tissue surrounded by a vascular ring and the presence of centrally located xylem elements with no pith tissue in the lower part of the propagule it appears that the propagule contains both stem and root tissue and serves as a transitional stucture. Sprouting propagules may produce a single shoot as indicated in Figure 4 or in some cases multiple shoots. This feature is also shown in Figure 4 where there is a meristematic region which appears to be a developing bud.

Hogpotato has the potential to become a serious problem to cotton producers in Oklahoma. At present, herbicides typically used in cotton production do not afford adequate control of the weed. Additionally, producers that utilize hoe labor to remove escaped weeds often skip hogpotato infestations since they require considerable time and effort for efficient removal. Although seed production does not

appear to be a major problem in perpetuation of hogpotato, the vegetative propagule may cause severe problems. We have observed that many propagules may be found at depths well below those commonly used in plowing operations. Most propagules are found at depths of 15 to 50 cm however, in the 1984 date of planting experiment we found evidence of initial propagule formation 1.2 m below the soil surface 21 months after the experiment was established. Ease of establishment and emergence three to four weeks after planting indicates that the propagule does not have a strict dormancy period before it will sprout. Additionally, propagules did emerge from as deep as 80 cm in the depth of planting experiment. Efforts aimed at effective, long term control of hogpotato will be complicated by the necessity of long distance translocation of toxic concentrations of herbicides.

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Table 1. Effect of planting date on various growth parameters of hogpotato cultured from freshly collected vegetative propagules grown in the field during 1984 and 1985.

| Planting date | Days till sprouting | | Secondary plants | | Spread | Sprouting |
|---|---|---|---|---|---|---|
| | 1984 | 1985 | 1984 | 1985 | | |
| | ------(days)------ | | ----(number)---- | | (cm) | (%) |
| May 22 | 21±1.0 | 29±2.0 | 129±9 | 160±20 | 147±11 | 93±3 |
| June 8 | 22±1.3 | 31±1.4 | 33±5 | 68±11 | 99±11 | 94±3 |
| June 21 | 31±1.5 | 29±1.0 | 9±4 | 50±11 | 76±12 | 80±5 |
| July 5 | 22±1.0 | 26±0.6 | 4±1 | 7±1 | 30±9 | 91±3 |
| July 19 | 24±1.6 | 23±1.0 | 0 | 1±0.6 | 4±1 | 79±5 |
| C.V. (%) | 6 | 3 | 3 | 2 | 2 | 1 |

Table 2. Effect of planting depth on time of emergence of freshly collected hogpotato vegetative propagules.[a]

| Planting Depth (cm) | Sprouting (%) | Planting to Emergence (days) |
|---|---|---|
| 20 | 75 | 37a |
| 40 | 100 | 51ab |
| 60 | 100 | 57ab |
| 80 | 100 | 65b |
| LSD(0.07) | NS | 18 |
| C.V.(%) | 27 | 24 |

[a]Within a column, values followed by the same letter are not significantly different at the 5% level according to LSD test.

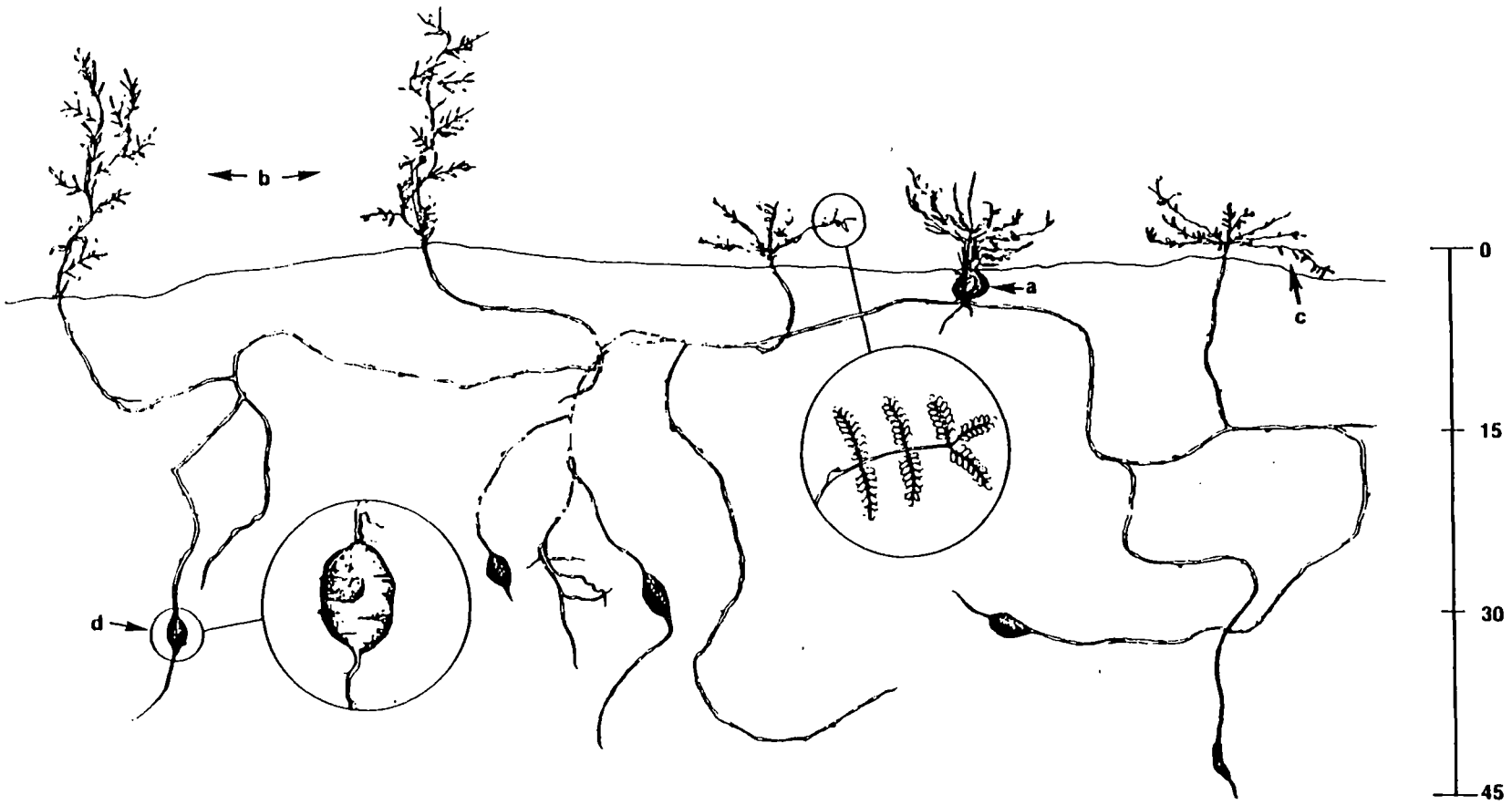


Figure 1. **Underground development of hogpotato from a transplanted vegetative propagule 87 days after sprouting; (a) transplanted vegetative propagule, (b) established plants found in the field, (c) shoot growth typical of a rapidly spreading plant, (d) newly formed vegetative propagule.**

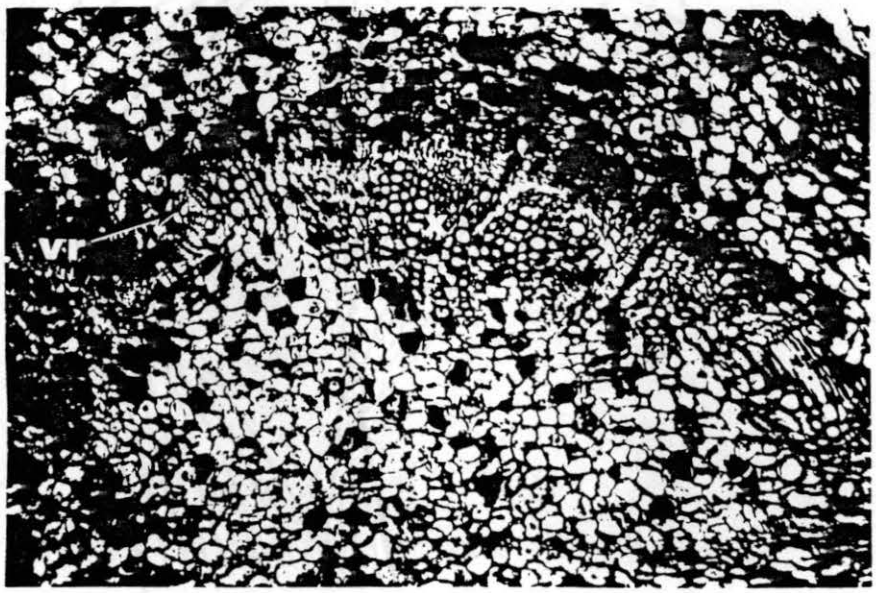


**Figure 2. 200X cross section of propagule stem tissue (c) cortex, (p) pith, (x) xylem element, (vr) vascular ring.**

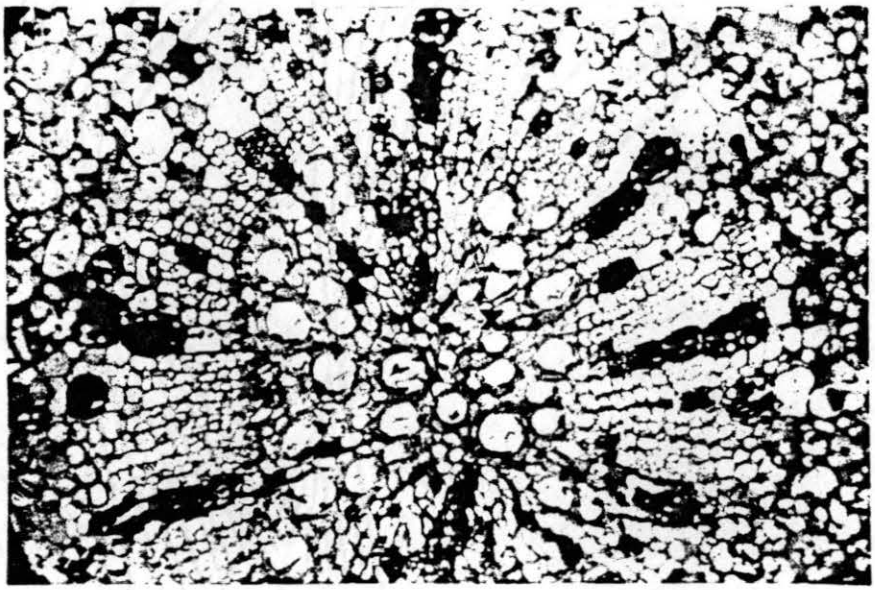

**Figure 3. 200X cross section of propagule root tissue (x) centrally located xylem elements, (p) phloem tissue.**

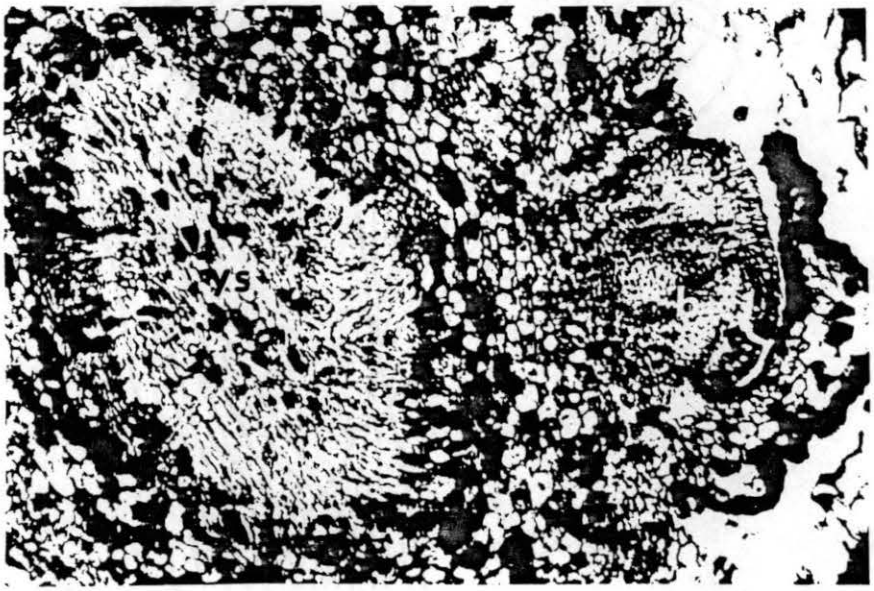


**Figure 4.** **100X cross section of propagule showing emerging young stem (ys) and developing bud (b).**

# PART II

## GERMINATION AND SEEDLING DEVELOPMENT OF HOGPOTATO (*HOFFMANSEGGIA DENSIFLORA*)

# Germination and Seedling Development of Hogpotato (*Hoffmanseggia densiflora*)

*Abstract*. Hogpotato (*Hoffmanseggia densiflora* Benth ex. Gray #[3] HOFDE) seed incubated in distilled water germinated at least 94% at constant 15, 20, 30 C and at alternating temperatures 20 to 30 C. Highest germination in buffered solutions occurred at pH 5 and 6. Sodium chloride concentrations of 50 mM and greater reduced the rate of germination. Cumulative percent germination after 9 days was reduced at NaCl concentrations of 100 mM and greater. Radicle lengths measured after 3 days were significantly reduced with increasing NaCl concentration. Hogpotato seedlings 20-days old and having 3 true leaves were able to resprout after topgrowth removal. Regrowth occurred on 15% of the seedlings approximately 15 days after top removal.

*Additional index words*. pH, temperature, salinity, HOFDE, *Hoffmanseggia glauca*, perennating activity.

## INTRODUCTION

Members of the legume genus Hoffmanseggia are herbaceous perennials reproducing by both seed and vegetative propagules. These propagules are usually found in the upper 60 cm of the soil profile; however, they have been collected them from as deep as 1 m below the soil surface (2). Plants rarely exceed 30 cm in height and they produce yellow flowers on erect racemes.

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[3] Letters following this symbol are a WSSA-approved computer code from Composite List of Weeds, Weed Sci. 32 Suppl. 2. Available from WSSA, 309 West Clark St., Champaign. IL 61820.

Waterfall (8) lists three species of Hoffmanseggia that may be found in Oklahoma. Infestations of H. densiflora appear to be increasing in southwestern Oklahoma, an important cotton producing region to the state. At this time, it is not a wide spread problem to cotton producers but occasional heavy infestations have been found. Yield reductions of 60 to 90% have been documented from full season weed interference (3).

Seed are produced in typical legume pods from 2.5 to 4.0 cm long. Although there is typically room for seven to eight seed, usually only three to four seed reach full maturity. Low seed production made collection of large numbers of viable seed difficult. Additionally, Johnson (4) reported that a particular bruchid (seed beetle), (Acanthoscelides compressicornis (Schaeffer)) feeds on hogpotato seed. This beetle was responsible for damage to many of the seed we collected.

A search of the literature indicated that no information has been published concerning hogpotato. Since hogpotato seems to be increasing on infested sites its potential to become a serious weed problem must be assessed. The objective of this paper was to describe the effects of temperature, pH, and salinity on hogpotato seed germination and to access seedling development into perennial plants.

## MATERIALS AND METHODS

An evaluation of the effects of temperature, pH, and salinity on hogpotato seed germinationwas made under controlled environmental conditions. Hogpotato seed were collected during the summers of 1984 and 1985 from a natural infestation located near Altus in southwestern Oklahoma. Dry, mature, seed pods were collected by hand during late

July and early August of each year, threshed by hand, and then cleaned with a seed blower to remove debris and lightweight seed. All seed were stored for 30 days at 4 C before use. Preliminary experiments indicated that scarification was necessary to stimulate germination; therefore, unless otherwise noted, all seed collected were scarified for 12 min in concentrated sulfuric acid. The scarification process was terminated by rinsing the seed with a saturated solution of sodium bicarbonate, followed by a 2 min rinse in distilled water.

All germination experiments were conducted using 9 by 9 cm plastic germination dishes. Seed were placed on 2 filter paper discs cut to fit each dish. The filter paper was moistened with 5 ml of the appropriate solution described below and seed were covered with an additional filter paper disc. Seed were considered germinated when the radicle reached 1 mm in length. Each experiment was repeated and values presented are an average of two experiments. Seed were incubated in the controlled environment chambers for a total of 9 days.

Salinity. The effects of increasing concentrations of salt on germination was evaluated by incubating seed in NaCl solutions. Concentrations were 50, 100, 150, and 200 mM. These solutions had pH values of 5.5±0.2. A distilled water (pH=6.7) treatment served as the control. Osmotic potential of these solutions was determined using calibrated thermocouple psychrometers. The experiment was arranged as a randomized complete block design with 4 replications. An experimental unit consisted of 20 seed per germination dish. The experiment was conducted in the dark at a constant 30 C. Radicle lengths were measured on 5 seed per replication after 3 days. After the 9 day incubation period ungerminated seed from the two highest

concentrations were removed, rinsed, and placed in a new dish moistened with 5 ml of distilled water. Germination and radicle length were recorded 3 days later.

Temperature and pH. Four temperature regimes were evaluated. Constant temperatures of 15, 20, and 30 C were evaluated under dark conditions and an alternating 20 C, 16 h dark; 30 C, 8 h light was included. Buffered pH solutions were prepared using a method described by Wilson (9). A solution of 0.1 M potassium hydrogen thalate in combination with either 0.1 M HCl or 0.1 M NaOH was used to prepare solutions at pH levels of 4.0, 5.0, and 6.0 (±0.1 pH units). A 0.025 M borax solution in combination with 0.1 M HCl was used to prepare solutions having pH levels of 7.0 and 8.0 (±0.1 pH units). A distilled water control (pH=6.7) was included. Fresh (unscarified) seed were placed in distilled water to measure their germination at different temperatures. An experimental unit consisted of 25 seed per dish and all treatments were replicated four times.

Resprouting ability. Hogpotato seed were grown under greenhouse conditions (25±5 C) to evaluate seedling development. Treatments consisted of clipping topgrowth at the soil surface on 5-day intervals from 20 to 55 days after emergence. All pots were harvested 100 days after emergence. Plants were fertilized approximately every 3 weeks using a commercial fertilizer. Measurements taken included; percent resprouting, number of days until regrowth occurred, number of leaves and their dryweight at each clipping date.

An attempt was made to recover a major portion of the roots at harvest by washing the soil away from the roots and obtaining an oven dry weight. Seed were planted in 946 ml plastic cups filled with 1100 g of air dry Port Silt Loam (Cumulic Haplutolls) soil. Cups were sub-

irrigated initially and subsequent waterings were surface applied. Each cup was planted with 2 seed. The experiment was conducted as a randomized complete block with 10 replications and repeated.

## RESULTS AND DISCUSSION

Salinity. Hogpotato seed germination after 3 days was significantly reduced from the distilled water control at NaCl concentrations of 50 mM and greater (Table 1). After the first 3 days of incubation 93% of the seed in the control had germinated. Germination in 50, 100, 150, and 200 mM NaCl after 3 days was 71, 16, 3, and 0% respectively. Radicle lengths measured after 3 days followed a similar pattern. Radicle length was reduced approximately 30% by the 50 mM concentration and by over 60% by the 100, and 150 mM concentration. No seed germinated in the 200 mM concentration during the first 3 days; however, 12% did germinate at this concentration by the 9 day reading.

After 9 days, percent germination was significantly reduced from the distilled water control by NaCl concentrations of 100 mM and greater. Increases in percent germination from 3 to 9 days were 18, 60, 28, and 12% for the 50, 100, 150, and 200 mM NaCl solutions respectively. The large increases in germination in the NaCl solutions relative to the increase in germination in the distilled water control, indicates that NaCl decreased the rate at which hogpotato seed germinated.

Several authors have noted that increased osmotic potential from NaCl solutions decreased germination (1,5,6,7). Uhvits (7) also indicated that the $Na^+$ and $Cl^-$ ions can exert a toxic effect on germination. After the 9 day incubation period we removed

ungerminated seed from the 150 and 200 mM solutions, rinsed them and placed them in a new dish moistened with distilled water. Seed were checked after 6 h and we observed that 99% of the seed had begun to germinate. After 3 days radicle lengths were measured (Table 2). These data suggest that the effects of NaCl on hogpotato seed germination were osmotic effects since nearly all seed germinated and appeared normal. Mayeux (5) reported that false broomweed seed germination in 150 mM NaCl (osmotic potential = -0.65 mPa) was about equal to germination in a -0.6 mPa polyethlene glycol solution. He concluded that the osmotic property of the NaCl solution reduced germination more than the physiological effect of the solute ions. The longer radicles observed, after re-incubation, when compared to the control from the germination experiment may have been due to the fact that the seed were already partially imbibed enabling them to germinate faster.

Temperature and pH. This experiment was analyzed as a split plot with temperature as main plots and pH as the subplots. The analysis of variance showed that the main plot error (error a) was less than the subplot error (error b). Therefore we pooled error terms and used one LSD value for the temperature by pH table (Table 3). After 9 days of incubation cumulative percent germination of scarified seed in distilled water was at least 94% in the control, regardless of temperature. In contrast, fresh seed (unscarified) had only 2 to 6% germination at the same temperatures. Highest germination in the pH solutions occurred at pH levels of 5.0 and 6.0. Germination at these pH values was 66% at 15 C, significantly less than all other temperatures. Percent germination increased with

temperature at pH levels 7.0 and 8.0; however, the radicles from those seedlings did not appear normal.

At the temperatures evaluated, hogpotato does not appear to have rigid requirements for germination relative to temperature. Scarification of freshly collected seed was necessary for good germination.

Resprouting ability. Hogpotato was able to regenerate topgrowth 20 days after emergence (Table 4). As seedlings became older percent regrowth increased. Number of leaves and their dryweight, measured at each clipping date, also increased with plant age. Although statistical differences exist among days for regrowth to occur, no obvious trend is present. Regrowth normally occurred 13 to 16 days after clipping. Root weights were fairly consistent at all clipping dates with the exception of the 25 and 35 day intervals. We observed that there was no apparent trend in the formation of propagules or multiple stems. At harvest some seedlings in the last four clipping dates showed some evidence of root swelling which may be an indication of initial propagule formation. Additionally, in each of the last four clipping dates there were from 1 to 3 fairly well defined propagules present. Formation of multiple stems upon regrowth followed a similar pattern. Some seedlings produced multiple stems in the last 4 clipping dates but no trend was apparent.

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Table 1. Effect of various concentrations of NaCl on germination and radicle length of hogpotato seed after incubation for 3 and 9 days.[a]

| Calculated NaCl concentration | Measured | | Germination | | Radicle length |
|---|---|---|---|---|---|
| | Osmotic potential | Electrical conductivity | 3 days | 9 days | 3 days |
| (mM) | (mPa) | (m mhos/cm) | (%) | (%) | (mm) |
| 0 | -0.10 | 6 | 93a | 95a | 16.7a |
| 50 | -0.33 | 5470 | 71b | 89ab | 11.7b |
| 100 | -0.55 | 10000 | 16c | 76b | 6.0c |
| 150 | -0.62 | 14450 | 3d | 31c | 5.8c |
| 200 | -0.84 | 18860 | 0e | 12d | 0d |
| LSD (.05) | --- | --- | 8 | 14 | 0.8 |
| C.V. (%) | --- | --- | 22 | 22 | 7 |

[a]Within each column, values followed by the same letter are not significantly different at the 5% level according to LSD test.

Table 2. Percent germination and radicle lengths of seed, incubated for 9 days in 150 and 200 mM NaCl, after washing and reincubation for 3 days in distlled water.

| NaCl Concentation (mM) | Germination (%) | Radicle Length (mm) |
|---|---|---|
| 150 | 99 | 29.0±8.0 |
| 200 | 99 | 29.0±9.8 |
| C.V. (%) | 3 | 36 |

Table 3. Effect of Temperature and pH on hogpotato seed germination. after 9 days of incubation.[a]

| pH Level[b] | TEMPERATURE (C) | | | |
|---|---|---|---|---|
| | 15 | 20 | alt 20-30 | 30 |
| | (%) | | | |
| Dist. water control | 94a-c | 96ab | 95a-c | 97a |
| Fresh seed in dist. water | 2k | 6k | 6k | 6k |
| 4.0 | 2k | 38g | 26hi | 1k |
| 5.0 | 66e | 88b-d | 90b-d | 86d |
| 6.0 | 66e | 90b-d | 89b-d | 84d |
| 7.0 | 0k | 15j | 16j | 32gh |
| 8.0 | 0k | 16j | 25i | 48f |

[a]Within columns and rows, values followed by the same letter are not significantly different at the 5% level according to LSD test.

[b]pH levels were prepared to ±0.1 pH units.

Table 4. Effect of various clipping intervals, after emergence, on hogpotato seedling regrowth.

| Clipping Interval (days) | Regrowth (%) | Clipping date | | Harvest Root Wt. (mg) | Time till Regrowth (days) |
|---|---|---|---|---|---|
| | | Leaf # | Leaf Wt. (mg) | | |
| 20 | 15 | 3.2±0.2 | 38.0±10.9 | 266.5±50.2 | 14.7±1.3 |
| 25 | 48 | 4.4±0.2 | 61.0±10.8 | 180.1±28.1 | 14.5±0.7 |
| 30 | 43 | 5.4±0.2 | 61.1±10.9 | 234.4±34.9 | 13.4±0.9 |
| 35 | 78 | 6.4±0.2 | 86.6±11.2 | 192.3±22.3 | 15.6±0.6 |
| 40 | 70 | 7.3±0.2 | 136.4±10.9 | 265.3±24.1 | 12.7±0.6 |
| 45 | 75 | 9.4±0.2 | 196.2±11.4 | 288.8±22.7 | 13.4±0.6 |
| 50 | 80 | 10.1±0.2 | 248.3±11.4 | 298.7±22.1 | 14.1±0.6 |
| 55 | 98 | 12.4±0.2 | 256.1±10.6 | 241.9±19.6 | 13.3±0.5 |

# PART III

## HOGPOTATO (*HOFFMANSEGGIA DENSIFLORA*) INTERFERENCE WITH COTTON (*GOSSYPIUM HIRSUTUM*)

# Hogpotato (*Hoffmanseggia densiflora*) Interference with Cotton (*Gossypium hirsutum*)

*Abstract*. The effects of hogpotato (*Hoffmanseggia densiflora* Benth. ex Gray #[3] HOFDE) interference on cotton (*Gossypium hirsutum* L. 'Paymaster 404, Paymaster 145') yield and fiber quality was measured under field conditions in a natural infestation of the weed. Lint yield reductions ranged from 58 to 99% from full season weed interference. Interference during the first 7 weeks of crop growth reduced lint yields by 41% while interference after 7 weeks of weed free maintenance reduced lint yield by only 5%. Hogpotato interference significantly reduced cotton fiber length, strength, and micronaire in 1 of 2 years. Cotton plant height appeared to be a good indicator of interference only under full season weed interference. Cotton plant height was not appreciably affected by early or late hogpotato infestations when compared to full season interference as indicated by late season height measurements. None of the soil measurements made inside or outside the hogpotato infestation appeared to give any evidence for presence or absence of hogpotato.

*Additional index words*. crop height, lint yield, competition, soil, HOFDE, *Hoffmanseggia glauca*.

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[3] Letters following this symbol are a WSSA-approved computer code from Composite List of Weeds, Weed Sci. 32 Suppl. 2. Available from WSSA, 309 West Clark St., Champaign. IL 61820.

# INTRODUCTION

Hogpotato is a perennial legume native to the southwestern United States and California (6). Waterfall (9) places hogpotato in the legume subfamily Caesalpinioideae. Other common names for hogpotato have been reported, including pignut, camote de raton, and indian rushpea (1,2,11). The plant may be described as a low growing perennial seldom reaching over 30 cm in height. The leaves are bipinnately compound and yellow flowers are born on erect racemes.

Some workers (1,5) have indicated that hogpotato is commonly found on alkaline soils. As early as 1935 hogpotato was recognized as a potential problem in California . Ball (1) reported that hogpotato occasionaly is found in the San Joaquin Valley and may be commonly found in the Mohave and Colorado deserts. Hogpotato infestations have been reported in several of the vegetational areas in Texas as outlined by Gould (2). Wiese (11) reported that there are severe infestations on sandy soils in the Rolling Plains area of Texas and that hogpotato occasionally infests fine-textured soils in the Central Panhandle of Texas.

Hogpotato infestations are found in southwestern Oklahoma, an important cotton producing area of the state. Infestations normally appear as sharply defined isolated patches in the field. We have also observed many light infestations growing along roadsides and near the edges of fields.

Hogpotato produces a vegetative propagule that may be found up to 1 m below the soil surface and the weed appears to be spreading. Many cotton producers still rely on hoe labor as a means to remove escaped annual and perennial weeds, however hogpotato patches are

often ignored due to the length of time it takes to hoe these patches clean. Wiese (11) evaluated 2,4,-D [(2,4-dichlorophenoxy)acetic acid], 2,4,5-T [(2,4,5-trichlorophenoxy)acetic acid], Silvex [2-(2,4,5-trichlorophenoxy)propionic acid], MCPA [(4-chloro-2-methylphenoxy)acetic acid], and 2,3,6-TBA [(2,3,6-trichloro-phenoxy)benzoic acid] for control of hogpotato. Rates ranged from 1.12 to 4.48 kg/ha. All herbicide treatments and rates except MCPA, gave good control of hogpotato when 2 applications were made approximately 10 months apart, based on ratings made 2 months after the second application. Ratings one year later showed only 2,3,6-TBA provided good control at 2.24 and 4.48 kg/ha. In another study (10) Wiese reported good control of hogpotato 2 years after application using the soil sterilants monuron [3-(p-chlorophenyl)-1,1-dimethyl-urea] and fenuron [1,1-dimethyl-3-phenylurea] at 44.8 to 89.6 kg/ha, sodium chlorate at 896 to 1244 kg/ha, and concentrated borascu at 2867 to 3584 kg/ha. Both of these experiments included herbicides which cannot be selectively used in cotton.

The objectives of this research were to evaluate the effects of hopotato interference on cotton lint yield and fiber quality and to determine if soil characteristics might provide some evidence for the presence or potential spread of hogpotato to other areas.

## MATERIALS AND METHODS

Experiments were conducted on a Tillman Hollister clay loam (Typic Paleustolls) near Altus in southwest Oklahoma. Paymaster 404 and Paymaster 145 were planted on June 2, 1984 and May 10, 1985, respectively, in 101 cm rows with a conventional planter. The growing season from planting to a killing freeze was 118 and 201 days in 1984

and 1985, respectively. Cotton was planted in an area with a heavy, natural infestation of hogpotato. Interference plots were established at cotton emergence each year.

Within the infested area, treatments in the initial experiment (1984) were arranged in a completely randomized design with four replications and consisted of full season weed-free maintenance or full season weed interference. In 1985, the experiment was repeated as a randomized complete block with four replications on the same general location. Treatments included full season weed-free maintenance, full season weed interference, weed interference for the first 7 weeks after crop emergence, and weed free maintenance for the first 7 weeks after crop emergence. The last two treatments will be referred to as early season and late season weed interference in this paper, respectively. All plot maintenance was accomplished by hand pulling or hoeing throughout the growing season. Plots, each four rows wide, were 10 m long in 1984 and 8 m long in 1985.

Cotton plant height was measured on six plants per plot every two weeks from early July to harvest. Yield data from all plots was collected by hand harvesting the two center rows of each four row plot. Before cotton harvest each year, one mature boll/plant was removed from the center portion of 15 randomly selected plants in the two center rows of each plot. These samples were ginned and used to estimate picked[(wt. lint/wt. seed cotton)x100] and pulled [(wt. lint/wt. sample)x 100] lint percents. Measurements of fiber length, strength, and micronaire were also made from the lint samples. Fiber length was measured on a digital fibrograph as 2.5 and 50% span lengths in inches (converted to mm). Uniformity index is a ratio

calculated by dividing the 50% span length by the 2.5% span length and expressing the ratio as a percentage. Fiber strength was measured on a stelometer in grams force/tex (gf/tex) and converted into kilonewtons meter/kg (k N m/kg). Micronaire was measured in standard units on a micronaire instrument. All quality analyses on cotton fiber were conducted by personnal in the Oklahoma State University Cotton Quality Research Laboratory.

Fertilizer and insecticide applications were made according to recommendations from state extension soil tests and by extension entomology field scouts. Forty-five kg/ha of N was applied as anhydrous ammonia in 1985. No fertilizer applications were made in 1984. Two applications of chlordimeform [N'-(4-chloro-o-tolyl)-N,N-dimethylformamidine] and pydrin [cyano(3-phenoxyphenyl) methyl-4-chloro-alpha-(1-methylethyl)benzeneacetate] were made in 1984 for control of tobacco budworm [(Heliothis virescens (F)] complex and boll weevil (Anthonomus grandis Boheman). No insecticide applications were made in 1985. In both years, trifluralin [2,6-dinitro-N,N-dipropyl-4-(trifluoromethyl)benzenamine] was applied preplant incorporated at 1.12 kg/ha for general weed control. Furrow irrigation was applied at various times throughout the growing season. In 1984, six irrigations supplied 30 to 35 cm of water. In 1985, early season environmental conditions were excellent for cotton establishment and growth. The experimental area received two irrigations which supplied 20 to 23 cm of water.

Cotton yield was determined by hand harvesting the two center rows of each four row plot on December 1, 1984 and December 19, 1985. At that time, estimates of weed weight were obtained by harvesting

above ground hogpotato growth. Using the estimate of pulled lint percent, seed cotton yields from each plot were converted into lint yield and expressed in kg/ha.

All data were subjected to analysis of variance. Data are discussed as individual years since planting dates varied by 23 days, treatment numbers increased the second year, and two different cultivars were used. The authors realize that a combined analysis could have been conducted, however, due to the reasons mentioned above and difference in the growing seasons for the two years, a discussion by year was chosen.

Soil samples were collected from three hogpotato infested sites in southwestern Oklahoma. At each of these locations, soil samples were collected from three areas in the field containing the hogpotato infestation. Samples were collected with a 1.9 cm i.d. probe in 15 cm increments to a depth of 60 cm. Ten cores were collected from each of three areas in the field; inside the infestation, around the perimeter of the infestation, and well outside the infestation. The ten samples from each area were composited by depth and area and analyzed by the Oklahoma State University Soils Testing Laboratory. Analysis included measurements of pH, total soluble salts, sodium adsorption ratio (SAR), exchangeable sodium percentage (%ESP), percent sodium, and concentrations of $Na^{+}$,$Ca^{++}$,$Mg^{++}$, $NO_3^{-}$,$Cl^{-}$,$SO_4^{-}$, and $HCO_3^{-}$. For purposes of comparision, similar data from a location near Stillwater, Oklahoma (Bethany Silt Loam, Pachic Paleustolls) is included. Hogpotato was propagated and grew well for two years at this location.

Several experiments designed to evaluate the potential allelopathic effects of hogpotato plant extracts on cotton seed

germination were conducted. Included were experiments involving the propagule, leaves, and soil samples collected from infested areas. Initial bioassays involving aqueous extracts of ground hogpotato propagules and leaves evaluated cotton seed germination at concentrations up to 15 mg of extract per germination dish. Later experiments involved extractions of plant parts and soil using 50 and 100% methanol and dichloromethane.

## RESULTS AND DISCUSSION

In 1984, full season hogpotao interference reduced cotton lint yield by over 99% (Table 1). Hogpotato dry matter production, measured just prior to harvest, amounted to approximately 2800 kg/ha. Bolls harvested from the weedy plots were smaller and poorly developed when compared to bolls from weed free plots. Pulled and picked lint percents were also significantly reduced by hogpotato interference. These percents may have an influence on ginning costs to the producer (3). Fiber length, strength, and micronaire (fineness) are the three fiber properties that determine the price the producer receives for his lint (3). In the initial experiment all three fiber length parameters, 2.5% span, 50% span, and uniformity index were reduced by hogpotato interference. Fiber fineness, measured in micronaire units, was also reduced by hogpotato interference. The acceptable range for micronaire is from 3.5 to 4.9 micronaire units with a value of 3.5 considered fine and a value of 4.9 coarse. Price penalties exist beyond each extreme and are more severe at values less than 3.5. Fiber strength was not influenced by hogpotao interference, however, this is generally considered to be a genetically inherited trait that is not appreciably influenced by environment.

In the expanded 1985 experiment full season hogpotato interference reduced cotton lint yield by approximately 58% (Table 2). Dry weed weight taken at harvest indicated a hogpotato biomass of 4700 kg/ha, 40% more than in 1984. Late season interference, or that allowed to occur after 7 weeks of weed free maintenance reduced yield by only 5%, not statistically significant. Hogpotato biomass in this treatment was approximately 1650 kg/ha. Early season weed interference, or that allowed to occur for the first 7 weeks after crop emergence before removal for the remainder of the season, reduced lint yields by 41%. In contrast to 1984, no effects on fiber length, strength, or micronaire were observed. Statistical differences in pulled and picked lint percents were observed with the early season weed interference treatment, but not in the full season weed interference treatment.

Cotton plant height, measured during the growing season, indicated that height was reduced by the first week in July of each year (Table 3). In 1984, height reduction from the full season interference treatment ranged from 28% on July 6 to 52% on August 15. A reduction in cotton plant height of 44% was observed on November 3, approximately 4 weeks before cotton harvest. Comparison of full season weed free maintenance or weed interference in the 1985 experiment gave similar results. A reduction of 16% was observed on July 5 and plant height was reduced 36% on December 19, the day of cotton harvest. Hogpotato was allowed to infest or was removed from the cotton plots on July 16 or about 2 weeks before the July 30 measuring date. Our data indicate that the late season infestation reduced cotton plant height by only 6 cm. Removal of the hogpotato

after early season interference enabled the cotton plant to attain a height to within 4 cm of the weed free check. Although cotton plant height recovered well, lint yield was still reduced by 41% while the late season infestation reduced yield by only 5% (Table 2).

Measured soil parameters are presented in Table 4. The statistical analysis conducted on these data considered locations (Altus, Hollis, Humphreys) as replications and the following interaction terms were pooled and used as an estimate of experimental error; location by depth, location by area sampled, and location by depth by area sampled. The analysis indicated that there was no depth by area interaction for any of the soil parameters measured. Area (infested, tranitional, and weed free) main effects, averaged over depths, indicated statistically significant effects at the 5% level of probability for pH and bicarbonate ($HCO_3^-$). The average pH value for the weed free and tranitional areas was 7.1, significantly greater than the pH value of 6.9 observed in the infested area. Although a statistically significant difference was observed, it is doubtful that the difference is important agronomically. Other researchers (1,5) have stated that hogpotato is commonly found on alkaline soils. Our results indicate that hogpotato is just as likely to be found on soils that do not have an alkaline pH. The bicarbonate analysis indicated that the infested area contained 556 ppm, significantly less than the weed free area (961 ppm) and the transitional area (662 ppm).

Also presented in table 4 are soil parameters determined from a previously hogpotato free area near Stillwater. After sampling, hogpotato was established on the area in order to evaluate vegetative growth and spread. Growth and vegetative spread was excellent during

a two year study. Although no statistical information is presented for this data, a comparison of the Stillwater values with values from other locations suggests that none of the parameters measured influenced hogpotato growth and spread.

Aqueous, methanol, and dichloromethane extracts failed to inhibit cotton seed germination when compared to control treatments. The initial experiments are not intended to suggest that allelopathic effects can be ruled out. Efforts aimed at isolation and identification of allelopathic compounds will require much additional time and effort.

The data presented indicate that hogpotato infestations can cause severe lint yield reductions if allowed to interfere for the entire season. Data from the 1985 experiment showed that early season weed interference was much more detrimental to lint yield than was late season weed interference. This data reinforces the opinion that early season weed control is critical for optimum cotton production.

The detrimental effects observed in the fiber properties of micronaire and length in 1984 were partly caused by environmental factors. The later planting date combined with a killing freeze in late September shortened the growing season to approximately 118 days. The effects observed on fiber quality in 1985 probably give a more realistic representation of what effects hogpotato may have on fiber quality. The 1985 fiber data would tend to support the findings of Rushing (7,8) and Mercer (4) who found only occasional effects on fiber quality from weed competition. The effects observed on fiber quality and yield in 1984 may have been due to delayed cotton maturity caused by hogpotato interference combined with a short growing season.

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Table 1. Effect of full season hogpotato interference on cotton lint yield and fiber quality- 1984.[a]

| TREATMENT | LINT YIELD | PULLED LINT | PICKED LINT | FIBER LENGTH SPAN 2.5% | FIBER LENGTH LNTH 50% | UNIFOR INDEX | MICRO-NAIRE | STRENGTH |
|---|---|---|---|---|---|---|---|---|
| | kg/ha | -----(%)----- | | ----(mm)---- | | ratio | units | kN m/kg |
| WEED FREE FULL SEASON | 479a | 27.7a | 36.2a | 28.0a | 13.5a | 48.2a | 4.4a | 205 |
| WEED INTER. FULL SEASON | 7b | 21.4b | 32.1b | 25.4b | 11.4b | 45.0b | 2.6b | 201 |
| LSD (0.05) | 79 | 3.1 | 2.8 | 0.8 | 1.3 | 3.9 | 0.8 | NS |
| C.V. (%) | 15 | 6 | 4 | 1 | 4 | 4 | 10 | 33 |

[a]Within each column, values followed by the same letter are not significantly different at the 5% level according to LSD test.

Table 2. Effect of full season hogpotato interference on cotton lint yield and fiber quality- 1985.[a]

| TREATMENT | LINT YIELD | PULLED LINT | PICKED LINT | FIBER LENGTH SPAN 2.5% | FIBER LENGTH LNTH 50% | UNIFOR INDEX | MICRO-NAIRE | STRENGTH |
|---|---|---|---|---|---|---|---|---|
| | kg/ha | -----(%)----- | | ----(mm)---- | | ratio | units | kN m/kg |
| WEED FREE FULL SEASON | 638a | 30.7a | 38.3a | 25.1 | 12.2 | 48.6 | 4.8 | 199 |
| WEED FREE 7 WKS | 607a | 30.7a | 38.3a | 25.4 | 12.7 | 50.0 | 4.8 | 201 |
| WEED INTER. 7 WKS | 377b | 28.8b | 36.6b | 25.4 | 12.2 | 48.0 | 4.5 | 200 |
| WEED INTER. FULL SEASON | 269c | 30.4a | 38.7a | 25.1 | 11.9 | 47.4 | 4.7 | 200 |
| LSD (0.05) | 93 | 1.5 | 1.0 | NS | NS | NS | NS | NS |
| C.V. (%) | 12 | 3 | 2 | 2 | 4 | 3 | 6 | 32 |

[a]Within each column, values followed by the same letter are not significantly different at the 5% level according to LSD test.

Table 3. Cotton plant height as affected by hogpotato interference.[a]

| TREATMENT | 1984 | | | | 1985 | | | |
|---|---|---|---|---|---|---|---|---|
| | 7/6 | 7/23 | 8/15 | 11/3 | 7/5 | 7/30 | 8/21 | 12/19 |
| | (cm) | | | | | | | |
| WEED FREE | 14a | 35a | 61a | 77a | 25a | 51a | 57a | 61a |
| WEED FREE 7 WKS | - | - | - | - | 25a | 48a | 56a | 55a |
| WEED INTER. 7 WKS | - | - | - | - | 21b | 34b | 51b | 57b |
| WEED INTER. FULL SEASON | 10b | 18b | 29b | 43b | 21b | 29c | 33c | 39c |
| LSD (0.05) | 3.2 | 4.1 | 3.5 | 9.6 | 2.2 | 3.6 | 4.5 | 2.4 |
| C.V. (%) | 19 | 12 | 12 | 11 | 15 | 14 | 14 | 7 |

[a]Within each column, values followed by yhe same letter are not significantly different at the 5% level according to LSD test.

Table 4. Comparison of various soil characteristics from hogpotato infested, transitional, and weed free areas from four locations in Oklahoma.

| DEPTH (cm) | SAR [a] | %ESP [b] | pH | PPM SALT | $Na^{+}$ | $Ca^{++}$ | $Mg^{++}$ | $NO_3^-$ | $Cl^-$ | $SO_4^-$ | $HCO_3^-$ | LOCATION |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 to 15 Infested | 8 | 9 | 6.7 | 4435 | 575 | 314 | 70 | 17 | 2230 | 1065 | 464 | ALTUS |
| 0 to 15 Transitional | 7 | 8 | 7.0 | 4138 | 581 | 346 | 85 | 15 | 2227 | 689 | 354 | ALTUS |
| 0 to 15 Weed Free | 8 | 9 | 7.3 | 4099 | 631 | 317 | 73 | 20 | 2127 | 731 | 450 | ALTUS |
| 15 to 30 Infested | 7 | 8 | 6.9 | 8670 | 728 | 584 | 129 | 7 | 1529 | 2127 | 591 | ALTUS |
| 15 to 30 Transitional | 7 | 8 | 7.0 | 5720 | 701 | 554 | 124 | 11 | 1929 | 1900 | 418 | ALTUS |
| 15 to 30 Weed Free | 8 | 9 | 7.1 | 6197 | 842 | 556 | 129 | 12 | 1657 | 1795 | 636 | ALTUS |
| 30 to 45 Infested | 7 | 8 | 6.8 | 10163 | 1148 | 1520 | 351 | 7 | 1465 | 7870 | 468 | ALTUS |
| 30 to 45 Transitional | 6 | 7 | 6.9 | 10534 | 1159 | 1920 | 417 | 6 | 1757 | 8914 | 550 | ALTUS |
| 0 to 45 Weed Free | 8 | 9 | 6.6 | 10078 | 1268 | 1453 | 357 | 8 | 1565 | 6722 | 654 | ALTUS |
| 45 to 60 Infested | 9 | 10 | 7.0 | 9405 | 1459 | 1353 | 434 | 5 | 1979 | 7014 | 354 | ALTUS |
| 45 to 60 Transitional | 8 | 9 | 7.0 | 11326 | 1409 | 1453 | 428 | 7 | 2171 | 6033 | 504 | ALTUS |
| 45 to 60 Weed Free | 10 | 11 | 6.9 | 11880 | 1662 | 1386 | 484 | 9 | 2302 | 7661 | 945 | ALTUS |
| 0 to 15 Infested | 2 | 2 | 7.2 | 8910 | 395 | 1987 | 160 | 16 | 809 | 6534 | 1236 | HOLLIS |
| 0 to 15 Transitional | 2 | 2 | 7.2 | 10593 | 445 | 2522 | 227 | 18 | 450 | 11940 | 100 | HOLLIS |
| 0 to 15 Weed Free | 3 | 2 | 7.1 | 8336 | 439 | 1653 | 165 | 12 | 967 | 6429 | 1000 | HOLLIS |

4. continued

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15 to 30 Infested | 3 | 2 | 7.1 | 11920 | 542 | 2806 | 254 | 7 | 742 | 10876 | 977 | HOLLIS |
| 15 to 30 Transitional | 2 | 2 | 6.9 | 9108 | 484 | 2772 | 240 | 12 | 381 | 9289 | 445 | HOLLIS |
| 15 to 30 Weed Free | 3 | 2 | 7.1 | 11326 | 512 | 2538 | 261 | 8 | 751 | 9832 | 1027 | HOLLIS |
| 30 to 45 Infested | 3 | 3 | 6.8 | 9643 | 587 | 1971 | 222 | 4 | 664 | 9477 | 223 | HOLLIS |
| 30 to 45 Transitional | 4 | 4 | 7.0 | 8811 | 648 | 1620 | 220 | 10 | 884 | 7223 | 59 | HOLLIS |
| 30 to 45 Weed Free | 3 | 3 | 7.1 | 11108 | 670 | 2388 | 301 | 7 | 826 | 10396 | 1463 | HOLLIS |
| 45 to 60 Infested | 5 | 5 | 7.0 | 10514 | 912 | 1870 | 342 | 6 | 1935 | 10918 | 241 | HOLLIS |
| 45 to 60 Transitional | 3 | 3 | 7.1 | 13563 | 762 | 3323 | 414 | 6 | 1037 | 9456 | 214 | HOLLIS |
| 45 to 60 Weed Free | 3 | 3 | 7.2 | 8950 | 606 | 1954 | 264 | 4 | 653 | 8580 | 1009 | HOLLIS |
| 0 to 15 Infested | 4 | 4 | 7.0 | 3604 | 381 | 484 | 77 | 65 | 1974 | 877 | 791 | HUMPHREYS |
| 0 to 15 Transitional | 5 | 5 | 7.3 | 3059 | 339 | 269 | 47 | 37 | 1193 | 250 | 1718 | HUMPHREYS |
| 0 to 15 Weed Free | 6 | 6 | 7.3 | 2924 | 364 | 235 | 42 | 57 | 1473 | 376 | 1104 | HUMPHREYS |
| 15 to 30 Infested | 5 | 6 | 6.8 | 3887 | 434 | 367 | 65 | 58 | 2274 | 480 | 609 | HUMPHREYS |
| 15 to 30 Transitional | 6 | 6 | 7.2 | 3637 | 434 | 316 | 55 | 32 | 1790 | 313 | 1341 | HUMPHREYS |
| 15 to 30 Weed Free | 6 | 7 | 7.5 | 2960 | 420 | 262 | 43 | 20 | 2091 | 271 | 1132 | HUMPHREYS |
| 30 to 45 Infested | 7 | 7 | 7.1 | 5742 | 651 | 546 | 102 | 51 | 306 | 1503 | 645 | HUMPHREYS |
| 30 to 45 Transitional | 7 | 8 | 7.3 | 5128 | 631 | 494 | 77 | 26 | 1924 | 1002 | 1241 | HUMPHREYS |
| 30 to 45 Weed Free | 7 | 8 | 7.4 | 4138 | 570 | 359 | 58 | 24 | 1882 | 751 | 941 | HUMPHREYS |

4. continued

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 45 to 60 Infested | 9 | 10 | 7.0 | 6692 | 903 | 586 | 127 | 69 | 3809 | 1440 | 77 | HUMPHREYS |
| 45 to 60 Transitional | 8 | 9 | 7.5 | 7682 | 931 | 751 | 135 | 22 | 2257 | 2547 | 1000 | HUMPHREYS |
| 45 to 60 Weed Free | 9 | 10 | 7.5 | 7484 | 887 | 606 | 109 | 18 | 2744 | 2714 | 1173 | HUMPHREYS |
| 0 to 15 Weed Free | 2 | 2 | 6.6 | 1251 | 145 | 205 | 38 | 13 | 1298 | 417 | 1268 | STILLWATER |
| 15 to 30 Weed Free | 1 | 0 | 6.1 | 911 | 50 | 99 | 20 | 6 | 1982 | 214 | -- | STILLWATER |
| 30 to 45 Weed Free | 1 | 0 | 6.2 | 780 | 47 | 80 | 17 | 6 | 1826 | 207 | -- | STILLWATER |
| 45 to 60 Weed Free | 1 | 0 | 6.1 | 729 | 50 | 70 | 13 | 7 | 2104 | 207 | -- | STILLWATER |

[a]SAR= sodium adsorption ratio.
[b]%ESP= exchangeable sodium percentage.

VITA

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Doctor of Philosophy

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