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Use of Short-Term Floods as an Additional Management Strategy for Controlling Dodder (Cuscuta gronovii Willd.) in Commercial Cranberry Production

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USE OF SHORT-TERM FLOODS AS AN ADDITIONAL MANAGEMENT STRATEGY FOR CONTROLLING DODDER (*CUSCUTA GRONOVII* WILLD.) IN COMMERCIAL CRANBERRY PRODUCTION

A Thesis Presented

by

JAMES M. O'CONNELL

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DEDICATION

To my mother, for her encouragement throughout my life's endeavors and to my father, whom I know is proud of me.

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I would like to thank the following people for all that they have done for me:

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Last, but most certainly not least, my beautiful Christina. Your love and encouragement came near the end when it's easiest to lose sight of one's goal.

ABSTRACT

USE OF SHORT-TERM FLOODS AS AN ADDITIONAL MANAGEMENT STRATEGY FOR CONTROLLING DODDER (*CUSCUTA GRONOVII* WILLD.) IN COMMERCIAL CRANBERRY PRODUCTION

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Dodder (*Cuscuta gronovii* Willd.) is a weed of serious concern to cranberry (*Vaccinium macrocarpon* Ait.) growers. It develops vigorously and has a long-lived seed bank. Cranberries are a perennial crop and therefore strategies available to growers of annual crops are not practical. Herbicides, the primary management tool for dodder, although effective, have a narrow window of application and extended seedling emergence after applications can result in escapes. This project examined the effect of water temperature on dodder seed germination and the use of short-term floods (less than 72 hr) for dodder management.

Experiments investigated the effect of water temperature on dodder seed germination. Studies, ran twice, submerged dodder seed in water for 0 to 48 hr at 10, 15, and 20 C in one experiment (simulating spring water temperatures) and 0 to 48 hr at 15, 20, and 25 C in a separate experiment (simulating summer water temperatures). In Run 1, the effect of temperature on percent seed germination varied by flood duration; and by temperature alone in Run 2. Percent seed germination however, always fell within normal ranges (35-59%), indicating that flooding may not impact seed germination.

Two 1-yr field studies were conducted to evaluate the use of short-term floods (24 to 48 hr) for managing dodder in cranberries. Two scenarios were simulated: cranberry beds with no emergent weed populations (cranberries alone) and cranberries with emergent weed populations (cranberries with additional host). There were three flood durations (0, 24, and 48 hr) and four flood initiations (1 to 4 wk after first seedling emergence). In 2006, mean percent germination from seeds incubated in Petri dishes was lower for seeds submerged 3 and 4 wk after first emergence (AFE) for the 48-hr flood durations. In 2007, mean percent germination for seeds submerged for 24 and 48-hr decreased for floods initiated at 4 wk AFE. Flooding 4 wk AFE resulted in lowest mean attachment ratings in both years and lowest mean dodder biomass on cranberry in the 2007 cranberry and tomato study, suggesting later flood initiation may provide better dodder management.

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CHAPTER 1

INTRODUCTION

Cranberry and dodder background

Growth characteristics of dodder. Dodder (*Cuscuta gronovii* Willd.) is a serious pest in cranberries (*Vaccinium macrocarpon* Ait.). It is a parasitic plant characterized by slender, thread-like yellow-orange twining stems (Ashton and Santana 1976). Dodder is an annual weed that can be problematic in both annual and perennial crop systems. Its vigorous growth habit, combined with a long-lived seed bank, makes management difficult. A single plant can produce thousands of seeds (Stevens 1957). In addition, yield losses in cranberries associated with dodder can range up to 80-100% (Devlin and Deubert 1980).

Dodder has become a greater concern to cranberry growers during the latter part of the 20th century because of changes in the culture of cranberries. Prior to the 1960's, cranberry bogs were flooded until mid-May for winter and frost protection (Franklin 1914). With the widespread use of solid-set sprinkler systems, growers reduced the duration of winter floods. Prior to the 1960's, cranberries were dry harvested with mechanical picking machines or by hand (Eck 1990). Since then, most bogs are flooded shallowly and mechanical harvesters with water reels are used to remove the fruit (water harvesting). This harvest method facilitates the spread of dodder since the mechanical harvesters that remove the berries from the vine also disperse the buoyant dodder seed capsules into flood waters (H. Sandler, pers. comm.). As the flood waters are moved from one section of a bog to another, they deposit seed that can germinate over the next several years.

Dodder is an obligate parasite, requiring a host to survive. Although dodder is initially dependent on stored seed energy, it is physically and metabolically linked to the host after attachment (Ashton and Santana 1976). Dodder produces specialized structures called haustoria that penetrate the vascular tissues of the host. When parasitism is successful, dodder can have multiple attachments that create a dense mat reducing the amount of light penetrating into the plant canopy. Light reduction, combined with the removal of water and nutrients from the cranberry vine by the haustoria, can lead to reduced yields (Devlin and Deubert 1980).

Cranberry description. The American cranberry is indigenous to North America and is one of only three native fruits grown commercially in the U.S. (Eck 1990). It is closely related to the small cranberry (*V. oxycoccus* L.) and the lingonberry (*V. vitis-idaea* L.), which are found throughout Europe, Asia, and parts of North America (Eck 1990). It is a low-growing, slender, vine-like woody perennial that can remain commercially productive for decades. The cranberry industry is of large economic importance to Massachusetts, with 2008 sales valued at $88.06 million (National Agricultural Statistics Service 2010). Massachusetts cranberry growers currently cultivate about 14,000 acres. The price per barrel of cranberries in Massachusetts for 2008 was $48.80 dollars per barrel (100 pounds) (National Agricultural Statistics Service 2010).

Cranberry belongs to the Ericaceous family and is commonly found in wetland areas. It produces short vertical branches 5 to 20 cm in height, called uprights, and long prostrate branches from 1 to 2 m in length, called runners (Eck 1990). Runners colonize the open soil, while the uprights produce flowering and vegetative buds. Flowering buds produce uprights that bear fruit, while vegetative buds produce uprights with foliage only.

Management strategies. Because of the perennial nature of cranberries, growers have limited control options for dodder. Unlike annual crops, which use crop rotation, resistant varieties, and different planting times to control dodder (Lanini and Kogan 2005), cranberries cannot be rotated annually. Furthermore, unlike tomatoes (*Lycopersicon esculentum* Miller), where resistant varieties have been developed (Goldwasser 2001), the susceptibility of various cranberry cultivars to dodder is not known.

Chemical herbicides (e.g., dichlobenil, mesotrione) are the predominant method available to cranberry growers for dodder management (Sandler 2010). Currently, most options involve preemergence applications, and although effective, extended dodder germination can result in escapes (Sandler and Ghantous 2007). Growers currently spend \$59.70-\$119.4/acre/season on dichlobenil and \$15.94-\$31.88/acre/season (depending on one or two applications within the labeled rate) on mesotrione to manage dodder (M. Utley, pers. comm.). Postemergence control options include raking (Hunsberger et al. 2006), hand-pulling, and the application of household cleaning products (Morrison et al. 2005). Control with microorganisms such as *Alternaria destruens* strain 059 (Smolder®) has not been successful in field trials (Sandler et al. 2010). Postemergence control with glyphosate, though effective in alfalfa (Dawson 1989; Dawson 1990), is not a viable option for cranberries since the herbicide will injure the vine (Ghantous et al. 2009; Shawa 1980). Two newly tested herbicides, mesotrione and quinclorac, may work as postemergence controls. Mesotrione reduced dodder seed viability (Sandler and O'Connell 2010), and initial tests with quinclorac (dry formulation manufactured by BASF) reduced early postemergence dodder populations (J. Colquhoun, unpublished data). Further testing of these compounds is needed to determine efficacy on dodder.

Flooding is an important management tool used by growers to protect plants from the cold and drying winds of winter and to manage many insect pests (DeMoranville 2008). Growers currently use 48-hr floods in mid-May as a management option for black-headed fireworm (*Rhopobota naevana* Hubner). Demonstration-style studies (field studies that may not meet the standards of conventional experimental design but provide quantitative data that are typically more informative than anecdotal observations*)* to study this flooding practice as a management tool for dodder have produced varied results (Sandler and Mason 2010) Controlled studies have not been conducted to determine the effect of flooding and various environmental factors on dodder.

Temperature of the flood water is also an important factor for cranberry growers to consider. Flood water temperatures that are too warm can negatively impact stored carbohydrates in cranberry and reduce yields (Botelho and Vanden Heuvel 2006). Seed germination, in general, is also affected by temperature, declining above an optimal level (Hartman et al. 1997).

The focus of this thesis is to evaluate several parameters that could maximize the use of short-term floods (24 to 48 hr) as a management tool for dodder in cranberries. I hypothesize that flood duration, flood timing, and water temperature affect dodder seed germination and attachment. I further hypothesize that the presence of an additional herbaceous host may favor dodder attachment and decrease the effectiveness of flood management.

CHAPTER 2

MATERIALS AND METHODS

Effects of water temperature on dodder seed germination.

Spring flood temperatures. The intent of this study was to test the hypothesis that water temperature of early spring floods affects dodder seed germination. Three temperatures (10, 15, and 20 C) were evaluated. These temperatures represent a reasonable range of temperatures for flood waters on cranberry farms in the spring in Massachusetts (J. Vanden Heuvel, pers. comm.). For this experiment, 100 scarified seeds, determined by weight (as described in general study design section below) were placed into cloth seed pouches and submerged for 0, 24, and 48 hr at the desired temperature. Thirty-six pouches (3 flood durations by 3 temperatures by 4 replicates) were used in each run for this study, with a total of 2 runs. Pouches were made from cotton sheets that were cleaned and cut into 10.2 cm squares. They were then stitched on three sides, with the top open. Once seeds were placed in the pouches, the top was folded over twice and stapled shut (to prevent seeds from escaping).

Four Fisher brand incubators were used for this study. Inside each incubator, there was a single water-filled 19-L plastic container. The incubators functioned as the replicates for this study, which was conducted over a 3-wk period. Each week, all four incubators were set to the same temperature. Inside each incubator was a single mercury thermometer used to monitor temperature. Incubators and electrical systems were checked daily to assure no power interruptions occurred during the course of the study, and that the incubators were operating at the proper temperatures. It is important to note, though, that the effects of week on these results cannot be entirely disregarded since the temperature for each treatment were carried out over each week (i.e., 10 C in week 1, 15 C in week 2, etc). The containers were placed inside the incubators, and were allowed to thermoequilibrate at each temperature level for at least 24 hr before submerging seeds. Seeds in pouches representing the 0 hr treatment were planted directly to Petri dishes. The remaining 2 pouches/container/incubator (i.e., 1 pouch for each treatment with a total of 4 pouches from the 4 incubators) were submerged and removed after 24 or 48 hr as appropriate. Seeds from each pouch were planted as a group, with the contents of one pouch per Petri dish that contained a 50:50 sand:peat mix. They were incubated at 22 C for at least 3 wk in the dark. During this incubation period, the dishes were checked weekly for dodder seed germination. Germinated seeds were counted, removed, and percent germination was determined.

Summer flood temperatures. To further define the best management practices for short summer floods as a postemergence dodder control, the procedure described above for spring floods was repeated using temperature levels of 15, 20, and 25 C and 12-hr flood durations. Sixty pouches were used for each run of this experiment (5 durations, 3 temperatures, 4 replicates) with a total of 2 runs. Research has shown that warmer flood temperatures (20 C) reduce stored carbohydrates in cranberry vines (Vanden Heuvel and Goffinet 2008). This reduction in stored carbohydrates may affect crop yield (Botelho and Vanden Heuvel 2006). As a result, this study used shorter (12-hr) collection times to examine if dodder control was obtainable at warmer temperatures and shorter flood durations. The pouches were submerged for 12-hr intervals for a maximum of 48 hr. After the 12-hr flood duration, pouches were removed and seeds planted as described above. Seed viability was evaluated in a similar manner to the spring temperature study.

Flood duration and initiation experiment.

General study design. The intent of this experiment was to examine the effect of duration and timing of initiation of short-term floods on dodder. Previous research indicated that emergent herbaceous weeds on cranberry bogs may serve as additional hosts for dodder (M.J. Else, unpublished data). Therefore, this experiment was designed to simulate two scenarios: cranberry beds with no weeds and cranberry beds with emergent weed populations. The two scenarios were established as separate studies to allow for simpler analysis of the data. Also, in the event of a catastrophic event (such as plant death), data loss from both studies was less likely if they were separated. Cranberries alone represented cranberry beds with no weeds, and cranberries with an additional host represented cranberry beds with emergent weed populations.

To reduce variability caused by environmental conditions, the short-term floods were simulated under controlled conditions inside of a growth chamber (Percival Scientific, Perry, IA 50220, Model No. PGC-10). The growth chamber was programmed to mimic environmental conditions on the bog in Massachusetts during mid-May. Lights were turned on and off gradually, starting at 6 AM and ending at 9 PM for a 15-hr day. Night temperature was 15 C, and was raised at a rate of 1 C per hour from 6 AM until the temperature reached 19 C at 2 PM. The temperature was then reduced from 4 PM to 11 PM. The growth chamber was started at least 24 hr in advance of the treatment application to allow the water to thermoequilibrate with the surrounding environment.

In both years, flood duration had three levels (0, 24, and 48 hr) and time of flood initiation had four levels (1, 2, 3 and 4 wk after first dodder seedling emergence). All treatment combinations were replicated 5 times. Prior to submersion, a portion of the seeds were planted directly to cranberries alone, to cranberries with alternate host, and to Petri dishes (representing the 0-hr flooding treatment). The seeds in Petri dishes were included in the study to assess germination in a controlled environment. The remaining pouches were submerged (six per bucket) in five 11-L plastic buckets inside a single Percival growth chamber. Each bucket was filled to a depth of 27 cm and pouches were held to the bottom with a weight. As each flooding time period elapsed, three pouches were removed from each bucket and the seeds were removed from each pouch and planted to a pot containing cranberry, to a pot containing cranberry with an additional host, or to a Petri dish. Seed germination and attachment were monitored as described below.

Vine propagation. Sand obtained from a local cranberry bog was sifted through various sized sieves to obtain the proper particle size used in cranberry production (DeMoranville and Sandler 2008; Gee and Bauder 1986). The peat moss (Southland®) was purchased from a local garden center as a 62-L compressed bale. The sand and peat were combined in 3:1 v:v mix in an electric cement mixer to thoroughly blend the sand and peat. Water was added periodically to evenly wet the mixture.

Pots used in were 10.2 cm in diameter for cranberries alone, and 15.2 cm in diameter for cranberries with the alternate host. Larger diameter pots used for cranberries with additional host plants allowed more room for plant growth and development. A

10.2x10.2 cm piece of Weedblock® landscape cloth (Easy Gardener Waco, TX), purchased from a local garden center, was placed in the bottom of each pot to help contain the sand-peat mix. Pots were filled to approximately 2 cm of the top edge and tamped down, taking care not to pack the mixture too tightly. In each pot, four uniform holes were made in the sand-peat mix with a pencil or similar sized item prior to planting the uprights.

Cranberry plants (cv. Stevens) were propagated from cuttings taken from State Bog at the University of Massachusetts Cranberry Station in East Wareham, MA. A common but unpublished method (T. Roper pers. comm.) among cranberry researchers was employed for upright propagation. Uprights at least 7 cm in length were cut with hand pruners from the established planting. Before planting in the pots, vines were cut to 7.6 cm lengths. Once cut, the uprights were kept damp at 5 C until planted into a sand-peat mix. Under these conditions, the cuttings will stay viable for 1 to 2 wk. Just prior to planting, the bottom 5 cm of leaves were stripped off the vine. Each upright was individually placed in the pre-made holes; no rooting hormone was used. The sand-peat mix was then used to fill in around the base of the upright. Pots were placed in the greenhouse and watered as needed for the next 2 to 3 wk, allowing the uprights to root. Tomato plants (cv. Early Girl) were purchased from a local garden center.

Dodder seed collection and preparation. Dodder seed for all experiments discussed in this paper was collected previously from commercial Massachusetts cranberry bogs. Dodder was removed with its host, taken back to the lab, placed on benches and allowed to air dry. Once the hosts and dodder dried, everything was placed into a paper bag, and stored at 21 C.

Dodder was removed from its host plant and placed on tray. Seed capsules were separated from all other plant material. The seed capsules were placed onto a fine mesh sieve (U.S. Standard Sieve, Sieve No. 100, 150 µm) and crushed repeatedly by hand in a back and forth motion, separating the seed from the capsules. Gently shaking the sieve separated the seeds from any remaining chaff. Using a stereoscopic microscope, the damaged seeds were visually assessed and sorted from the healthy seeds. The damaged seeds were discarded, and the healthy ones placed in labeled glass scintillation vials where they were stored at 21 C until needed.

Scarification. Working in small batches, dodder seed was scarified in concentrated sulfuric acid (36.8 N, Fisher Scientific, Pittsburgh, PA) to break dormancy (Gaertner 1950) with a modified soak time of 15 minutes. Once dried, seeds were first counted and weighed, then separated into batches of approximately 200 and 100 seeds for the 2006 and 2007 experiments, respectively. Average seed weight was first determined from four separate batches of 100 seeds. Once weighed, the allotment of seeds was placed into 11 cm x 11 cm cloth pouches (bed sheets purchased from a local department store). In total, 180 pouches (same as used in previous experiment) were used for this experiment.

Host selection. Pansy (*Viola x wittrockiana*) and tomato (cv. Early Girl) served as the additional host in the 2006 and 2007 experiments, respectively. Pansies were selected as an additional host because of their tolerance to early spring temperatures, and because they are succulent. Tomatoes were used as the additional host in 2007 since pansies was found to be an unsuitable host for dodder and tomatoes are known to be acceptable hosts (Lanini and Kogan 2005).

2006 Experiment. Since recent research indicated that peak dodder seedling emergence on cranberry bogs occurred 2 to 3 wk after first (seedling) emergence (AFE) (Sandler and Ghantous 2007), first seedling emergence was selected to be the biofix (a biological marker or starting point) for flood initiation. First emergence was determined by observing seed germination in plastic containers located off bog. These containers represented a simple system of simulated bogs, and were used to monitor the germination pattern of Massachusetts dodder seed for more than 10 years (Sandler and Ghantous 2007). Both studies (cranberries alone and cranberries with pansy) were initiated on May 7, 2006, 1 wk after first emergence (AFE) by placing the pouches into each bucket. After immersion for the appropriate duration, the pouches were removed from the water and seeds were planted as described above.

All pots were planted in a section of State Bog located at the University of Massachussetts Cranberry Station in East Wareham, MA to expose seeds to realistic environmental field and weather conditions. The site was prepared by hand-pruning runners in the plot area, and then cultivating it with a front tine, forward rotating, 23-cm width rototiller (Echo Incorporated, Lake Zurich, IL). For each study, there were a total of five rows with 12 plants per row (each row represented a replicate or block) spaced 0.5 m apart. Within each row, pots were spaced 0.25 m apart. Pots were planted with the rims above the soil line (approximately 6 to 8 cm deep in the soil). A 1.5 m space separated the cranberries with pansies study and cranberries alone study. Pots were arranged in a randomized complete block design.

All plants received 1 g of Osmocote® 14-14-14 slow-release fertilizer on May 5, 2006. Plants were irrigated by overhead sprinklers when the bog was irrigated, and received supplemental hand watering as needed. Cranberry plants potted with pansies as an additional host received 2.4 g/L of monopotassium phosphate (MKP) on June 22, 2006 to correct phosphorus deficiency in the pansies.

2007 Experiment. Based on the negative experience in the 2006 field experiment, the 2007 experiment was conducted in the greenhouse. Previous research indicated that dodder identifies volatile cues from tomato plants (Runyon 2006). Additionally, tomatoes were selected as an additional host because of their known susceptibility to dodder (Lanini and Kogan 2005). Both studies (cranberries alone and cranberries with tomatoes) were started on May 15, 2007, 1 wk AFE. Pouches were prepared and treated as described in the scarification and general study design sections for 2006. Dodder seeds were planted as described for the 2006 experiment after removal from pouches.

Cranberry uprights and tomato were planted as described for the 2006 experiment. The experiments were set up on a greenhouse bench, with 0.5 m between studies, 0.1 m between pots with cranberry only and 0.2 m between pots with cranberry and tomato (to allow the tomato plants room to grow and to limit the spread of dodder from host to host). Pots were arranged in a randomized complete block design with five replicates.

Both studies were fertilized with 0.39 g of Osmocote® 14-14-14 slow-release fertilizer on May 15, 2007. Pots containing cranberries and cranberries with tomato were supplemented with 100 ppm solution of potassium nitrate (KNO_3) once a week for the duration of the experiment. On May 16, 2006, tomato plants also received monopotassium phosphate (MKP) at the rate of 2.4 g/L water to correct phosphorus deficiency. Further treatment with MKP was made as needed. All plants were watered as needed.

Germination and attachment. Petri dishes were placed in an incubator at 22 C and checked weekly for dodder germination. Seedlings were counted, removed, and germination percentage was determined. Petri dishes were in the incubator for at least 3 wk. Experiments were maintained for six months (May through October). At the end of each experiment, dodder seed produced in the cranberry alone studies was collected by pot, while dodder produced in the cranberry and additional host studies was collected by cranberry and host, making certain to keep dodder seed found on cranberry separate from the dodder seed found on an additional host. All seed collected was tested for germination as described above.

Following inoculation, all pots were visually rated weekly for dodder infestation. A qualitative rating scale of 0 to 4 was used to assess the degree of dodder attachment to its host. A rating of 0 indicated there were zero attachments, a rating of 1 indicated scarce attachment (less than 3 stems), a rating of 2 indicated few attachments (4 to 6 stems), a rating of 3 indicated moderate attachments (6 to 10 stems), and a rating of 4 (more than 10 stems) indicated many attachments (see pictures in Appendix A for further explanation).

All aboveground plant biomass was collected October 27-30, 2006 and October 16-17, 2007 (cranberry and additional host) and October 24, 2007 (cranberry only). The vegetation was cut at soil level using hand pruners, one replicate at a time. Cranberry biomass, additional host biomass, dodder biomass, and dodder seed were separated and placed into individual paper bags. Plant biomass (cranberries and tomatoes) was dried at 60 C for at least 2 d, and the dry weights recorded. Dodder biomass and seeds were allowed to air-dry prior to recording their weights.

Statistics. All data were analyzed in SAS version 9.1. The incubator experiment was comprised of two studies (spring and summer), which each examined the effect of flood duration and water temperature on dodder seed germination. Percent dodder seed germination was first analyzed in PROC UNIVARIATE to test for normality. Data were found not to have a normal distribution and were therefore analyzed in PROC GENMOD. The model used in this procedure, with chi-square analysis, for the spring flood study consisted of three levels of temperature (10, 15 and 20 C), three levels of flood durations (0, 24 and 48-hr), two runs, and all combinations of interactions. The model for the summer flood study consisted of three levels of temperatures (15, 20, and 25 C) and five levels of flood durations (0, 12, 24, 36, and 48-hr), two runs, and all combinations of interactions. When significant treatment effects were noted for continuous independent variables (e.g., temperature), orthogonal polynomial contrasts were used to determine linear and quadratic relationships and regression lines were calculated and drawn as appropriate.

The flood duration and initiation experiment was set up as a randomized complete block design with 5 blocks. The effects of flood duration (0, 24, and 48-hr), week of initiation (1, 2, 3, and 4 wk AFE), block, and the interaction between flood duration and week of initiation on dodder biomass (dodder stem and seed) and total number of dodder seed produced were subjected to an analyses of variance using PROC GLM. Mean separation for significant treatment levels was performed using Tukey's Honestly Significant Difference test at P=0.05. When significant treatment effects were noted for continuous independent variables (e.g., flood duration), orthogonal polynomial contrasts were used to determine linear and quadratic relationships and regression lines were calculated and drawn as appropriate.

Attachment ratings were categorized as ordinal responses and ranged from 0 (no attachment) to 4 (severe infestation). Ordinal response variables are categorical rather than continuous, multinomial rather than Gaussian-distributed, multivariate rather than univariate, are not independent, and as such violate the assumptions of a standard analysis of variance (Schabenberger and Pierce 2002). Therefore, the effect of flood duration and week of initiation on dodder seed germination and attachment were analyzed in PROC LOGISTIC. Treatment effects for continuous independent variables were handled as described above.

The effect of flood duration and week of initiation on percent seed germination of seeds planted to Petri dishes was first tested for normality in PROC UNIVARIATE and was found not to have a normal distribution. One of the assumptions of the analysis of variance is that the model is normally distributed (Damon and Harvey 1987). Percentages from 0 to 100% or proportions from 0 to 1 form a binomial, rather than normal distribution (Zar 1999). Treatment effects for continuous independent variables were handled as described above.

CHAPTER 3

RESULTS AND DISCUSSION

Effects of water temperature on dodder seed germination

Both spring and summer flood temperature studies were repeated twice and there was a run by treatment interaction for each temperature study. Therefore, the results from each run will be discussed separately. In Run 1 of the spring flood simulation, the effect of flood duration on dodder seed germination varied by temperature (X^2 =24.27; df = 4; $p \leq 0.01$) (Table 1). Dodder seed germination at 10 C decreased linearly from 45% (0-hr duration) to 36% (24 and 48-hr durations) (Table 24). In Run 2 of the spring flood simulation, temperature was significant (X^2 =16.67; df = 2; p= 0.0127); however, the relationship between flood temperature and seed germination was not defined by a linear or quadratic response (Table 24).

In Run 1 of the summer flood simulation, the effect of flood duration on dodder seed germination varied by temperature (X^2 = 19.79; df = 8; p= 0.01) (Table 2). Dodder seed germination at 15 and 20 C exhibited a quadratic response at varying flood durations. Flood durations at 25 C were not significant. In Run 2 of the summer flood simulation, the effect of flood duration on dodder seed germination varied by temperature (X^2 = 10.86; df = 2; p= 0.004) and had a quadratic relationship (Table 25).

Although the interaction of temperature and flood duration for Run 1 and temperature alone for Run 2 were statistically significant in both studies, the mean germination values represented here fell within normal dodder seed germination ranges (H.A. Sandler, unpublished data), and likely did not reduce germination enough to have an expectation of negative impact from a management perspective. Herbicide field experiments conducted on dodder in alfalfa considered treatments effective when 95% of the dodder was controlled (Dawson 1971). Similarly, herbicide experiments done in cranberry and carrot (*Daucus carota*) considered treatments effective when 90% of the dodder was controlled (Bewick 1988). Although these previously published experiments were conducted in the field and with herbicides, the 90-95% criterion for control of dodder appears to be a realistic expectation and can be applied to this incubator experiment to place the results in some context.

If short-term floods were able to reduce dodder germination by 90-95%, one may theorize that over time dodder would become less of a problem. However, as previously stated, dodder seed germination fell within normal rates and therefore these results show that in a controlled environment, floods had no practical impact on seed germination. This conclusion supports work done by Sandler and Mason who also found that in demonstration style field work flooding reduced dodder stem weights, but did not impact seed germination (Sandler and Mason 2010) The results from the incubator experiment further suggest that since flooding did not affect dodder seed germination, it may instead affect actively growing stages such as emerging seedlings. This theory is supported by a study conducted on hairy beggarticks (*Bidens pilosa*) seedlings, in which results showed a decrease of emergent hairy beggarticks seedlings with increased duration of flooding (Reddy and Singh 1992). Results shown below for the flood duration and initiation experiment further support the premise that short-term floods are affecting dodder growth (i.e., biomass) and not seed germination.

Flood duration and initiation experiment

Germination data. In both years, the effect of flood duration on the percentage of germination in the Petri dish (Tables 3 and 4) varied by week of flood initiation (2006 $X^2 = 52.72$; $p \leq 0.01$; 2007 $X^2 = 17.06$; df = 6; p= 0.009). In 2006, flood initiations at 3 and 4 wk AFE had lower percent germination at the 48-hr flood duration, with the lowest percent germination overall at 4 wk AFE (Figure 9). This finding supports work that showed that short-term floods initiated later (3 wk AFE) reduced dodder growth (Sandler and Mason 2010).

In 2007, week of flood initiation was only significant at 3 wk AFE and showed a linear increase in percent germination (Figure 10), unlike in the 2006 experiment where percent germination declined at the 48-hr flood duration.

Attachment rating. Mean attachment ratings in 2006 were affected by flood initiation (wk AFE). Mean attachment ratings for cranberry alone (Figure 1) were lowest at 4 wk AFE for observations recorded on June 20 ($X^2 = 14.25$; df = 3; p= 0.003) (Table 5) and June 27, 2006 ($X^2 = 9.29$; df = 3; p= 0.03) (Table 6). There was no treatment effect seen for July 14, 2006 or later, suggesting that dodder may have senesced (data not shown).

Dodder parasitism of the pansies (2006 study) was unsuccessful. As dodder germinated and began actively searching for a host, it did not attach to the pansies. It was therefore decided not to analyze data from this study since no attachments were made to the additional host. Since pansies were not a favorable host for dodder, tomatoes were chosen as the additional host in 2007 for the cranberry and additional host study.

In the 2007 experiment, for both cranberries alone (Figure 2) and cranberries with tomato (Figure 3) mean attachment rating was lowest at 4 wk AFE. In the cranberry alone study, the effect of flood initiation at 4 wk AFE was observed for dates of July 13, 2007 ($X^2 = 13.49$; df = 3; p= 0.004) (Table 7) and August 6, 2007 ($X^2 = 14.95$; df = 3; p= 0.002) (Table 8). In the cranberry plus tomato study, the effect of flood initiation at 4 wk AFE was observed for dates of July 3, 2007 ($X^2 = 14.76$; df = 3; p= 0.002) (Table 9), July 13, 2007 ($X^2=13.68$; df = 3; p= 0.003) (Table 10) and July 19, 2007 ($X^2 = 11.97$; df = 3; p= 0.008) (Table 11). The inclusion of an additional, more succulent host may have provided an opportunity to support more vigorous dodder growth, resulting in no treatment effects seen after July 19, 2007.

The design of the 2006 and 2007 experiments focused on evaluating control of dodder through the use of short-term floods with durations no longer than 48-hr and floods initiated from 1 to 4 wk AFE. Previous research on flood studies for the control of dodder indicated short-term floods may be a viable option for dodder control (Sandler and Mason 2010). The results from the 2006 and 2007 flood experiments showed that attachment ratings were lowest at 4 wk AFE, indicating that a later flood initiation may provide better control of dodder than an earlier flood initiation. These results are supported by previous field research (Sandler and Mason 2010), which found that short-term floods initiated 1 wk after initial germination had no effect on dodder pouch seed germination in one year, while in another year, floods initiated 3 wk after initial germination reduced dodder stem weights.

Research conducted in rice (*Oryza sativa*) on two species of morning glory (*Ipomoea wrightii* and *I. lacunosa*) (Gealy 1998), a close relative of dodder, and texasweed (*Capernoia palustris*) (Koger et al. 2004) examined the effect of flooding on seed germination and emergent plants. In morning glory, a 13-cm flood in a controlled greenhouse environment was successful at reducing plant heights by more than 85% for both species. In addition, a 13-cm flood inhibited emergence of both species by at least 50% when initiated at the 2-cm emerged seedling stage (Gealy 1998). Similarly, in texasweed, germination was inhibited while the soil was constantly saturated or flooded 10 cm above the soil surface (Koger et al. 2004). However, floods had no effect on the survival of texasweed at any emergent growth stage when compared to the untreated control (Koger et al. 2004). These studies differ from the present study in that the uses of floods for dodder control in cranberries were short-term (24 and 48 hr) as compared to floods used in rice that were in excess of 6 wk.

Biomass. In the 2006 experiment (cranberry alone study), there was no effect of flood duration or initiation on dodder biomass or dodder seed biomass (Tables 12-13, Table 26). Mean total seed number (Table 14, Figure 10) was lower at the 48-hr flood duration than at the 24-hr flood duration ($F_{2,44}$ p=0.011). However, total seed number from the 48-hr flood duration was not significantly different from those of the untreated control. This result is contrary expectations since it was thought that flooding would reduce seed production. The effects seen may not be a true description of the effect of flood duration on dodder seed numbers since there were so few seeds produced per plant (1-6), and the standard errors (0.4-1.3) were so large. Future research might focus on validating the effect of flood duration on seed number while also ensuring good pollination and seed production.

In the cranberry with tomato study, dodder biomass present on the cranberry vine decreased linearly and was lowest with a flood initiation of wk 4 ($F_{3,44}$ p=0.04) (Table 15, Figure 4). This finding was consistent with the percent germination data and the attachment rating data, all of which had lower values when flooding was initiated 4 wk AFE. There was no effect of flood duration ($F_{2,44}$ p=0.29) or week of initiation ($F_{3,44}$ p=0.125) on dodder biomass on tomato (Table 18). It is unclear why the effects of flood duration and initiation on dodder biomass on tomato were not significant. One may speculate that with the additional host of tomato dodder produced large enough biomass to overcome the effects of flood duration and week of initiation. No other treatment effects were noted for the cranberry alone study (Tables 16-17, Table 27) or the cranberry with tomato study (Tables 19-23, Table 28) with respect to dodder productivity. These results are contrary to those found in a texasweed study where flooding at an earlier growth stage (2.5 cm tall plants) reduced plant biomass, but flooding at a later growth stage (7.5 cm and 15 cm tall plants) did not (Koger et al. 2004).

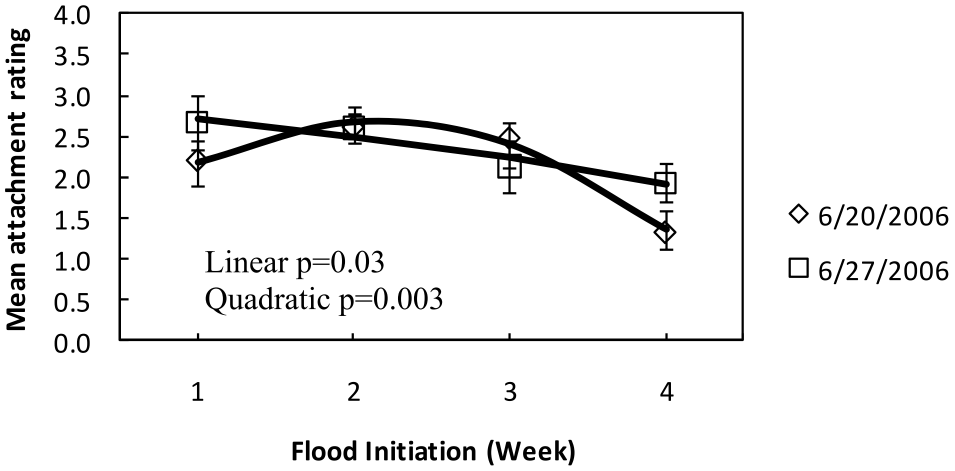

Figure 1. Mean attachment rating of dodder on cranberries alone at observation dates of June 20 and June 27, 2006. A rating of 0 indicated there were no attachments, 1

indicated scarce attachment, 2 indicated few attachments, 3 indicated good dodder attachments, and 4 indicated many dodder attachments.

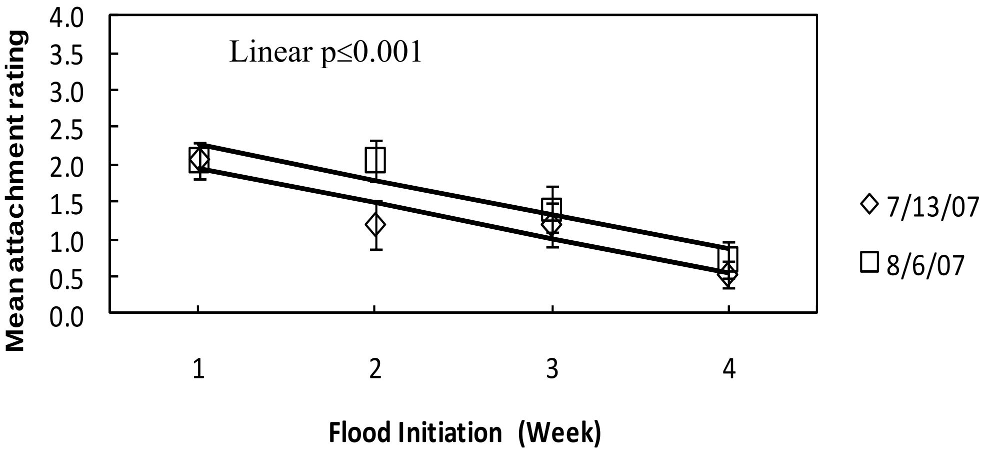

Figure 2. Mean attachment rating of dodder on cranberries alone following submersion in water for a certain number of weeks after first seedling emergence for several dates in July and August 2007. A rating of 0 indicated there were no attachments, 1 indicated scarce attachment, 2 indicated few attachments, 3 indicated good dodder attachments, and 4 indicated many dodder attachments. Dates of 7/19/07, 8/1/07, and 8/28/07 were also significant, but not included since dates in figure are representative of the effects seen on dodder attachment ratings.

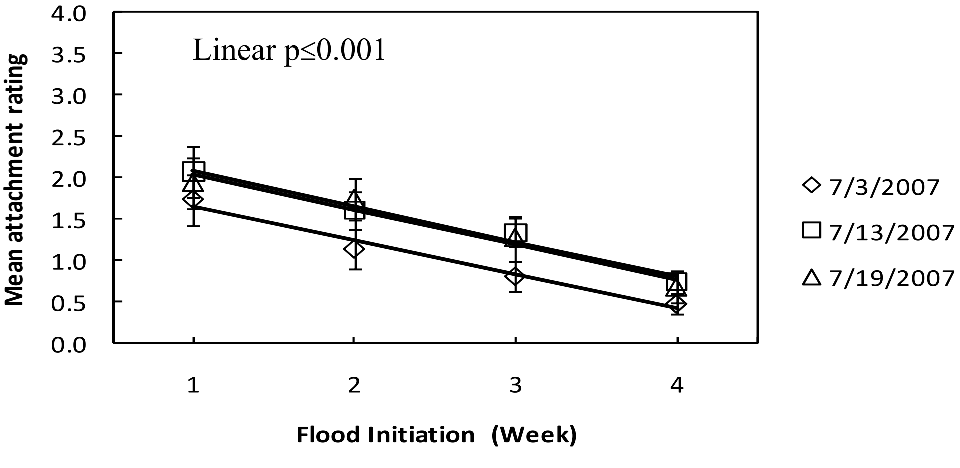

Figure 3. Mean attachment rating of dodder on cranberries (from cranberries with tomato study) following submersion in water for a certain number of weeks after first seedling emergence for several dates in July 2007. A rating of 0 indicated there were no attachments, 1 indicated scarce attachment, 2 indicated few attachments, 3 indicated good dodder attachments, and 4 indicated many dodder attachments

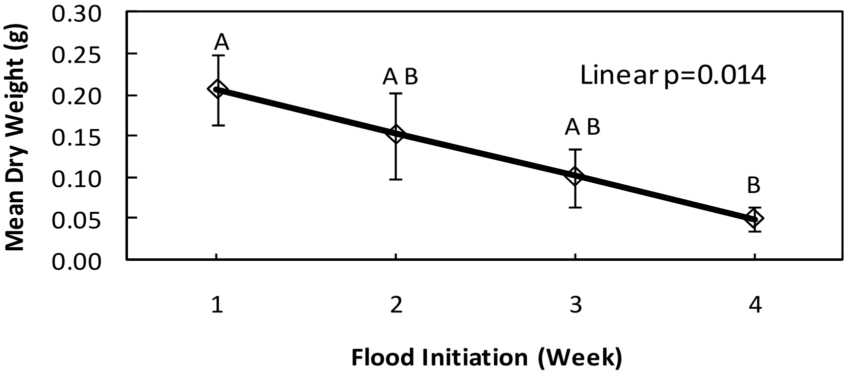

Figure 4. 2007. Mean dry weight of dodder on cranberry only subjected to floods initiated 1 to 4 wk after first seedling emergence. Mean separation with Tukey's HSD; means with the same letter are not significantly different.

CHAPTER 4

CONCLUSION

Experimental summary and discussion of future research

Summary. The effect of temperature on percent seed germination in the incubator experiment varied by flood duration in Run 1, and by temperature alone in Run 2. Percent seed germination however, always fell within normal ranges (35-59%), indicating that flooding may not impact seed germination and that reductions were likely not enough to translate into a measurable practical management impact. In the 2006 flood duration and initiation experiment, initiating a short-term flood 4 wk AFE resulted in the lowest mean attachment rating of dodder. This result was again seen in the 2007 flood duration and initiation experiment. In both studies of the 2007 experiment, mean attachment ratings for dodder were lowest at 4 wk AFE. Also in the 2007 cranberry and tomato study, short-term floods initiated 4 wk AFE resulted in the lowest mean dodder stem biomass. No effects of temperature, flood duration or week of initiation on dodder seed germination were noted, implying that flooding retards dodder stem growth rather than reducing seed germination.

Furthermore, in the 2007 cranberry and tomato study, there was no treatment effect of flood duration or initiation on attachment ratings observed after July 19, 2007. This result suggests that late season dodder growth was more vigorous when tomato was present.

Pansies were chosen as the additional host for the 2006 flood duration and initiation experiment since they are succulent plants and can tolerate early spring temperatures. However, as previously stated, dodder did not successfully attach to them.

In 2007, tomatoes replaced pansies as the additional host. Tomatoes were chosen because of their susceptibility to dodder. However, there was no effect of flood duration or week of initiation on dodder biomass on tomato. It may be that dodder produced large enough biomass on tomato to overcome the effects of flood duration or week of initiation. Additionally, maintaining tomatoes in acidic soil conditions (like those found on cranberry bogs) proved challenging. The tomato plants required constant fertilizer applications, as well as frequent applications of MKP to correct phosphorous deficiency. Future repetitions of these experiments may consider a host which is tolerant of acidic soils, tolerant of early spring temperatures like pansies, but requires less fertilizer input that the tomato plants.

Future research. Results from both the 2006 and 2007 experiments showed that short-term floods affected attachment ratings, with the lowest mean attachment rating at 4 wk AFE. These results indicate that one must allow time for dodder seed to germinate before applying a short-term flood, suggesting that the short-term floods may impact emergent dodder seedlings.

Based on that premise, additional areas of research to consider are flooding at various stages of dodder growth, such as early germinated seedlings, pre-attachment searching, and post-attachment growth stages, which may be more susceptible to a short-term flood than dodder seed. At 4 wk AFE, there may be more newly emergent seedlings, which may be more susceptible to a short-term flood. Therefore, it may be useful to explore floods initiated later than 4 wk AFE, to document the effect on dodder and cranberries, and to see if a flood initiated later will impact a greater proportion of susceptible growth stages.

As stated previously, dodder seed production was poor for this experiment. Future experiments should apply techniques to improve pollination. Improved pollination may help to increase overall the number of dodder seeds produced.

Future research into the use of short-term floods for dodder control should further examine the effect of an additional host plant on dodder biomass production. Results from the flood duration and initiation experiment found that floods initiated 4 wk AFE produced the lowest mean dodder attachment rating. Repeating the greenhouse experiment flood duration/initiation experiment with this flood initiation (4 wk AFE), cranberries alone, cranberries with an additional host, and 3 flood durations (0, 24, 48 hr) may provide more informative data on the use of short-term floods for dodder control when an additional host is present.

In addition to repeating the flood duration and initiation experiments in a greenhouse, it may also be beneficial to repeat them in a field environment. The flood duration and initiation experiment showed that floods initiated 4 wk AFE resulted in the lowest mean attachment rating of dodder. Repeating this experiment in the field would allow one to assess the impact of floods on dodder and cranberry growth under more realistic conditions. The cranberry bog at the University of Massachusetts Cranberry Station was renovated in 2007, and eight small flood beds (scaled down versions of cranberry bogs) were added. These beds would allow for replicated comparisons of short-term floods with non-flooded vines on various growth stages of dodder.

Figure 5. This picture represents an attachment rating of 1 (scarce) on a scale of 0-4.

Figure 6. This picture represents an attachment rating of 2 (few) on a scale of 0-4.

Figure 7. This picture represents an attachment rating of 3 (moderate) on a scale of 0-4.

Figure 8. This picture represents an attachment rating of 4 (heavy) on a scale of 0-4.

Table 1. GENMOD statistics output for percent germination of seeds from the spring temperature incubator study.

Source	df	Chi-Square	Pr > ChiSq
Temp	2	16.67	0.0002
Flood	2	1.59	0.4522
Run	1	9.14	0.0025
Temp*Flood	4	24.27	<.0001
Temp*Run	2	50.33	<.0001
Flood*Run	2	3.41	0.182
Temp*Flood*Run	4	17.76	0.0014

Table 2. GENMOD statistics output for percent germination of seeds from the summer temperature incubator study.

Source	df	Chi-Square	Pr > ChiSq
Temp	2	10.86	0.0044
Flood	4	2.20	0.6991
Run	1	33.61	<.0001
Temp*Flood	8	19.79	0.0112
Run*Temp	2	31.64	<.0001
Run*Flood	4	16.78	0.0021
Run*Temp*Flood	8	32.43	<.0001

Table 3. GENMOD statistics output for percent germination of seeds plated to Petri dishes from the 2006 flood duration and initiation study.

Source	df	Chi-Square	Pr > ChiSq
Week	3	160.50	<.0001
Flood	2	108.12	<.0001
Week*Flood	6	52.72	<.0001
Block	4	38.39	<.0001
Week*Block	12	82.62	<.0001
Flood*Block	8	47.16	<.0001
Week*Flood*Block	22	102.22	<.0001

Table 4. GENMOD statistics output for percent germination of seeds plated to Petri dishes from the 2007 flood duration and initiation study.

Source	df	Chi-Square	Pr > ChiSq
Week	3	6.50	0.0897
Flood	2	3.59	0.1664
Week*Flood	6	17.06	0.0091
Block	4	2.05	0.7267
Week*Block	12	25.76	0.0116
Flood*Block	8	17.08	0.0293
Week*Flood*Block	24	52.79	0.0006

Table 5. Logistic statistics output for attachment ratings on cranberry only for the 2006 (6/20/2006) flood duration and initiation study.

Model Fit Statistics

Criterion	Intercept	Intercept and Covariates
AIC	148.506	150.699
SC	154.789	180.020
-2 Log L	142.506	122.699

Type 3 Analysis of Effects

Effect	df	Wald Chi-Square	Pr > ChiSq
Week	3	14.246	0.003
Flood	2	0.824	0.662
Week*Flood	6	3.872	0.694

Table 6. Logistic statistics output for attachment ratings on cranberry only for the 2006 (6/27/2006) flood duration and initiation study.

Model Fit Statistics

Criterion	Intercept	Intercept and Covariates
AIC	160.463	163.202
SC	168.840	194.617
-2 Log L	152.463	133.202

Type 3 Analysis of Effects

Effect	df	Wald Chi-Square	Pr > ChiSq
Week	3	9.289	0.026
Flood	2	3.030	0.220
Week*Flood	6	7.950	0.242

Table 7. Logistic statistics output for attachment ratings on cranberry only for the 2007 (7/13/2007) flood duration and initiation study.

Model Fit Statistics

Criterion	Intercept	Intercept and Covariates
AIC	167.683	169.785
SC	173.966	199.106
-2 Log L	161.683	141.785

Type 3 Analysis of Effects

Effect	DF	Wald Chi-Square	Pr > ChiSq
Week	3.000	13.489	0.004
Flood	2.000	0.404	0.817
Week*Flood	6.000	5.159	0.524

Table 8. Logistic statistics output for attachment ratings on cranberry only for the 2007 (8/6/2007) flood duration and initiation study.

Criterion	Intercept	Intercept and Covariates
AIC	169.771	169.213
SC	176.054	198.534
-2 Log L	163.771	141.213

Type 3 Analysis of Effects

Effect	DF	Wald Chi-Square	Pr > ChiSq
Week	3	14.952	0.002
Flood	2	0.710	0.701
Week*Flood	6	6.545	0.365

Table 9. Logistic statistics output for attachment ratings on cranberry and additional host for the 2007 (7/3/2007) flood duration and initiation study.

Model Fit Statistics

Criterion	Intercept	Intercept and Covariates
AIC	152.972	153.142
SC	159.255	182.463
-2 Log L	146.972	125.142

Type 3 Analysis of Effects

Effect	df	Wald Chi-Square	Pr > ChiSq
Week	3	14.760	0.002
Flood	2	1.892	0.388
Week*Flood	6	5.380	0.496

Table 10. Logistic statistics output for attachment ratings on cranberry and additional host for the 2007 (7/13/2007) flood duration and initiation study.

Model Fit Statistics

Criterion	Intercept	Intercept and Covariates
AIC	171.820	171.050
SC	178.103	200.371
-2 Log L	165.820	143.050

Type 3 Analysis of Effects

Effect	DF	Wald Chi-Square	Pr > ChiSq
Week	3	13.682	0.003
Flood	2	2.533	0.282
Week*Flood	6	7.056	0.316

Table 11. Logistic statistics output for attachment ratings on cranberry and additional host for the 2007 (7/19/2007) flood duration and initiation study.

Model Fit Statistics

Criterion	Intercept	Intercept and Covariates
AIC	182.641	187.376
SC	191.019	218.791
-2 Log L	174.641	157.376

Type 3 Analysis of Effects

Effect	DF	Wald Chi-Square	Pr > ChiSq
Week	3	11.972	0.008
Flood	2	2.148	0.342
Week*Flood	6	4.277	0.639

Table 12. ANOVA table for dodder stem biomass on cranberry only for the 2006 flood duration and initiation study.

Source	df	SS	F	Pr > F
Block	4	1.11	1.41	0.24
Flood	2	0.04	0.11	0.90
Week	3	0.49	0.84	0.48
Week*Flood	6	1.12	0.95	0.47
Error	44	8.61		

Table 13. ANOVA table for dodder seed biomass on cranberry only for the 2006 flood duration and initiation study.

Source	df	SS	F	Pr > F
Block	4	0.002069	3.24	0.02
Flood	2	0.000426	1.33	0.27
Week	3	0.000521	1.09	0.36
Week*Flood	6	0.000936	0.98	0.45
Error	44	0.00703		

Table 14. ANOVA table for total number of dodder seed on cranberry only for the 2006 flood duration and initiation study.

Source	df	SS	F	Pr >F
Block	4	306.4	5.31	0.0014
Flood	2	228.9	7.93	0.0011
Week	3	13.4	0.31	0.8185
Week*Flood	6	33.5	0.39	0.8836
Error	44	635.2		

Table 15. ANOVA table for dodder stem biomass on cranberry only for the 2007 flood duration and initiation study.

Source	df	SS	F	Pr > F
Rep	4	0.10	2.67	0.04
Flood	2	0.01	0.39	0.68
Week	3	0.55	1.86	0.15
Week*Flood	6	0.59	1.00	0.44
Error	44	0.43		

Table 16. ANOVA table for dodder seed biomass on cranberry only for the 2007 flood duration and initiation study.

Source	df	SS	F	Pr > F
Rep	4	0.00023	1.27	0.30
Flood	2	0.00002	0.20	0.82
Week	3	0.00025	1.89	0.15
Week*Flood	6	0.00029	1.07	0.40
Error	44	0.00196		

Table 17. ANOVA table for total number of dodder seed on cranberry only for the 2007 flood duration and initiation study.

Source	df	SS	F	Pr > F
Rep	4	233.43	1.16	0.34
Flood	2	32.43	0.32	0.73
Week	3	347.33	2.30	0.09
Week*Flood	6	284.77	0.94	0.48
Error	44	2216.97		

Table 18. ANOVA table for dodder stem biomass on cranberry for the 2007 flood duration and initiation study with additional host plant.

Source	df	SS	F	Pr > F
Rep	4	0.02	0.20	0.94
Flood	2	0.07	1.60	0.21
Week	3	0.20	2.96	0.04
Week*Flood	6	0.15	1.12	0.37
Error	44	1.01		

Table 19. ANOVA table for dodder seed biomass on cranberry for the 2007 flood duration and initiation study with additional host plant.

Source	df	SS	F	Pr > F
Rep	4	0.000015	0.44	0.78
Flood	2	0.000002	0.11	0.89
Week	3	0.000026	1.03	0.39
Week*Flood	6	0.000053	1.06	0.40
Error	44	0.000366		

Table 20. ANOVA table for total number of dodder seed on cranberry for the 2007 flood duration and initiation study with additional host plant.

Source	df	SS	F	Pr > F
Rep	4	12.10	0.30	0.88
Flood	2	7.03	0.35	0.71
Week	3	34.80	1.15	0.34
Week*Flood	6	80.30	1.32	0.27
Error	44	444.70		

Table 21. ANOVA table for dodder stem biomass on tomato for the 2007 flood duration and initiation study with additional host plant.

Source	df	SS	F	Pr > F
Rep	4	0.008	0.450	0.769
Flood	2	0.011	1.270	0.292
Week	3	0.026	2.020	0.125
Week*Flood	6	0.042	1.630	0.161
Error	44	0.187		

Table 22. ANOVA table for dodder seed biomass on tomato for the 2007 flood duration and initiation study with additional host plant.

Source	df	SS	F	Pr > F
Rep	4	9.00E-7	1.80	0.15
Flood	2	3.00E-7	1.20	0.31
Week	3	3.33E-7	0.89	0.45
Week*Flood	6	3.67E-7	0.49	0.81
Error	44	5.5E-6		

Table 23. ANOVA table for total number of dodder seed on tomato for the 2007 flood duration and initiation study with additional host plant.

Source	df	SS	F	Pr > F
Rep	4	0.90	1.80	0.15
Flood	2	0.30	1.20	0.31
Week	3	0.33	0.89	0.45
Week*Flood	6	0.37	0.49	0.81
Error	44	5.50		

Table 24. Percent germination of dodder seed plated directly to Petri dishes after being subjected to flooding durations of 0, 24, and 48 hr at temperatures of 10, 15, and 20 C simulating spring water temperatures. Values are mean of 4 replicates ± standard error.

		Germination (%)	
Temp (C)	Flood (hr)	Run 1[z]	Run 2[y]
10	0	45±10.2	53±1.8
	24	36±5.8	51±4.1
	48	36±3.9	52±1.9
15	0	35±1.5	45±2.3
	24	45±9.6	49±4.1
	48	48±5.9	48±3.6
20	0	56±3.4	43±0.7
	24	59±6.8	48±3.3
	48	46±7.8	49±3.1

[z] TxF significant $p \leq 0.01$

[y] T significant $p = 0.01$

Table 25. Percent germination of dodder seed plated directly to Petri dishes after being subjected to flooding durations of 0, 12, 24, 36 and 48 hr at temperatures of 15, 20, and 25 C simulating summer water temperatures. Values are mean of 4 replicates ± standard error.

		Germination (%)	
Temp (C)	Flood (hr)	Run 1[z]	Run 2[y]
15	0	51±6.3	41±1.9
	12	56±2.7	45±2.6
	24	51±4.7	44±2.0
	36	58±2.8	49±1.0
	48	59±3.4	37±4.2
20	0	46±4.8	52±1.6
	12	49±3.1	43±4.7
	24	54±1.7	40±1.3
	36	50±2.4	46±4.3
	48	52±3.9	45±3.7
25	0	51±3.0	56±4.0
	12	54±3.4	42±3.9
	24	49±2.0	59±7.2
	36	49±3.9	49±3.4
	48	51±2.2	53±4.3

[z] T significant $p < 0.004$

[y] TxF significant $p \leq 0.007$

Table 26. 2006. The effect of flooding duration and week initiation (1-4 wk after first seedling emergence) on dodder stem biomass, mean seed biomass, and seed number on cranberry alone (N=5).

Initiation (wk)^z	Flood (hr)	Dodder Biomass (g)	Seed Biomass (g)	Total seed (no.)
1	0	0.79	0.000	0.8
	24	0.87	0.008	7.2
	48	0.53	0.003	2.2
2	0	0.76	0.002	1.4
	24	0.49	0.006	5.0
	48	0.88	0.022	3.0
3	0	0.42	0.001	0.8
	24	0.83	0.004	5.2
	48	0.65	0.001	0.4
4	0	0.84	0.001	0.6
	24	0.87	0.007	4.8
	48	0.94	0.004	3.4
P-Values^y	week	NS	NS	NS
	flood	NS	NS	0.011
	W*F	NS	NS	NS

^{z}Initiation of flooding event occurred 1 to 4 wk after first seedling emergence.

^{y}Values of $p \leq 0.05$ are significant; NS, not significant.

Table 27. 2007. The effect of flooding duration and week of flood initiation on dodder stem biomass production, mean seed number and total number of seed on cranberry alone (N=5).

Initiation (wk)^z	Flood (hr)	Dodder Biomass (g)	Seed Biomass (g)	Total seed (no.)
1	0	0.12	0.007	7.60
	24	0.15	0.010	9.80
	48	0.07	0.003	4.00
2	0	0.12	0.005	6.20
	24	0.05	0.003	2.80
	48	0.10	0.100	11.20
3	0	0.11	0.002	2.00
	24	0.12	0.003	2.00
	48	0.03	0.002	2.00
4	0	0.02	0.002	2.20
	24	0.00	0.000	0.00
	48	0.07	0.010	4.60
P-Values^y	week	NS	NS	NS
	flood	NS	NS	NS
	W*F	NS	NS	NS

^{z}Initiation of flooding event occurred 1 to 4 wk after first seedling emergence.

^{y}Values of $p \leq 0.05$ are significant; NS, not significant

Table 28. 2007. Effect of flooding duration and week of flood initiation (1-4 wk after first seedling emergence) on dodder stem biomass production, mean seed number, and total seed number on cranberries and on the additional host (tomatoes) (N=5).

		Cranberry			Tomato		
Initiation (wk)[z]	Flood (hr)	Dodder Biomass (g)	Seed Biomass (g)	Seed (no.)	Dodder Biomass (g)	Seed Biomass (g)	Seed (no.)
1	0	0.23	0.001	1.40	0.07	0.000	0.20
	24	0.20	0.001	1.40	0.10	0.000	0.00
	48	0.19	0.002	2.00	0.07	0.000	0.20
2	0	0.24	0.003	2.80	0.11	0.000	0.00
	24	0.03	0.002	2.00	0.00	0.000	0.00
	48	0.18	0.001	1.80	0.06	0.000	0.00
3	0	0.04	0.002	2.40	0.02	0.000	0.00
	24	0.05	0.000	0.60	0.01	0.000	0.20
	48	0.21	0.004	5.60	0.08	0.000	0.40
4	0	0.03	0.000	0.00	0.02	0.000	0.00
	24	0.04	0.002	2.40	0.01	0.000	0.00
	48	0.08	0.000	0.00	0.04	0.000	0.20
P-Values[y]	week	0.04	NS	NS	NS	NS	NS
	flood	NS	NS	NS	NS	NS	NS
	W*F	NS	NS	NS	NS	NS	NS

[z] Initiation of flooding event occurred 1 to 4 wk after first seedling emergence.

[y] Values of p≤0.05 are significant; NS, not significant.

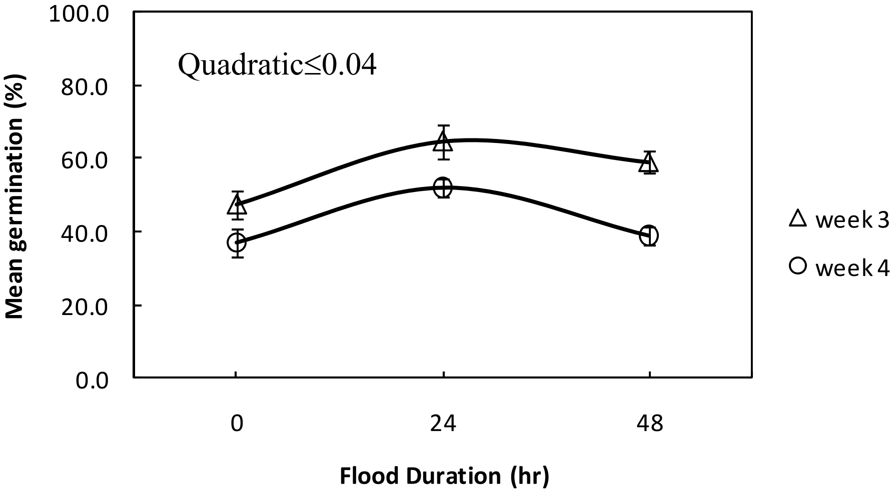

Figure 9. 2006. Percent germination of seed plated to Petri dishes after being subjected to 0, 24, or 48 hr flood duration initiated 1 to 4 wk after first seedling emergence.

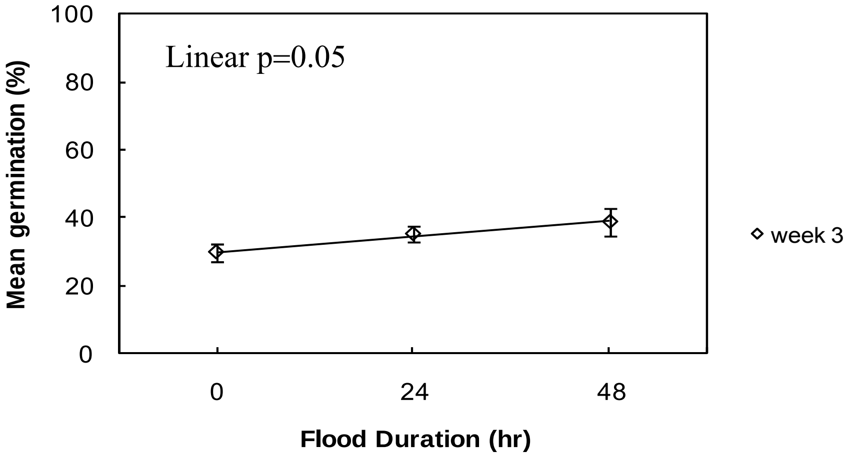

Figure 10. 2007. Percent germination of dodder seed plated to Petri dishes after being subjected to 0, 24, 48 hr flood duration initiated 3 or 4 wk after first seedling emergence.

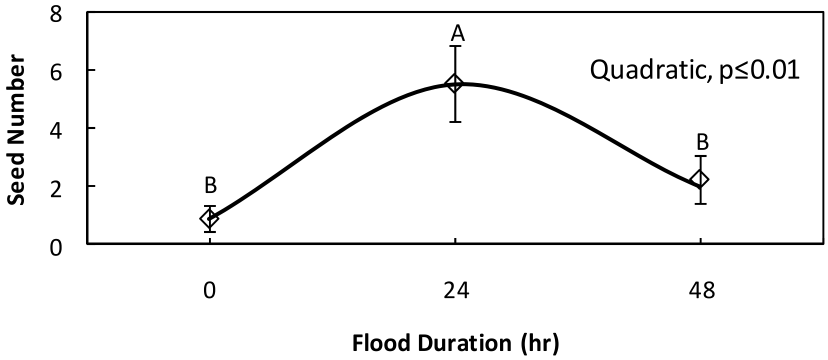

Figure 11. 2006. Mean number of dodder seed produced after host attachment to cranberry only after being subjected to flood durations of 0, 24, and 48 hr. Mean separation with Tukey's HSD. Means with the same letter are not significantly different.

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