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EFFECTS OF DROUGHTS ON DAMAGE CAUSED BY CABBAGE ROOT FLY LARVAE

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ABSTRACT

The goal of this study was to observe the potential effects of drought on the damage caused by insect pests in horticulture in Ghana, using cauliflower *Brassica oleracea* (L.) as a model plant, and cabbage root fly *Delia radicum* (L.) as a model insect pest. The study provided information on potential interactions between droughts and insect pests in cauliflower production. The experiment consisted of four treatments and four blocks organised as a full factorial design of: +/- drought and +/- pesticide treatment. The plants were planted on June 26 and harvested on August 2. During the experiment the longest leaf length was measured, the condition of plants was assessed and egg laying of cabbage root flies was monitored. After harvesting, damage on roots was assessed, the number of larvae and pupae recorded and biomass of plants measured. R software was used to test the effects of the different treatments on the variables that were measured. Pesticide treated plots had significantly higher aboveground and belowground biomass than non-treated plots. The treatments had a significant effect on the number of larvae on plant roots; the lowest number of larvae was found on plants treated with pesticide and the highest on plants not treated with insecticide and subjected to drought. The implications of these findings on horticulture in Ghana under future climate conditions are discussed.

Key words: drought, climate change, insect pest, horticulture, Ghana

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1. INTRODUCTION

1.1 Vegetable production in Ghana

Agriculture contributes 48.1% of the gross domestic product (GDP) to the economy and 53.6% of the human labour force in Ghana (Diao and Sarpong 2007). Ghana grows most of its vegetables for local consumption. Vegetables that are commonly grown in Ghana are tomato, onion, okra, shallots, eggplant, chili pepper and spinach (Oppong-Sekyere et al. 2012). Most of the vegetables of European origin, such as cucumber, carrots, cauliflower and radish, are grown to supply hotels and restaurants.

Vegetable production in Ghana mainly takes place in the urban and per-urban communities because of proximity to the source of market. Obuobie et al. (2006) reported that agriculture in the urban areas is more accessible to market centres and less costly in terms of transportation. Vegetables produced in the urban areas supply about 90% of vegetables to consumers in Ghana (Drechsel et al. 2006). Darkey et al. (2014) revealed that agriculture in the urban centres helps farmers to mitigate poverty and food security problems, enhances human developments and serves as a source of income to increasing urban human population. Vegetables are also produced on a smaller scale in rural communities (but are transported to the other parts of the country) and are also grown in the small backyard gardens located in every corner of the country (Oppong-Sekyere et al. 2012).

Consumers of vegetables with different income levels in the urban and rural areas depend on vegetables for their dietary needs. Farmers in Ghana use various control and management strategies for growing their crops, such as supplementary irrigation or the use of synthetic pesticides to curb infestations caused by insect pests. Gerken et al. (2001) observed that farmers often apply pesticides to manage insect pest attack. Weinberger and Srinivasan (2009) observed that these insecticides require a relatively low labour force for their application and are fast to react in the soils. However, according to Devanand and Rani (2008) application of synthetic insecticides comes with costs including environmental hazards, health issues, expense, and potential development of resistance by insect pests.

Cabbage (*Brassica oleracea var. capitata L.*) (Cruciferae) is a vegetable crop which is widely adapted to both temperate and tropical climates (Amoabeng et al. 2013). The USDA (2009) reported that cabbage contains essential vitamins, proteins and minerals for proper functioning of the human body. Cabbage is commonly grown in cities and rural communities in Ghana (Osei et al. 2013). Cabbage serves as an essential source of livelihood for many smallholder farmers in Ghana (Osei et al. 2013). Fening et al. (2012) observed that infestations of cabbage by insect pests reduce its yields, market price and taste. Hence, there is the need for strategies to manage cabbage insect pests (Zehnder et al. 2007).

Cabbage and related crops are faced with several production constraints throughout the world, and Ghana is not an exception. The major production constraints identified in Ghana are insect pests, diseases, the need for high fertilizer input and the cost of pesticides (Osei et al. 2013). Fening et al. (2013) reported that the major insect pests of cabbage crops in Ghana are the cabbage aphid (*Brevicoryne brassicae*), the diamond back moth (*Zonocerus variegatus*), and caterpillars of cabbage webworm or old world webworm (*Hellula undalis*). According to Osei et al. (2013), the diamond back moth is the most destructive pest in cabbage-related crops (for example cauliflower and cabbage). The diamond back moth can develop resistance to most approved pesticides in Ghana and can cause losses up to 60%. There is limited information to support how insect pests of cabbage crops were introduced into Ghana. But there is evidence to indicate their presence in other vegetables such as okra and spinach, among others. Some of the insect pests probably already existed with the native vegetables or were introduced with the foreign crop.

The utilisation of synthetic insecticides comes with some associated costs including human and animal health issues, destruction of the natural environment, build-up of resistance by insect pests and their cost, which makes them inaccessible to some farmers (Devanand and Rani 2008). In addition, some farmers would normally apply inappropriate doses of these pesticides to their farms; hence there is a need for other measures for insect pest control (Amoabeng et al. 2013). Insecticides from plant extracts could be a good replacement because of their environmentally friendly nature and their effects seem to be long lasting (Rathi and Gopalakrishnan 2006, Martin et al. 2016). But the high demand for these insecticides, including azadirachtin, makes them relatively costly for farmers to purchase.

1.2 Effects of climate change on vegetable production

Climate change could lead to a serious impact on ecology in the future (Ayyogari et al. 2014). Bergengren et al. (2011) predicted that the global mean temperature is likely to increase between 1.1°C up to 6.4°C by the end of this century. This change in temperature will result in irregular patterns of precipitation and unpredictable weather patterns (Ayyogari 2014). Climate change will impact a series of events, including impacting both plant and animal forms, which will in turn affect crop production (Breisinger 2011). Pest problems will probably also increase due to the rise in global temperatures (Parry 2007). The negative effects of climate change on vegetable production will largely depend on the extent of the vulnerability of the crop (Patwardhan et al. 2007). Shifts in environmental conditions, such as the increase in temperature, could be beneficial to cooler regions of the world while affecting negatively crop yields in many parts of the world (Qian et al. 2013).

In a review focussing on the implications of climate change for crop yields, Parry (2007) observed that crop productivity is likely to decrease in both tropical and subtropical regions of the world with climate change and to increase for the mid- and high-mid latitudes. EPA (2000) has projected an increase in the mean annual temperature of 0.25°C in Ghana between 2010 and 2020. Guodaar (2015) reported lower production of vegetables over the last few decades in Ghana because of the rise in temperatures with a simultaneous increase in precipitation.

Ayyogari (2014) observed that climate change effects will impact the distribution and the genetic make-up of some insect pests of vegetables. Rising temperatures due to climate change may increase the number of eggs laid by insects and shorten the life-cycle, which may lead to more generations per year for some insect species, such as the diamond-back moth and aphids (Diao and Sarpong 2007). Hughes and Bazzaz (2001), Yamamura and Kiritani (1998) reported that the rise in temperatures stimulates increases in numbers and the activity of some insect pests, like thrips, whiteflies and aphids.

According to Diehl et al. (2013), because of temperature fluctuations due to climate change, insect species present above the soil surface will probably be more affected than those living below the soil surface because of the insulating properties of soil. Ayyogari (2014) anticipated that climate change will affect the global distribution of aphids (*Aphis gossypi*; *Aulacorthum solani*), diamond back moth (*Plutella xylostella*), cabbage butterfly (*Pieris brassicae*) and cabbage root fly (*Delia radicum*), and hence affect vegetable production.

Drought periods coupled with higher temperatures increase the incidence of insect pests on host plants (Mattson and Haack 1987). Drought negatively changes the physiological make-up of plants, thus rendering them more susceptible to insect pest attack (Mattson and Haack 1987). Furthermore, Mattson and Haack (1987) observed that the colour and chemical emissions produced from plants due to drought stress may expose crop plants to more insect pest infestation.

Droughts affect the survival of the natural enemies of insect pests (Cofie 2003). Many insect pests, for example grasshoppers, have a shorter life-cycle because of elevated temperatures (Cofie 2003). Willis et al. (1993) and Koricheva et al. (1998) reported that water stress has a negative effect on the complete life-cycle and feeding activity of both chewing and sucking insect pests. On the contrary, Willis et al. (1993) observed a positive relationship between an enduring water stress condition of host plants in the field and the activities of sucking and chewing insects.

1.3 The case study

Management measures for insect pest control and alternative methods for integrated management need to be developed for Ghana, especially in the face of climatic changes. This study sought to identify the potential effects of drought and insect pests on the production of cabbage-related crops in Ghana. Finding solutions to the pest problems of this crop will improve the income level of small-holder farmers who dominate the vegetable production sector. The goal of this study was to observe the effects of drought and insect pests on plant production, using cauliflower *Brassica oleracea* (L.) var. botrytis (Brassicales: Brassicaceae) as a model plant, and the cabbage root fly *Delia radicum* (L.) (Diptera: Anthomyiidae) as a model insect. The cabbage root fly is an important root insect pest affecting cabbage-related crops throughout the Northern European continent (Björkman et al. 2011).

Specifically, the objectives of this study were:
i. To assess the effects of drought on yields of cauliflower,
ii. To assess the effects of cabbage root larvae on yields of cauliflower,
iii. To assess potential interaction between drought and larval damage.

2. METHODS

2.1 Study site

A field experiment was carried out at Gunnarsholt, in Southern Iceland (64°05'N; 19°50'S; Fig. 1). The experiment was set up close to a field where there had been a heavy infestation of cabbage root fly larvae the previous year (2016). The study area is flat, with slopes generally < 5° (Crofts 2011). The area has a history of grazing, mostly by sheep, but also horses. The yearly mean temperature is < 3.7°C with precipitation of >1000 mm per annum (Crofts 2011). Due to the proximity of the study area to the volcano Mt Hekla, it is highly exposed to volcanic eruptions. This has led to build-up of relatively young and immature soils in the study area which are prone to erosion. The soils are mainly basalts originating from volcanic activity. Van Lynden et al. (2014) described the features of the soils in the area as Arenic Vitrisols, Leptosols and mixtures. Van Lynden et al. (2014) grouped the soils in the study area as Andosols, which are characterised as having low particle cohesion, high water holding capacity and low bulk density.

Figure 1. The location of the experiment and an overview of the experimental plots

2.2. Study species

According Harris and Sveg (1966), the 8mm long white maggots of the cabbage root fly hibernate as pupae in the soil around the roots after feeding on roots of cabbage or other brassica crops for about 3 weeks. After emergence from the pupal stage, adults are migratory. Soils around the base of the cabbage stem harbour the eggs after egg laying. The eggs thrive well under moist soil conditions but are vulnerable to high soil temperatures. The roots serve as a source of food for the larvae. The maggots are without legs and are mainly found in and around the roots of cabbage plants. In Iceland adults emerge in June and the females lay eggs from late June until early July (Halldórsson 1989). The pupae undergo diapause during winter (Bažok 2012).

The larvae affect vegetable crops such as broccoli, cabbage, cauliflower, parsnip, turnips, radishes and rutabaga, among others (Hazzard 2016). The feeding activities of cabbage root larvae cause symptoms such as stunting, slow growth and yellowing (Joseph and Martinez 2014). The germination percentage of the seeds is also affected and in some cases, total crop failure is observed (Hazzard 2016). Adult root flies are usually attracted to yellow sticky cards that can be used for monitoring potential egg laying. The cards must be changed after every 3 to 5 days (Hazzard 2016).

Some cultural control and prevention methods can reduce infestation by the cabbage root fly, such as the rotation of crops, delayed planting, the use of cover crops as an intercrop with cabbage, the cultivation of more vigorous varieties of brassica crops and the use of tillage methods (Hazzard 2016). Chemical control involves the use of recommended insecticides (for example chlorpyrifos) directed at the root zone or on the row of the cabbage plant to control the maggots (Hazzard 2016). The use of chemicals such as organophosphates does not guarantee 100% control but is currently used to manage cabbage maggots in brassicas (Joseph and Martinez 2014).

Additionally, there are usually some natural enemies that dwell in soils, such as ground beetles (carabids) and staphylinid beetles that feed on virtually every stage of cabbage root fly and can cause a high death rate (Hazzard 2016). Other natural enemies are parasitic wasps and predatory mites. Fungal diseases are also found to sometimes cause mortality of maggots of the root fly (Hazzard 2016). Nematodes are also believed to be a control measure against the maggots of the root fly (Hazzard 2016).

2.3. Experimental design and set-up of experiment

The experiment (Fig. 2) consisted of four treatments: (a) drought, no pesticide (DN), (b) drought and pesticide (DP), (c) water, no pesticide (WN), and (d) water and pesticide (WP). The treatments were randomly assigned to four blocks. Each plot was 1 x 1 m and the distance between plots was 0.5 m. Four cauliflower plants were planted in each plot and the distance between plants was 0.3 × 0.3 m. On each side of the field were planted four cauliflower plants for monitoring egg laying. The experimental plants were *Brassica oleracea* (L.), var. botrytis, cultivar Flamenco. The plants were bought at the plant nursery Flóra-garðyrkjustöð, Heiðmörk 38, 810 Hveragerði.

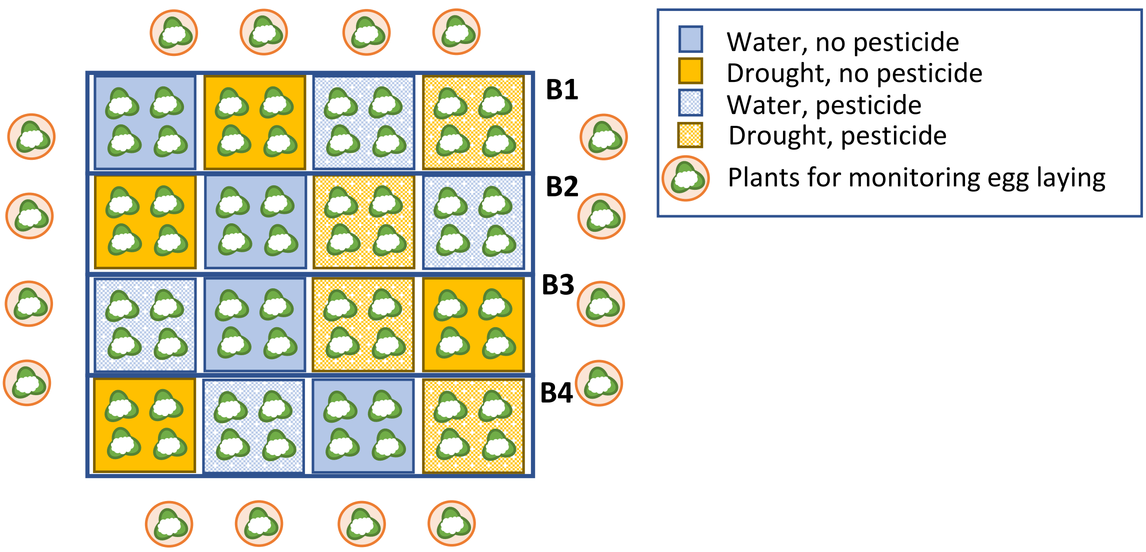

Figure 2: Experimental field at Gunnarsholt 2017: B1-B4 = Block 1 to Block 4

The plants had been cultivated in the plant nursery since April 25, 2017. The plants were planted in the experimental plots on June 26 and fertilized with Blákorn (N -12%, P - 12.6%, K- 14.1%); 25 g/plant. Plants for monitoring egg laying were planted on the same day and fertilised in the same way as the experimental plants.

Pesticide was applied to all relevant plots on June 11. The plants were treated with Perfection 400 EC (BASF AG, Germany, active compound: Dimethoate). Dosage: 50 ml/plant of 0.05% concentrated dimethoate solution. The pesticide was poured onto the ground around the root collar of the plants.

Drought conditions were simulated by covering all drought plots with transparent plastic sheeting during a 10-day rainy period from July 17 until July 26. The plastic sheet was held up approximately 20 cm above the soil surface by small poles and fastened by pushing the margins on two sides of the sheet approximately 5 cm into the ground. The other sides were left open to secure free passage of air. After that all plots were covered with acrylic sheeting to prevent further egg-laying by cabbage root flies on the experimental plants (Fig 3). The plastic sheets and acrylic sheets were installed on July 17 and removed on July 26. In order to enhance the effect of drought, plants in other plots (watered plots) were watered on one occasion before installing plastic sheets; on July 10 (2 l/plot) and four occasions after the sheets had been removed; on July 26, July 27, July 28 and July 30; 4 l/plot on each occasion. Total watering was therefore 18 l/plot, which is equivalent to 18 mm precipitation. The closest meteorological stations that measure precipitation are Sámsstaðir and Þykkvabær. The precipitation for these stations from June 26 until August 2 was 66.4 and 81.9 mm, respectively, or an average of 74.2 mm (IMO 2017). The precipitation for the period 17 July until 26 July was 23.8 and 23.2 mm for Sámsstaðir and Þykkvabær, respectively, or an average of 23.5 mm (IMO 2017). The total water/precipitation received by drought plots was thus 74.2-23.5 mm = 50.7 mm and for watered plots 74.2 + 18 mm = 92.2 mm.

Figure 3. The experimental area after installation of plastic and acrylic sheets

2.4 Data collection

During the experiment the following parameters were recorded/monitored: (a) egg laying of cabbage root flies, (b) plant growth and plant condition, (c) plant biomass, (e) larval and pupal density and root damage.

2.4.1 Monitoring of egg laying

Egg laying was monitored at the base of 16 specific egg monitoring plants (Fig. 2) which were planted at each side of the experiment in the field. On July 4 approximately 30 ml of clean black sand were placed around the base of the egg monitoring plants. After 3-4 days the sand was removed with a small spoon and placed in a 250 ml plastic cup. After removing the sand, new sand was placed around the plants. Eggs were sampled on: July 7, July 10, July 14 and July 17.

In the laboratory the cabbage root fly eggs were extracted from the sand by flotation in water. This was done by pouring approximately 150 ml of water into the cup and stirring the sand and counting the eggs that floated up under a 5x magnification glass (Fig. 4). In many cases the eggs were too many for accurate counting and in those cases the number was assessed to the nearest round figure. The eggs were also observed under a compound microscope (Olympus SZ-CTV) for confirmation of species identification. Hatched eggs were identified in the second egg count.

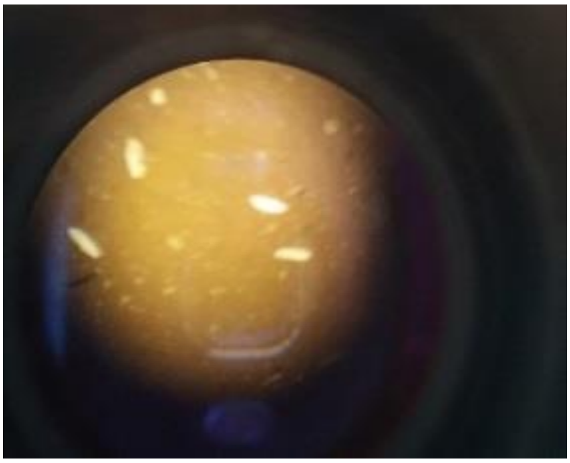

Figure 4. Cabbage root fly eggs floating in the sampling cup as seen under the compound microscope

2.4.2 Monitoring of plant growth and plant condition

Plant growth was monitored by measuring the length of the longest leaf of each plant with a tape (Fig. 5) on four separate dates (July 4, July 10, July 17 and August 2. The condition of the plants was recorded at the same time. The zero point on the tape was placed at the tip of the leaf blade and measured up to the broad end (at the beginning of the petiole, Fig. 5).

Figure 5. Measurement of the length of the longest leaf of experimental cauliflower plants

The condition of and damage to the plants were examined and scored using a scale of 1-5 (Hallett, 2009, Fig. 6) where 1 indicated 0% of plant damaged, 2: 1-25% of plant damaged, 3: 26-50% of plant damaged, 4: 51-75% of plant damaged to 5: 76-100% of plant damaged.

1 **2** **3** **4** **5**

Figure 6. Condition of cauliflower plants: 1 = 0% damage, 2 = 1-25% damage, 3 = 26-50% damage, 4 = 51-75% damage, and 5 = 76-100% plant damage

2.4.3 Plant biomass

The cauliflower plants were harvested on August 2 and the fresh and dry weight of shoots, flowers (heads) and roots recorded to the nearest mg, using a Sartorius Top-loading Balance (ED62025) (Fig. 7). The shoots, flowers and roots were oven-dried for 48 h at a temperature of 80°C, using a customized oven run by a Theben TR 610 digital time switch. After that, plant materials were weighed again.

Harvesting shoots weight flower/ball weight drying in oven
Figure 7: Harvesting, recording of fresh weight of shoots and flowers, and drying of plant material

2.4.4 Recording of larval density and root damage

After harvesting, the plants were brought into the laboratory and the roots cut from the aboveground tissues. After that the soil was carefully removed from the roots and all larvae and pupae that were observed, were counted. Root damage was subsequently assessed. Symptoms of cabbage root larvae damage on roots were also recorded with a scale from 1-5; where 1= no damage, 2= 1-25% damage, 3= 26-50% damage, 4= 51-75% damage and 5=76-100% damage (Fig. 8).

1 2 3 4 5
Figure 8. Symptoms of cabbage root maggot damage on roots of cauliflower plants

2.5 Data analysis

The relationship between the numbers of eggs laid on plants and leaf length and plant condition were explored using Pearson's linear correlation tests. The value of Pearson's linear coefficient ranges between -1 and 1, with values closer to zero indicating weak association between two variables, and values close to 1 indicating a strong positive or negative linear relationship.

The effect of the experimental treatment (drought and pesticide application) on plant measurements (length of the longest leaf, plant condition, observed damage, the number of larvae and pupae, and above-, below- and flower biomass production) was analysed using mixed effects models, given the nested structure of the experimental design (i.e. four plants were measured within each plot).

To assess the statistical significance of drought, the application of pesticides, and their combined effect on plant measurements, models with and without the interaction between drought and pesticide application were compared. The statistical significance of the interaction was assessed using Chi square and p-values from these comparisons of models. When the interaction was not significant, it was dropped from the models, and the values of the model estimates together with the associated t and p-values are reported. All statistical analyses were performed in R (R Core Team, 2015).

3. RESULTS

3.1 Egg laying

The average cumulative number of eggs laid on each plant from July 4 to July 17 ranged between 6 and 200 eggs (average 133.13, SD=38.94). The length of the longest leaf was positively associated with the total number of eggs laid on a plant (Pearson's linear correlation, r=0.542, t = 2.411, df = 14, p-value = 0.03; Fig.9a). However, plant condition as measured in a 1-5 scale, was not associated with the total number of eggs laid (Pearson's linear correlation, r=-0.247, t = -0.953, df = 14, p-value = 0.357; Fig.9b).

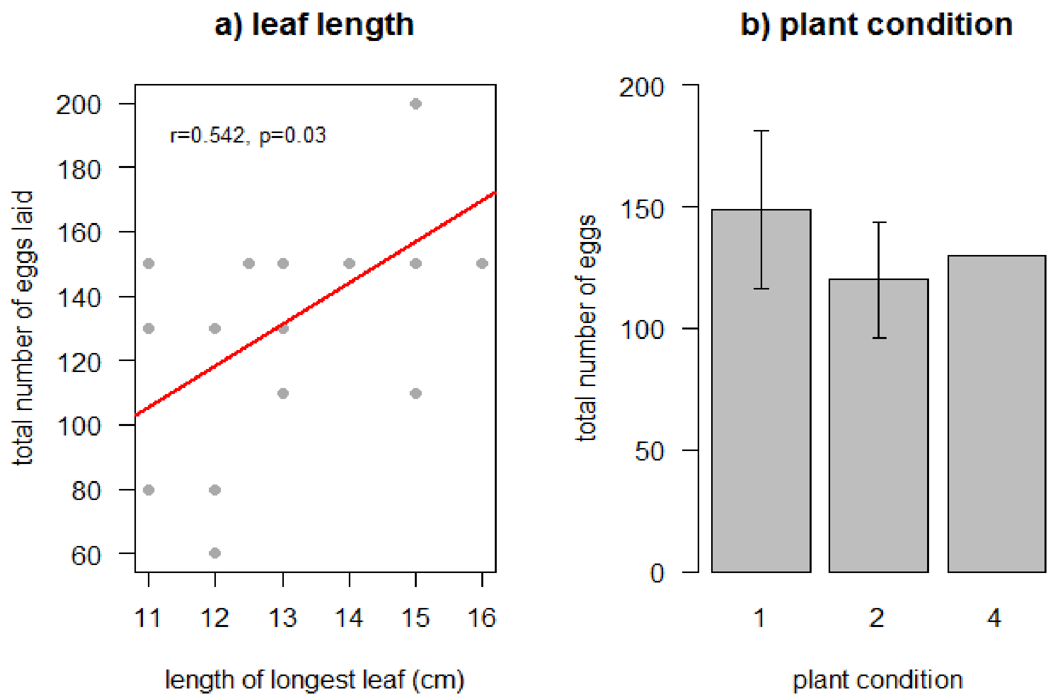

Figure 9. Relationship between the average cumulative numbers of eggs laid on individual monitoring plants and: (a) the length of the longest leaf and (b) plant condition. Bars show means with standard errors.

3.2 Effects of drought and pesticide application on leaf length, plant condition and observed damage

The interaction between drought and pesticide application was not significant in any of the models (leaf length: Chi-square=0.60, p=0.44; plant condition: Chi-square=0.30, p=0.59; damage score: Chi-square=0.65, p=0.42).

The application of pesticides had a positive effect on the length of the longest leaf (estimate=4.17, t=2.91, p=0.012; Fig. 3a); drought tended to increase leaf length but the effect was not significant (estimate=3.02, t=2.11, p=0.05). However, both the application of pesticides and drought had a negative effect on plant condition (pesticides: estimate=-1.17, t=-3.44, p=0.005; drought: estimate=-0.89, t=-2.63, p=0.02; Fig. 3b). Neither pesticide application (estimate=-0.28, t=-0.99, p=0.33; Fig. 3c) nor drought (estimate=-0.47, t=-1.66, p=0.10) affected the damage scored on the plant.

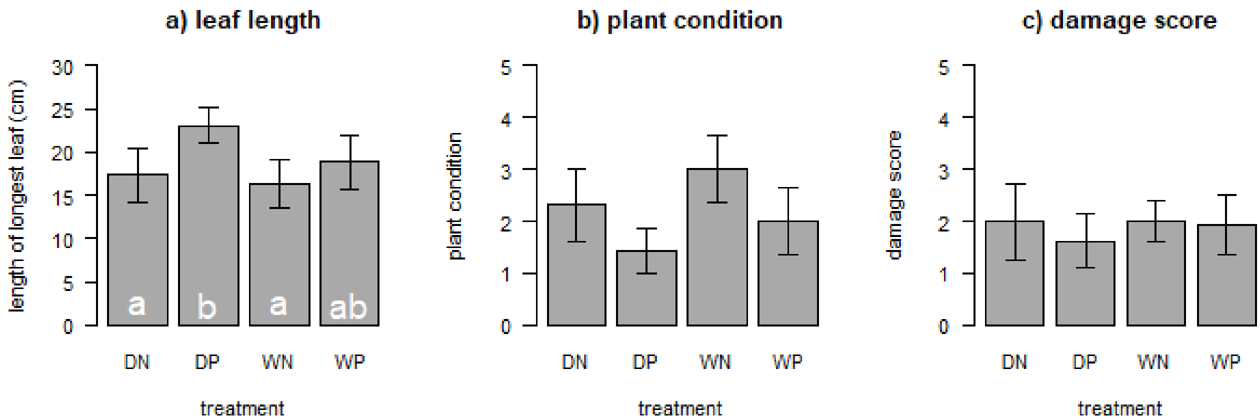

Figure 10. Effect of the experimental treatments on the length of the longest leaf (a), plant condition (b), and observed damage (c): DN: drought no pesticide, DP: drought and pesticide, WN: water no pesticide, WP: water and pesticide. Small case letters indicate significant differences between treatments. Bars show means with standard errors.

3.3 Effects of drought and pesticide application on the number of larvae and pupae

In total 648 larvae and 9 pupae were found on the roots of harvested plants. Number of larvae was highest in drought plots not treated with pesticide; 452 in total. In watered plots not treated with pesticide a total of 194 larvae were found. Only 2 larvae were found in plots treated with pesticide. All larvae were small and feeding on the surface of plant roots. Applying pesticides reduced the number of larvae found, but this effect was stronger in plots with simulated drought relative to watered plots (interaction: Chi-square=4.191, p=0.04; Fig. 11a). The number of pupae was highest in watered plots not treated with pesticide (Figure 11b). However, as the number of pupae was very low no further statistical analysis was done.

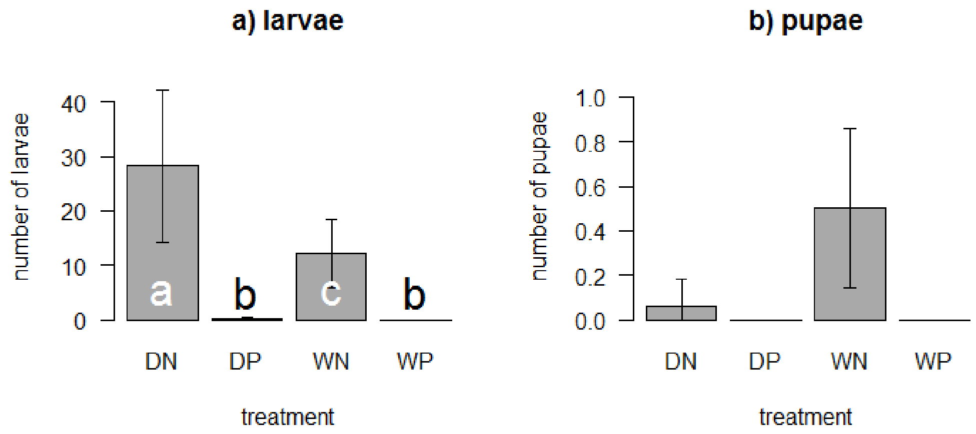

Figure 11. Effect of treatments on: the numbers of larvae (a) and pupae (b) found on roots of harvested plants. The numbers on y-axes are number/plant. DN: drought no pesticide, DP: drought and pesticide, WN: water no pesticide, WP: water and pesticide. Small case letters indicate significant differences between treatments. Bars show means with standard errors.

3.4 Effects of drought and pesticide application on biomass production

The interaction between drought and pesticide application was not significant in any of the models for biomass production (aboveground biomass: Chi-square=0.57, p=0.45; belowground biomass: Chi-square=0.35, p=0.55; flower biomass: Chi-square=0.48, p=0.49).

Aboveground biomass was higher in pesticide-treated plants (estimate=7.54, t=3.36, p=0.006; Fig. 5a) and tended to be higher in drought plots (estimate=4.77, t=2.12, p=0.05). Both pesticide application and drought had a positive effect on root biomass (pesticide: estimate=0.93, t=3.28, p=0.006; drought: estimate=0.63, t=2.21, p=0.046; Fig 5b). Neither pesticide application (estimate=2.97, t=1.37, p=0.19; Fig. 5c) nor drought (estimate=3.33, t=1.53, p=0.15) affected flower biomass.

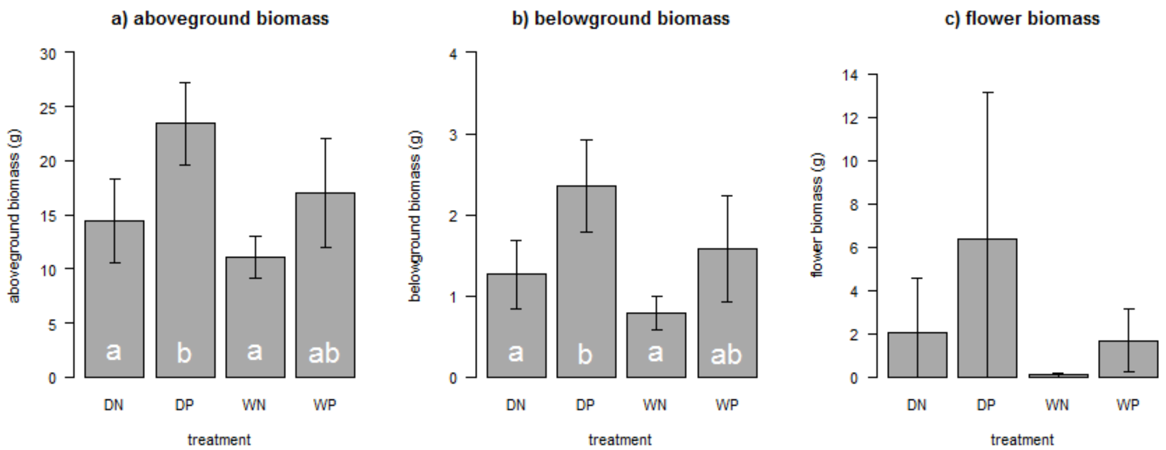

Figure 12. The effect of treatments on: aboveground biomass (a), belowground biomass (b) and flower biomass (c). DN: drought no pesticide, DP: drought and pesticide, WN: water no pesticide, WP: water and pesticide. Small case letters indicate significant differences between treatments. Bars show means with standard errors.

Wet and dry biomass weights were strongly and positively associated (Fig. 13) both for aboveground (Pearson's linear correlation, r=0.935, t = 20.774, df = 62, p-value <0.001) and belowground fractions (Pearson's linear correlation, r=0.542, t = 2.411, df = 14, p-value = 0.03; Fig.1a). Dry aboveground weight represented 10% of the wet weight of the aboveground part of the plant, while dry weight of the root fraction represented 20% of the wet weight of roots.

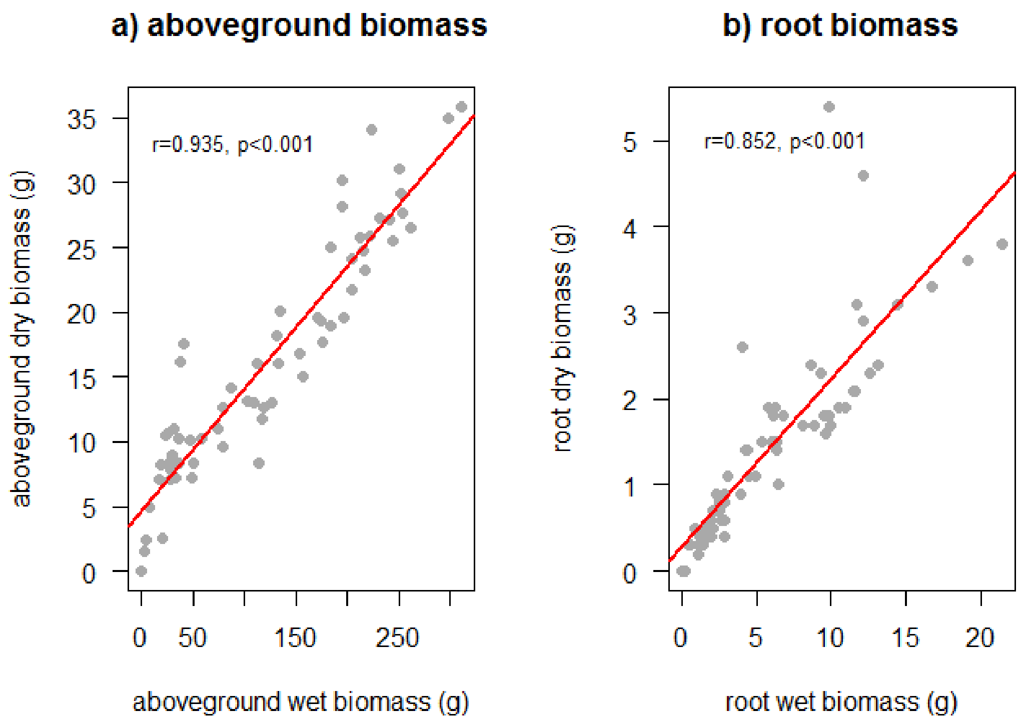

Figure 13. Relationship between wet and dry biomass weight of the aboveground (a) and belowground (b) part of the cabbage plants used in the experiment.

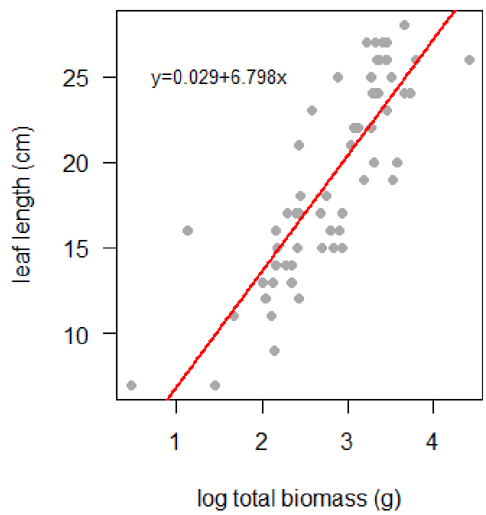

Figure 14. Relationship between leaf length and log total dry part biomass weight of the cauliflower plants used in the experiment.

Leaf length and log total dry biomass weights were strongly and positively associated (Fig. 14) (Pearson's linear correlation, $r=0.84$, $t=11.99$, $df = 61$, p-value <0.001).

4. DISCUSSION

4.1 Egg laying

Field observations show that cabbage root flies usually cluster their eggs on their host plant (Mukerji and Harcourt's 1970). Meanwhile some other workers have reported random placement of eggs by the cabbage root fly on the soil around the host plant. In this study the total number of eggs laid on individual plants ranged between 6 and 200 eggs. This is in line with the findings of Finch (1974) who observed that under laboratory conditions, a single female can lay up to 300 eggs per plant. The length of the longest leaf was positively associated with the total number of eggs laid on a plant. Gravid females of cabbage root fly will usually lay eggs on a host plant that represent an abundant food source for larvae, for example on plants with larger leaves (de Jong and Städler 2001). Plant condition, as measured on a 1-5 scale, was not found to be associated with the total number of eggs laid. This may be due to the fact that egg numbers were mostly assessed, rather than counted, and may therefore be subject to errors. It should also be noted that plant size (measured as length of longest leaf) was only weakly associated with the distribution of eggs. This could imply that egg laying in the field was relatively random, irrespective of plant size and condition.

4.2 Effects of drought and pesticide application on the number of larvae and pupae

The number of larvae was significantly affected by the application of pesticides and drought. Applying pesticides reduced the number of larvae found, but this effect was stronger in plots with simulated drought relative to watered plots. The plots with drought and no pesticides (DN) had the highest larval count, followed by plots with water and no pesticides (WP), and the lowest larval count was found in plots treated with pesticides (DP and WP) (Fig. 11). As explained earlier, the number of pupae was so low that no conclusions on the distribution of pupae among treatments can be drawn.
4.4
These results could be attributed to the effect of drought on the resistance of the plants to insect attacks. Drought negatively changes the physiological make-up of plants, rendering them more susceptible to insect pest attack (Mattson and Haack 1987). Drought can also affect important natural enemies. Entomopathogenic nematodes are important natural enemies of soil dwelling larvae and soil moisture has been shown to reduce the virulence of nematodes (Grant and Villani 2003).

4.3 Effects of drought and pesticide application on leaf length, plant condition and observed damage

The interaction between drought and pesticide application, in relation to leaf length, plant condition and observed damage, was not significant in any of the models, whereas the application of pesticides had a significant positive effect on the length of the longest leaf. Interestingly, plots with drought conditions and pesticide application (DP) had the highest leaf length on average, which was significantly different from the rest of the treatments (WP, DN and WN). Drought tended to increase leaf length, but the effect was not significant. This increase was mostly seen in the drought plots with pesticides (DP). However, both the application of pesticides and drought had a negative effect on plant condition (Fig. 10a and 10b). Neither pesticide application nor drought affected the damage scored for the plant. In general, plots with drought and pesticides suffered the least damage on their roots (Fig. 10c).

4.4 Effects of drought and pesticide application on biomass production

The interaction between drought and pesticide application was not significant in any of the models for biomass production. The drought and pesticides plots (DP) were not significantly different from the water and pesticides plots (WP) but they were significantly different from DN and WN plots. Aboveground biomass was higher in pesticide-treated plants and tended to be higher in watered plots. Both pesticide application and drought had a positive effect on root biomass. Neither pesticide application nor drought affected flower biomass.

In general, the effects of drought on vegetables may lead to small leaf size, reduce biomass production, closure of the stomata, decrease respiration and photosynthetic activity and lower protein in the plants (González 2009). In the present study, aboveground biomass was not significantly affected by drought although it tended to be so. Drought condition was simulated using plastic sheets (artificial means) for a relatively short period and watering of non-drought plots. The drought plots received approximately 50 mm of rainfall during the time of the experiment and the water plots received approximately 90 mm. This difference in "precipitation" may not have been sufficient to have a significant effect on plant growth. It should be noted that there was no significant effect of "precipitation" on plant condition, which supports this conclusion.

The objectives of this study were to: (a) assess the effects of drought on yields of cauliflower, (b) assess the effects of cabbage root larvae on yields of cauliflower, and (c) assess potential interaction between drought and larval damage. The study did not show a significant effect of simulated drought on yields of cauliflower, whereas total removal of cabbage root larvae by pesticide application was shown to increase plant biomass. No significant interaction between larval damage on roots and drought was found.

However, the study showed that treatments had strong effects on the number of larvae. Pesticide treatments almost totally eradicated all larvae, and the number of larvae in watered plots with no pesticide treatments was more than 50% lower than the number of larvae in drought plots with no pesticide treatments. This was not expressed in plant condition and the lower number of larvae had relatively little effect on plant biomass. The reason for this was most likely that the infestation of larvae was in an early stage and the larvae were still feeding superficially on the roots. A longer duration of the experiment might therefore have led to more effect of the larvae on plant condition and biomass.

5. CONCLUSIONS

The study showed that drought can cause higher levels of insect larvae feeding on plant roots. The study did not show a significant effect of higher levels of insect larvae on plant biomass, probably because plants were harvested too early for larval damage to have had a significant effect on plant biomass.

Many people in Ghana depend on vegetables for their dietary needs and they are an important source of income for many households. Insect pests cause serious losses of vegetable yields in Ghana and use of pesticides to control insect pests is often unfocussed and can have negative effects on both people and the environment.

This study showed that increasing drought in Ghana, due to climate change, is likely to increase insect damage in horticulture caused by insect species feeding on plant roots. It is important to respond to this as well as to build up better knowledge on insect pests among both the scientific community and the public.

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