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THE EFFECT OF TEMPERATURE AND HUMIDITY ON THE GRAZING ACTIVITY OF *DEROCERAS RETICULATUM* (O. F. MÜLLER, 1774) AND THE DAMAGE TO RAPE PLANTS

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ABSTRACT: Winter rape is susceptible to damage caused by *D. reticulatum* (O. F. Müller) mainly in the early phases of the plants' development. The degree of damage and the size of yield losses depend on the slug population and the grazing activity, which are governed by many environmental factors. Laboratory studies were performed to analyse the rate and amount of damage to rape plants (2–3 leaf stage) caused by *D. reticulatum*, and the effect of temperature and soil humidity on the slug's grazing activity. With increasing air temperature (up to 16°C) the amount of damage increased, but the effect was not lasting. The slugs were also active at low temperatures (+1°C), and although their grazing was less intense, the amount of damage after seven days could reach an average of 34%. In laboratory tests, the soil humidity had no marked effect on the amount of damage done by the slugs.

KEY WORDS: *D. reticulatum*, winter rape, plant damage, temperature, humidity

INTRODUCTION

Among the slugs which occur in Poland, the grey field slug *Deroceras reticulatum* (O. F. Müller, 1774) is one of the most important pests of cultivated plants. It is typical of open habitats and very widespread in north-western and central Europe. The slug is characterised by very high fecundity, fast development, and the highest level of damage to vegetables, other agricultural plants, ornamental plants and herbs (HUNTER 1966, WIKTOR 1989, GLEN et al. 1993, SHIRLEY et al. 1998, GLEN & MOENS 2002, KOZŁOWSKI & KOZŁOWSKI 2003). Among crop plants, it does the greatest damage to winter rape and winter wheat (MOENS & GLEN 2002, GLEN & MOENS 2002, KOZŁOWSKI & KOZŁOWSKA 2002). Winter rape plants are most susceptible to damage immediately after germination (MOENS et al. 1992, FRANK 1998, MOENS & GLEN 2002, KOZŁOWSKI & KOZŁOWSKA 2002). The slugs graze on the embryonic leaves as soon as the plants emerge from the soil, and later they eat the first true leaves. The degree of damage depends on the number, size and activity of the slugs. Sometimes the plant damage is so serious that it involves destruction of a large part of the crop and the need to discontinue its cultivation (KOZŁOWSKI & KOZŁOWSKI 2003). Proper forecasting of the slug population abundance and activity is fundamental to effective protection of winter rape from this pest. The slugs' grazing activity, and consequently the amount of damage to rape plants, is regulated by many factors relating to habitat, weather and cultivation (SOUTH 1992, ROLLO 1982, YOUNG & PORT 1989, MOENS et al. 1992, YOUNG et al. 1991, 1993, GLEN et al. 1993, HOMMAY et al. 1998, GLEN & MOENS 2002, CHOI et al. 2006). Recent years have brought progress in research on the construction of models forecasting the population dynamics and activity of the slugs, based on the effects of variable environmental conditions. These form a basis for im-

proving methods of forecasting the risk of plant damage caused by slugs and of developing optimum methods of pest control (SHIRLEY et al. 1998, 2001, CHOI et al. 2004, JENNA et al. 2006). According to some authors air temperature and soil humidity are the most important factors governing slugs' activity (CARRICK 1942, YOUNG & PORT 1989, YOUNG et al. 1991, 1993, GLEN et al. 1993). This claim was tested in the present study. The aim was to determine the rate and extent of damage caused to winter rape by *D. reticulatum* in various conditions of air temperature and soil humidity, and to assess the usefulness of those two factors in forecasting plant damage.

MATERIAL AND METHODS

D. reticulatum used in the tests came from eggs collected in October 2008 from a winter rape field near Kłodzko. The eggs, collected together with soil, were placed in containers and kept in the dark at 18°C. Until the time of hatching, the soil in the containers was moistened as necessary. The hatched slugs were transferred to plastic containers (26 × 26 × 14 cm) filled with a 5 cm layer of clay-humus soil. The containers had several air holes, protected with gauze. Three times a week the hatched slugs were fed and their remaining food replaced (wheat bran, cabbage leaves, carrot roots, potato tubers, milk powder, calcium carbonate). The slugs were raised until April of the following year, in a growth chamber with temperature 18°C, RH 93±2% and day length of 10 h.

The studies were carried out in climate chambers, at five air temperatures (1, 4, 8, 12 and 16°C, accuracy ±1°C) and at three values of soil water content (11, 33 and 50%), with a day length of 10 hours. Seeds of the Kana variety of winter rape were sown in crates with a 5 cm layer of gardening soil. After the plants had reached the stage of one true leaf, they were replanted singly into soil-filled test tubes (diameter 2.4 cm, length 6.5 cm). The upper surface of the soil in the tubes was covered with foil to prevent water evaporation. After four days the tubes with plants were inserted into soil in closed transparent plastic containers (26 × 26 × 14 cm), eight per container. The containers were half-filled with soil of different water content (11, 33 and 50%). The desired soil humidity was achieved by adding 250, 500 and 1000 ml of water respectively to 1 kg of 100% dried soil.

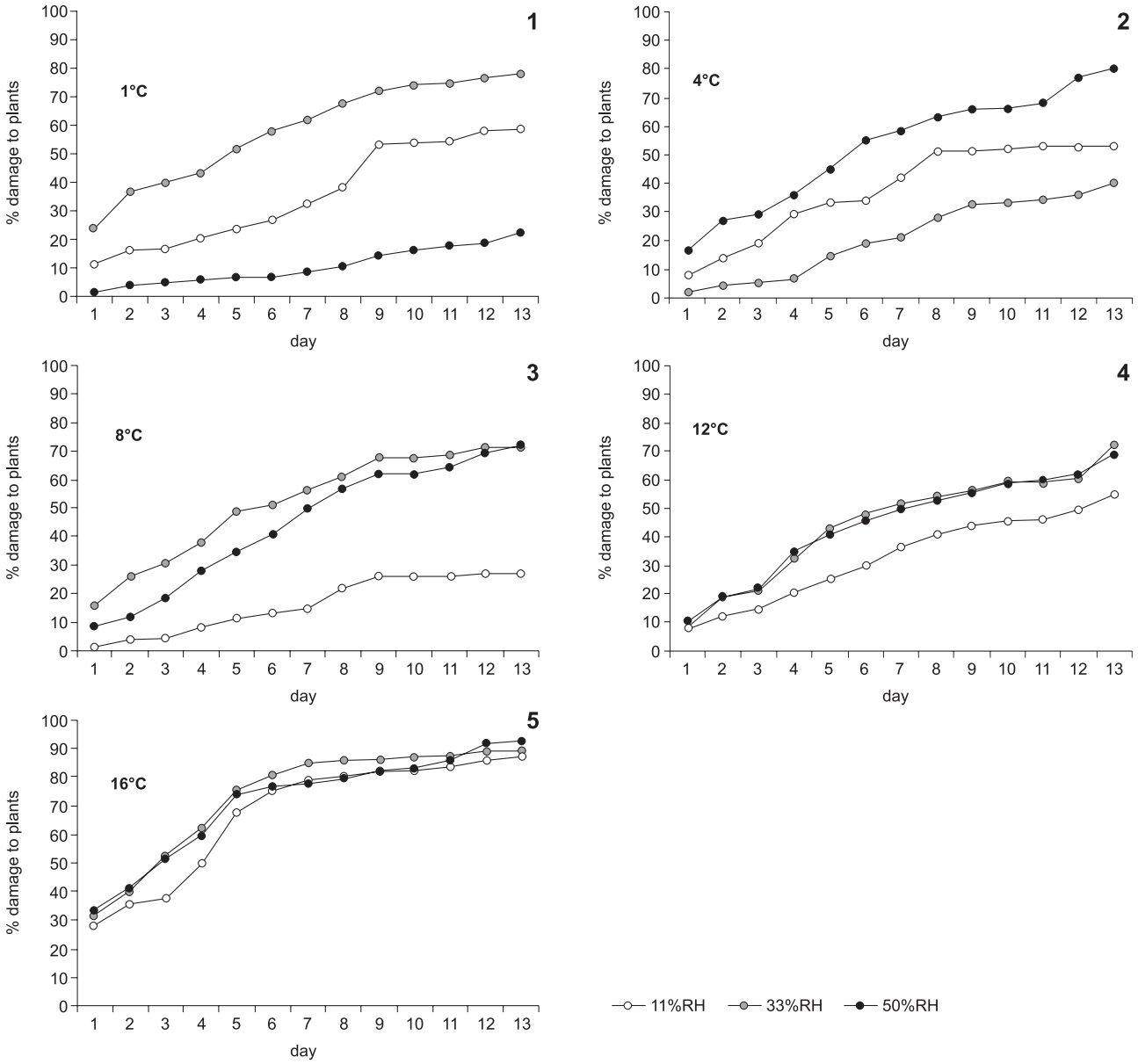
After the tubes with plants (then 2–3 leaf stage) had been inserted, two slugs which had been starved for 48 hours were placed in each container. The mean body mass of all slugs used in the experiment was 0.74 g (min. 0.52 g; max. 0.99 g). The slugs were selected so as to give a similar value for the average mass of the two specimens in each container (min. 0.61 g; max. 0.87 g), and almost identical values for particular combinations in five replicates (min. 0.71 g; max. 0.78 g). The mean square deviations for the body mass of slugs in null experiment within and between containers were 0.012 g^2 and 0.008 g^2, respectively. Containers with plants (prepared as above) but without slugs were used as control. Plant damage was determined once per day (between 9 and 11 am), using a five-point scale of damage (0, 25, 50, 75 and 100% damaged plant surface), and then the mean percentage damage was calculated. For each air temperature and soil water content, five replicates were carried out. The results were subject to statistical analysis using variance analysis and Tukey's test at a significance level of α=0.05.

RESULTS

Comparison of the amount of damage to rape plants on successive days of grazing by *D. reticulatum* showed that it increased successively at each of the considered air temperatures and soil water content values (Figs 1–5). The greatest damage was recorded at 16°C (Fig. 5). At this temperature even after 24 hours the degree of plant damage was around 30%, while after a week it was around 80%.

Significant differences in the degree of damage caused by the slugs occurred at some soil humidity values between the temperature 16°C (Fig. 5) and the temperatures of 1, 4 and 8°C (Figs 1–3). After 24 hours of slug grazing, the percentage of plant damage was highly differentiated (ranging from 1.3% to 33.9%). Interaction was found to be present ($F=2.46$; 8 and 60 d.f.; $p=0.023$). The differentiation in the level of damage continued to increase over subsequent days. Like on the first day, interaction was detected (up to the sixth day $0.01<p<0.05$, from the seventh day onwards $p\leq0.003$). After seven days the lowest percentage of plant damage was 8.8%, and the highest was 85%. The study was concluded on the 14th day, when the plants in some containers were 100% damaged.

The effect of air temperature on the amount of plant damage was observed to be unstable. This was particularly marked at temperatures 4, 8 and 12°C at the soil water content of 50, 33 and 11%. For the temperatures 1, 4, 8 and 12°C during successive days nearly all differences in the degree of damage were statistically insignificant (Figs 1–4), although variation in the degree of plant damage was observed at each temperature.



Figs 1–5. Damage done to winter rape plants in the 2–3 leaf phase by *D. reticulatum* at air temperature 1, 4, 8, 12 and 16°C and three soil humidity values

No significant differences were found in the degree of plant damage done by the slugs in containers with soil with different water content. An exception was the damage done to plants at the temperature of 1°C with the soil humidity of 33% (Fig. 1). In these conditions the damage was significantly higher than at the soil humidity of 50%. This suggests that at 1°C a higher soil humidity (50%) reduced the slug grazing. The water content in the soil over the analysed range (11–50%) had no significant effect on the slug grazing activity at the other temperatures (4–16°C) (Figs 2–5). Comparing the effect of temperature on the level of plant damage done by the slugs at one of the analysed soil humidities on successive days of observation, significant differences were found: at 11% humidity between the extent of damage at temperatures of 16°C and 8°C, at 33% between 16°C and 4°C, and at 50% between 16°C and 1°C.

DISCUSSION

Slug activity is controlled by many factors, such as air and soil temperature, precipitation, presence of dew, soil humidity, water content in the soil, water vapour pressure, wind velocity, soil type, soil aggregation, exposure to sunlight, day length, cultivation conditions, presence of shelters, depth of sowing, ag-

ricultural treatments, presence of natural enemies, etc. (ROLLO 1982, YOUNG & PORT 1989, 1991, YOUNG et al. 1991, 1993, MOENS et al. 1992, SOUTH 1992, GLEN et al. 1993, HOMMAY et al. 1998, GLEN & MOENS 2002, CHOI et al. 2006). It is difficult to judge which of them have the greatest effect on the slug grazing activity and the amount of plant damage.

The risk of damage caused to winter rape by slugs is known to depend on the number and activity of the slugs, these being controlled by various environmental factors. It is also known that the activity including grazing of individuals of *D. reticulatum* of the same age and weight displays a high level of individual variation.

The laboratory studies showed that, regardless of temperature and soil water content, the plant damage caused by grazing *D. reticulatum* (two slugs per 8 plants at the 2–3 leaf phase) successively increased, which means that the slugs' food requirements outstripped the rate of growth of the rape plants (Figs 1–5). The amount of damage done to plants at the same temperatures varied widely. On each day of observation the damage to rape plants at the highest analysed temperature (16°C) differed significantly from the damage at other temperatures. After seven days at this temperature the degree of damage to the plants was ca. 80%. It was concluded that the slug grazing activity, and with it the degree of plant damage, increased as the temperature rose from the used lower temperatures (1, 4, 8, 12°C) to 16°C. Differences between the amount of damage at 16°C and the average amount of damage at other temperatures on successive days of observation averaged 33% (min. 21.8%; max. 41.8%). This confirms our supposition that air temperature is the important factor governing slug grazing activity.

In the earlier studies it was found that one individual of *D. reticulatum* did an average of 64% damage to 10 rape plants during seven days at daytime temperature of 18°C, night-time temperature 15°C, RH 95% and day length of 15 hours (KOZŁOWSKI & KOZŁOWSKA 2002).

In the laboratory tests, the studied soil humidity values (11, 33 and 50%) were not found to have any marked effect on the degree of damage to rape plants. There was a statistically different interaction between air temperature and soil humidity in influencing the extent of damage to rape plants caused by *D. reticulatum*. The slug grazing activity was observed to decrease only at the temperature of 1°C and soil humidity of 50%. It is possible that such a low temperature, combined with the high soil humidity, impairs the slug's locomotion.

It was observed that even at 1°C the slugs grazed and caused significant plant damage, which agrees with the observations of other authors (MELLANBY 1961, YOUNG et al. 1991, 1993, KOZŁOWSKI & KOZŁOWSKI 2003).

YOUNG et al. (1991) showed that slug activity decreased significantly at temperatures below 10°C. In these studies the passage from temperatures of 1, 4, 8 and 12°C to 16°C supports the conclusion that the slug grazing activity was statistically greatest at 16°C. CRAWFORD-SIDEBOTHAN (1972) states that a temperature increase of 2°C, from 4 to 6°C, and an increase in relative air humidity from 90% to 100%, causes the number of active slugs almost to double. In the laboratory tests at temperatures of 4–16°C the analysed soil humidity levels were probably too low to have a significant influence on the slugs' activity; further studies should determine the effect of higher soil humidity (in the range 50–100%) on the grazing activity.

Many authors believe that air temperature and soil humidity are the most important factors affecting slug behaviour (BEYER & SAARI 1978, YOUNG & PORT 1989, YOUNG et al. 1991, 1993, GLEN et al. 1993). These two parameters are undoubtedly of great significance. In the case of *D. reticulatum*, the amount of damage caused to plants in the completed laboratory tests may have been influence by – apart from air temperature and soil humidity – the type of food and its uniformity. The studied experimental factors were shown to interact in these special conditions (air temperature and soil humidity). This implies that air temperature alone is not a sufficient parameter to forecast the plant damage done by this slug, the same is true of soil humidity. Analysis of the joint influence of these factors will make it possible to properly forecast the risk of plant damage due to this slug.

In natural conditions, however, apart from the density and distribution of slugs on plant crops, their grazing activity will also be dependent on a combination of many factors, relating to weather, habitat and cultivation. It can be concluded that the parameters analysed here (air temperature and soil humidity) may help to forecast plant damage caused by *D. reticulatum*, but rather in combination with analysis of other environmental factors.

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