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REMARKS ON SLUG OCCURRENCE, HARMFULNESS AND ACTIVITY CONNECTED WITH PENETRATION OF GROUND

Maria Kozłowska[1], *Jan Kozłowski*[2]

[1]Agricultural University, Department of Mathematical and Statistical Methods
Wojska Polskiego 28, 60-637 Poznań, Poland
e-mail: markoz@au.poznan.pl

[2]Institute of Plant Protection, Miczurina 20, 60-318 Poznań, Poland
e-mail: J.Kozlowski@ior.poznan.pl

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Abstract: The intensity of *Arion lusitanicus* occurrence and the damage degree of 31 crop species have been estimated. It has been found that the slug damaged lettuce and cabbage plants very heavily (*Lactuca sativa* L. var. *capitata* L., *Brassica oleracea* L. var. *capitata* L. f. *alba*) and many species of other vegetables (*Cucumis sativus* L., *Phaseolus vulgaris* L., *Raphanus sativus* L. subvar. *radicula* Pers.). Plant damages in the edge strips were also observed on rape and barley plantations attacked by this slug. The moving activity of particular individuals of *Arion lusitanicus* was varying. Planning of the experiments in a nested block design has made it possible to statistically determine tendencies of the slug movement. It was observed that when some individuals remained at the point where they were initially placed, others, 2 hours after, moved over 7 m away. The mean weighed length of pathway covered by a single individual and the mean movement rate of one were estimated for each of 9 observation dates. It has been found that slugs penetrating the site surface under observation displayed their tendencies to move towards more moist places and towards food sources.

Key words: *Arion lusitanicus*, slug, occurrence, cultured plants, harmfulness, moving activity, nested block design

INTRODUCTION

Slugs (*Gastropoda: Pulmonata*) in the last few years have become important pests of cultured plants grown in Poland. Among harmful slug species occurring in horticultural crops, *Arion lusitanicus* Mabille that spread to Poland at the beginning of the 1990s (Kozłowski 1995) deserves special attention. It occurs the most numerously in the Foothill of Carpathian Mountains, in the vicinity Łańcut, Albigowa and Wysoka. Similar to other slugs, *A. lusitanicus* has different food preferences (Kozłowski and Kozłowska 1998). The size of damage of particular plant species caused by this slug depends on various factors, among others, on movement activity and on the ability to disperse.

Slugs are animals conducting a nocturnal way of life. During the day they most frequently remain in their shelters and leave them at dusk to resume their activity (Riedel and Wiktor 1974). Separate slug species have their own periods of maximum night activity. During summer the beginning of night activity in most species is related with sunset (Newell 1968; Lewis 1969; Wiktor 1989). The phase of slug activity is divided into the time of feeding, crawling, resting and mating (Newell 1968). The time and beginning of night activity as well as the rate and directions of slug movement depend on various environmental factors. Initially it was considered that slug activity is regulated by fluctuations in temperature and that light and air humidity or soil moisture are not of large importance (Daiton 1954). However, later investigations have showed that the main factor regulating moving activity of slugs is light intensity (Newell 1968; Lewis 1969). Air humidity and soil moisture also have a large influence on the slug activity (Kozłowski 2001). In sunny and dry weather, *A. lusitanicus* individuals, like other slugs, remain in their shelters during the daytime and start their moving activity after sunset (Kozłowski 1995; 2000). After emergence from overwintering shelters, slugs penetrate the ground in search of food and intensively feed.

The aim of this paper is the analysis of the occurrence, harmfulness and movement activity of *A. lusitanicus* after its emergence from the shelter.

METHODS OF STUDIES

Studies on the number of *A. lusitanicus* occurrence and its harmfulness were conducted in 2001–2002 on the area of Foothill of Carpathian Mountains in the vicinity of Łańcut and Wysoka. Damage of 31 species of cultured plants were determined at different developmental stages. 10 observation points were randomly designated for each crop of the studied plant species. At these points the degree of plant damage was determined for 20 randomly selected plants. The intensity of the slug occurrence per $1m^2$ of the sowing area was found out using two times a frame of 0.5×1.0 m. The degree of plant injuries was ascertained by a 5-grade scale (lack of injuries; weak injuries – from 1% to 25% of damaged plant surface; medium – from 26% to 50%; heavy – from 51% to 75%; very heavy – from 76% to 100%). The date and place of observations, plant species as well as the stage of plant development were recoded. The average damage of particular plant species and the mean number of slugs were determined on the basis of the obtained data.

Studies on the distribution rate of *A. lusitanicus* under field conditions were carried out at Wysoka near Łańcut. The experiment was conducted on a 0.3 ha field located among arable crops. The field was devoid of plants with harrowed and rolled soil surface. From the north it was contiguous to a field road covered with grass and to stubble, from the south – to a road and orchard, and from the west – to fruit bushes (currants, raspberries) and vegetables (different species). The field sloped towards the south and had a noticeable depression near the road. A square 16×16 m in size was marked out on the field. Prior to the experiments the field surface was cleaned from all kinds of remnants (stones, plant residues) and all the slugs were removed from it. A peg was hammered in the middle (central point) of the square to pull through strings dividing the field into 4 quadrants. Then, from the central point, circles 1 m, 2 m and up to 8 m apart were fixed. Starting the observations, 100 adult slugs collected from vegetable crops growing nearby were placed at the central point. Slugs occurring on the particular plots having the shape of consecutive 1m circles were counted each 10 minutes in the first 6 observations and then, each 20 minutes in the last 3 observations. The observations were performed on 5 and 6 August after sunset at the temperatures of 16–18°C and RH 85–98%. Observations conducted on the number of slugs constituted 576.

The mean weighed length of pathway covered by a single individual and the mean movement rate of one were estimated for each of 9 observation dates (treatment number v=9). The weighed means were estimated for simple 10-element samples taken each time from the experimental units, hence the weights were slug numbers observed 1, 2, ..., 8 m apart from the central point from among 10 slugs constituting a simple sample, and slugs for sample were randomly selected with the help of tables containing random numbers (using random numbers all the time). Therefore an experimental unit, the pathway and rate values for which were calculated, was a quadrant of the circle 16 m in diameter. A scheme of nested block design was used (Fig. 1) (Kozłowska and Kozłowski 2001; Morgan 1996). For a pathway covered by one individual and for a movement rate of 1 individual the accepted stable model of observations had the form of:

$$y_{ijw} = \mu + \beta_j + \rho_{w(j)} + \tau_i + e_{ijw},$$

where μ denotes general parameter, β_j the j-th super-block effect, j=1,2, $\rho_{w(j)}$ is w-th block effect in j-th super-block, w=1,2,3,4, τ_i the i-th treatment effect, i=1,2,...,9,

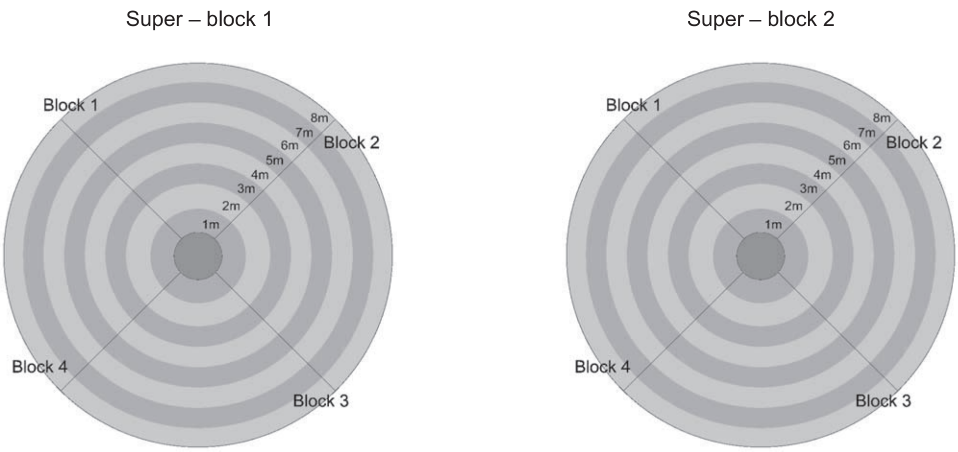

Fig. 1. A scheme of experimental field division (9 treatments – 9 observation dates)

a e_{ijw} denote the uncorrelated random variables having mean zero and variance σ^2 (Morgan 1996). It was assumed that there is no interaction between eliminated directions of the experimental material heterogeneity and objects. This is a model of observations carried out in nested block design with two super-blocks and four blocks in each of one.

An analysis of variance was performed for the variables (pathway length and movement rate of a single slug) being functions of the observed slug number, and F Fisher-Snedecor's test and Tukey's test were applied (Tabs. 3, 4). The obtained data of the pathway length and movement rate represent the rate of slug dispersal taking into consideration accidental changes in the directions of slug movement (their retreats, recurrences and turns) (Tab. 4).

RESULTS AND DISCUSSION

In 2001 and 2002, fields of 31 plant species from 9 families (Tabs. 1, 2) were examined. Among the studied plants species the highest average per cent of plant

Table 1. Intensity of *A. lusitanicus* occurrence and average per cent of damaged plant cultures at the stage of growth and fruit setting

Family	Plant species	Aver. slug no./1m^2	Aver. % of damage
Chenopodiaceae	*Beta vulgaris* L. var. *crassa*	5.1	22.3
	Beta vulgaris L. var. esculenta	6.2	20.3
	Beta vulgaris L. var. *saccharifera* Lnge.	6.4	11.1
Compositae	*Cichorium intybus* var. *foliosum* Bisch.	8.3	0.0
	Lactuca sativa L. var. *capitata* L.	16.7	66.3
Cruciferae	*Brassica juncea* (L.) var. *sareptana* Sinsk.	3.2	0.0
	Brassica oleracea L. var. *botrytis* subvar. *cauliflora* D.C.	5.0	3.2
	Brassica oleracea L. var. *capitata* L. f. *alba*	8.1	33.6
	Brassica pekinensis Rupr.	6.6	25.3
	Cochlearia armoracia L.	11.2	18.1
	Raphanus sativus L. subvar. *radicula* Pers.	14.0	49.5
Cucurbitaceae	*Cucurbita pepo* L.	10.5	40.0
	Cucumis sativus L.	16.0	96.9
Gramineae	*Triticum aestivum* L.	0.9	0.0
	Zea mays L.	1.9	0.0
Papillionaceae	*Phaseolus multiflorus* Lam.	10.4	28.4
	Phaseolus vulgaris L.	27.6	82.5
	Pisum arvense L.	4.1	0.0
	Trifolium resupinatum L.	5.5	29.3
	Vicia faba L. ssp. *maior*	1.5	0.9
	Vicia faba L. ssp. *minor*	5.2	18.1
Polygonaceae	*Fagopyrum esculentum* Minch.	6.4	40.3
	Rheum undulatum L.	16.3	12.5
Solanaceae	*Capsicum annuum* L.	3.3	12.3
	Lycopersicon esculentum Mill.	3.7	31.3
	Solanum tuberosum L.	5.8	21.9
Umbelliferae	*Apium graveolens* L. var. *rapaceum* D.C.	3.3	0.0
	Daucus carota L. var. *carota*	2.3	1.8
	Petroselinum sativum Hoffm. subsp. *Microcarpum* Mark.	4.0	10.6

Table 2. Intensity of *A. lusitanicus* occurrence and average % of cultured plant damage at the stage of the first leaves

Family	Plant species	Aver. slug no./1m^2	Aver. % of damage
Chenopodiaceae	*Beta vulgaris* L. var. *esculenta*	2.9	40.9
Cruciferae	*Brassica napus* L. var. *oleifera* L.	3.3	13.3
Cucurbitaceae	*Cucumis sativus* L.	4.5	16.9
Gramineae	*Hordeum vulgare* L.	4.3	29.8
Umbelliferae	*Daucus carota* L. var. *carota*	1.5	22.5
	Petroselinum sativum Hoffm. subsp. *Microcarpum* Mark.	2.4	23.3

damage was observed in *Cucumis sativus* L., *Phaseolus vulgaris* L., *Lactuca sativa* L. var. *capitata* L. and *Raphanus sativus* L. subvar. *radicula* Pers. (96.9%, 82.5%, 66.3% and 49.5%, respectively). The intensity of *A. lusitanicus* occurrence constituted respectively 16.0, 27.6, 16.7 and 14.0 slugs per 1 m^2 of the sowing area. Large damage were caused by the slugs to the plants of *Fagopyrum esculentum* Minch. and *Cucurbita pepo* L.. An average percent of plant damage amounted to 40.3% and 40%, respectively, but no severely or very heavily damaged plants were found on the plantation of *F. esculentum*. An average number of slugs per 1 m^2 of the plantation of these plant species amounted to 6.4 for *F. esculentum* and to 10.5 for *C. pepo*. Heavily damaged were also leaves of *Brassica oleracea* L. var. *capitata* L. f. *alba* (33.6%) at an average slug number – 8.1 slugs per 1 m^2 of the sowing area as well as juvenile plants of *Beta vulgaris* L. var. *esculenta* (40.9%) at 2.9 individuals per 1 m^2. In general, plants of *Cichorium intybus* var. *foliosum* Bisch. were not consumed despite the occurrence of 8.3 slugs per 1 m^2. The slugs did not damage plants of *Brassica juncea* (L.) var. *sareptana* Sinsk., *Apium graveolens* L. var. *rapaceum* D.C. and *Pisum arvense* L. The slug number on the plantations of these crops was respectively 3.2, 3.3 and 4.1 individuals per 1 m^2 of the sowing area under these plants. Among cereal plants the most seriously damaged were juvenile plants (2–4 leaves) of *Hordeum vulgare* L. (29.8%) at an average of 4.3 individuals per 1 m^2. The remaining cereal plants, *Zea mays* L. and *Triticum aestivum* L. were not injured by slugs. The percentage of plant damage of *Brassica napus* L. var. *oleifera* L. averaged 13.3%. On the plantations of *B. n.* var. *oleifera* and *H. vulgare* plant damage were observed only on the edge strip to 5 m from the baulk (a boundary between fields).

The question was during what time can *A. lusitanicus* cover a distance, for example, of 5 meters in search for food? An answer to this question has been obtained in the studies on the rate of *A. lusitanicus* spread in nested block design.

From the performed analysis of this experiment it follows that the occurred directions of elimination of the experimental material heterogeneity (super-blocks and blocks) as well as the experimental factor had a highly significant influence on the length of pathway covered by slugs (Tab. 3). The super-blocks and the date of observations (experimental factor) had a highly significant influence on the rate of slug movement. Slug individuals observed on the second super-block moved more slowly and over shorter distances. The reason of such behaviour of the slugs were suitable humid conditions (high air humidity and soil moisture after rain) which

Table 3. Results of verification of general hypotheses using F Fisher-Snedecor's test for the pathway (p) covered by *A. lusitanicus* and for its movement rate (mr)

Source	D.f.	F_p	F_{mr}
Super-blocks	1	43.09**	10.86**
Blocks (Super-bloks)	6	4.18**	1.35
Treatments	8	29.14**	6.12**
Error	56		
Total	71		

** – highly significant difference (α=0.01)

Table 4. Weighed means pathway and means movement rate of *A. lusitanicus* and results of Tukey's test at α=0.05

Treatments: observation dates (minutes)	pathway (cm)	movement rate (cm/minut)
10	62.50 f	6.25 a
20	99.83 ef	4.99 ab
30	128.12 de	4.27 abc
40	145.48 cd	3.64 abc
50	160.30 bcd	3.21 bc
60	161.21 bcd	2.68 bc
80	171.56 abc	2.15 c
100	194.29 ab	1.94 c
120	205.94 a	1.72 c

abcd – repetition at least one letter (inside column) goes to show that have not significant difference between treatments

limited slug dispersing movements in search of more moist places. Locomotion of the slugs in four quadrants marked out on the experimental field was varying.

The analysis of observations showed that 10 minutes after transferring 100 slugs it was found that the active ones moved, on the average, for 0.6 m, whereas 2 hours after they moved, on the average, for 2 m. However, the rate of their movement was not uniform. Despite recurrences, retreats and turns the slugs spread over all field quadrants in search of water and food – in all directions from the point, where they were placed at. The rate of their movement at the first dates of observations was significantly higher than that noted at the last observation date. That confirms our preceding observations on slug penetration of the site surface during their directed movement in search of water or food.

In the studies on the dispersal of *Agriolimax reticulatus (*Müller) conducted by South (1965), it was shown that slugs of that species after placing them at the central point made preliminary dispersing movements, penetrated the site surface and 2–3 days after their dispersal was inhibited and the slugs set the local range of their occurrence.

Moving activity of particular *A. lusitanicus* slugs varied greatly: when individuals were at the point of their initial placing, others, 2 hours after, were over 7 m away. The numbers of active slugs at consecutive dates of observations are presented in figure 2. Besides the observed penetration of the site surface while moving, *A. lusitanicus* slugs also spread quickly over the surface and covering new areas by their range (Kozłowski 1995; 2000).

Slugs of different species intensively penetrate the surface covering different distances searching water, food and shelters (Miles et al. 1931; Carrick 1938). For example, the slug *Deroceras sturanyi* (Siomroth) at the air temperature of 20°C moves over short distances at the average movement rate of 8.8 cm/min. (Kosińska 1980), whereas *Deroceras reticulatum* (Müller) covers an average distance of 133.08 m during 7 days (South 1965). Miles et al. (1931) as well as Carrick (1938) suggested that slugs migrate between bare fields and their surroundings (field edges). Other

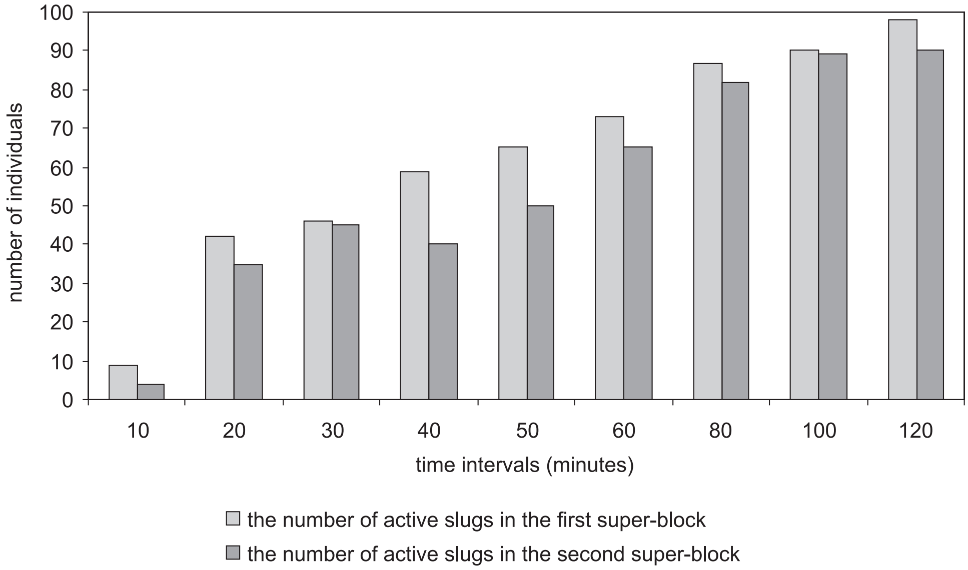

Fig. 2. The number of active slugs

authors, however, considered that some species, for instance, *D. reticulatum*, disperse poorly and colonize new areas with difficulty (Barnes 1953; South 1965).

The rate and directions of slug movement depend on many factors, such as the air humidity and soil moisture, temperature, light, location of shelters and food sources. According to Lewis (1969) the most important factor of the surroundings regulating moving activity of the slug *Arion ater* (Linnaeus) are diurnal light cycles. Light intensity determines the exact time of the beginning of slug activity, while other exogenous factors, such as wind, humidity and rainfall, may have their influence on the length of the activity phase. Newell (1968) showed that a fall of light intensity after sunset initiates moving activity of *D. reticulatum* more than a decrease of temperature. Moving activity of this slug was largely influenced also by soil moisture. *A. ater* slugs are able to recognize high and low moisture. A similar reaction to soil moisture was observed in *A. lusitanicus* during the present studies. Slugs generally display their preference for both high soil moisture and air humidity. Besides surface penetration to satisfy their requirements for food and shelters, slugs being in expanses, as in the case of *A. lusitanicus,* frequently move over large distances with the aim to expand their occupied acreages (Wiktor 1989; Kozłowski 1995; 2000).

CONCLUSIONS

1. *Arion lusitanicus* causes significant damage to many species of vegetables and field crops.
2. The degree of damage of particular plant species is very different, which is indicative of a distinct food specialization of the slug.

3. Slugs of *A. lusitanicus* after emergence from their shelters penetrate the ground moving in a certain direction in search for food or for a place with a higher humidity.
4. The speed of slug movement during penetration of the ground is the highest immediately after its emergence from the shelter and later it noticeably decreases.
5. The obtained results of the studies concerning speed, direction of movement and distances covered by slugs, permit to understand better the events connected with their distribution and spread in the habitat of cultured plants. It is very important for forecasting and estimation of plant damage caused by these slugs.

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POLISH SUMMARY

UWAGI O WYSTĘPOWANIU, SZKODLIWOŚCI I AKTYWNOŚCI ŚLIMAKÓW ZWIĄZANEJ Z PENETRACJĄ TERENU

Oceniano nasilenie występowania *Arion lusitanicus* i stopień uszkodzenia 31 gatunków roślin uprawnych. Ślimak bardzo silnie niszczył rośliny sałaty i kapusty (*Lactuca sativa* L. var. *capitata* L., *Brassica oleracea* L. var. *capitata* L. f. *alba*) oraz wiele gatunków innych warzyw (*Cucumis sativus* L., *Phaseolus vulgaris* L., *Raphanus sativus* L. subvar. *radicula* Pers.). Uszkodzenia roślin w pasach brzegowych, obserwowano także na plantacjach rzepaku i jęczmienia zaatakowanych przez *A. lusitanicus*. Aktywność ruchowa poszczególnych osobników *A. lusitanicus* była zróżnicowana. Poprzez zaplanowanie doświadczenia w zagnieżdżonym układzie blokowym uzyskano możliwość statystycznego określenia różnic w aktywności ruchowej ślimaków. Dla każdego z 9 terminów obserwacji wyznaczono średnie ważone długości drogi przebytej przez jednego osobnika oraz średnią prędkość przemieszczania się jednego osobnika. Zaobserwowano, że po dwóch godzinach jedne ślimaki były w punkcie ich umieszczenia a inne znajdowały się w odległości ponad 7 m. Stwierdzono, że ślimaki penetrują teren wykazując tendencję do przemieszczania się do miejsc o wyższej wilgotności i do źródeł pokarmu.