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ANNALES AGRICULTURAE FENNIAE, VOL. 28: 87—96 (1989)

Seria ANIMALIA NOCENTIA N. 138 — Sarja TUHOELÄIMET n:o 138

WHEAT BLOSSOM MIDGES, *SITODIPLOSIS MOSELLANA* (GEHIN) AND *CONTARINIA TRITICI* (KIRBY) IN FINLAND, DURING 1981 — 87

SIRPA KURPPA

KURPPA, S. 1989. **Wheat blossom midges, *Sitodiplosis mosellana* (Gehin) and *Contarinia tritici* (Kirby) in Finland, during 1981 — 87.** Ann. Agric. Fenn. 28: 87—96. (Agric. Res. Centre, Inst. Pl. Protect., SF-31600 Jokioinen, Finland.)

The orange wheat blossom midge *(Sitodiplosis mosellana)* infested winter and spring wheat and barley depending on the coincidence between midge oviposition and ear emergence of the crops. In the strongest infested, southeastern coastal area over 40 % of grains were injured. The yellow wheat blossom midge *(Contarinia tritici)* occurred more occasionally. Emergence of *S. mosellana* adults was predicted by cumulative daydegrees over 5 ° C, 400 daydegrees ° C being the critical temperature. Distribution of larvae in the field was random and the proportion of infested ears increased to 70 — 80 % before the mean number of larvae / infested grain began to grow exponentially. In the ears larvae were aggregated, but the mean number of larvae / ear, between 1 — 25, correlated linearly with the final proportion of injured grains. A sample of 400 ears / plot would be needed for receiving a reliable sign of an initiated infestation, on the level of 0.01 larvae / ear. The same sample size would be needed for getting an estimate of the mean number of larvae / ear, with 17 % deviation, on the level of over 1 larvae / ear.

Index words: wheat blossom midge, *Sitodiplosis mosellana, Contarinia tritici,* distribution, wheat, ear, kernel, grain.

INTRODUCTION

The wheat blossom midges, *Sitodiplosis mosellana* (Gehin) and *Contarinia tritici* (Kirby) are well distributed over Europe (WETZEL et al. 1984). In addition, they are pests in North America (BARKER 1984, WRIGHT and DOANE 1987), in Japan (KATAYMA et al. 1987), in China (MA 1979) and, also in North Africa (SKUHRAVA et al. 1984). Fluctuations of long duration have been typical of these gall midges. Population peaks in Central Europe and Sweden have been reported of the end of the 1890 's, the 1930 's, the 1950 's, and at the end of the 1970 's. The first report from Finland was given during the 1930 's (HUKKINEN and VAPPULA 1935). Then next attack on wheat by strong midge populations was in 1983, but the following year damage was again much milder (HELENIUS et al. 1984).

The major host of the wheat blossom midges is wheat, but rye, barley and gramineous weeds may be infested in the case that the ear emergence and oviposition of the midges coincide well. Adaptation of *S. mosellana* to early blossoming rye has been reported from Germany (BASEDOW 1972). Fifty years ago, the first report from Finland was issued on the infestation of rye. In the 1980's midge larvae were first reported in wheat, of which about 160 thousand hectares is grown, in southern Finland.

This study includes a survey on midge populations in fields during 1985—87. Additional information about the first years of midge gradation was obtained by conducting a survey on injured grains in the wheat yields of 1981 and 1983. The yield material for the second survey was provided by the laboratory the State Granary in Helsinki. The present work is intended to serve as a necessary basis for advisory activities.

MATERIAL AND METHODS

For the survey on previous damage, 83 yield samples were obtained from 1981 and 358 samples from 1983. These samples had been collected by the State Granary from all over the major wheat cultivation area (Fig. 1) in Finland. Injured grains were identified visually. Only the damage caused by *S. mosellana* could be identified, because grains damaged by *C. tritici* are totally destroyed and thus lost in harvest. Damaged samples were graded according to the frequency of injured grains as follows: 1) no damage, 2) 1—3 % of grains injured, 3) 3—10 % of grains injured, 4) over 10 % of grains injured.

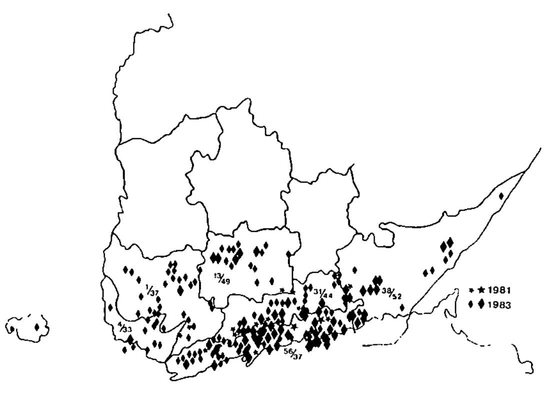

Fig. 1. Distribution of *S. mosellana* damaged yield lots of spring wheat, from 1981 and 1983. Frequency of the two grades of damage: 1981 1—3 % injured grains = small star, over 3 % injured = big star; 1983 1—10 % injured grains = small square, over 10 % injured = big square.

In 1985—87, 66, 79 and 82 private wheat fields were sampled by the advisory staff of the local Agricultural Advisory Centres. In addition samples were taken from the research stations in Anjalankoski, in southeastern Finland and in Mietoinen, in southwestern Finland. A questionnaire on relevant cultivation practices was filled out for each field sampled. Sampling period was the later part of July and the beginning of August. At this time, midge larvae were nearly fullgrown and easy to observe.

Each field sample consisted of 50 ears taken representatively from each field by walking in a w-form over the area. Samples were brought to a laboratory where glumes were opened to determine the number of larvae on each grain. The number of injured grains in each ear was recorded.

RESULTS

Damage in the yield material from 1981 and 1983

S. mosellana damaged grains were found in 24 (29 %) yield samples from 1981 (Fig. 1). The maximum proportion of injured grains was 3.2 %, and the mean 0.65 (± 0.99 %). In the material from 1983 injured grains were found in 66 % of the samples. The proportion of injured grains was 1 — 10 %, in 41 %, and over 10 %, in 25 % on the samples. Heavily damaged material originated mainly from the southern and southeastern coast (Fig. 1). Damage was found in various wheat varieties, with none of them being clearly more or less frequently damaged than the others.

Midge larvae in the fiedls in 1985 — 87.

In 1985 the majority of *S. mosellana* infested ear samples originated from the southern coast of Finland (Fig. 2a). These were spring wheat (Table 1). No significant differences among different varieties were noted. Larvae tended to be more common in the lower part of the ear. Unfortunately, the exact position of infested grains in the ears was not recorded. In winter wheat only occasional infested ears were detected in late varieties. Larvae were then always found in the top of the ear. *C. tritici* was not present in any larger scale. Only, a few groups of numerous larvae were seen, in winter wheat, always concentrated in the topmost grains of the ear.

In 1986 infestations were common in winter wheat (Table 1). The maximum number of *S. mosellana* larvae per ear was found in Hämeenlinna, while high infestations had disappeared from the earlier infested southeastern area (Fig. 2b). Infestations were found in various varieties in the survey, but in variety testing experiments the latest winter wheat variety, Linna, was the most infested everywhere. This was most likely due to a synchrony of ear emergence and midge oviposition. Infested grains were distributed throughout the ear. *C. tritici* was detected both in spring and winter wheat, in 1986. In the southwestern region it hardly occurred in winter wheat. The high infestations were scattered all over the central and western area (Fig. 2c). The variety Linna was the most damaged by *C. tritici.* In winter wheat yellow wheat blossom midge larvae were concentrated in the top of the ear whereas in spring wheat larvae were found more commonly in the lower part.

In 1987 the maximum infestation of *S. mosellana* in winter wheat was detected in a completely new site, at Kokemäki, in the northwestern wheat growing area. (Later, in 1988, infestations were concentrated in this area.) In 1987, strong infestations resumed in the southeastern area, the origin of high infestations. Spring wheats were the most damaged there, and the very high maximum number of larvae was found at the Kymenlaakso Research Station, in a field which had already been strongly infested in 1983. *C. tritici* was detected only in the southwestern area (Fig. 2d) mixed with populations of *S. mosellana.* Both midges were found in the same ears, and even on the same grains of spring wheat, mostly in the lower part of the ear. The larvae varied in size.

As to barley, in 1987, 27 samples out of a total of 142 were infested. Eight of these were over the mean of 1 larvae / ear, the maximum mean being 12. 2 larvae / ear. These samples were from Koria (Fig. 2e). In barley, *S. mosellana* had distributed to the area so far north, where wheat is rarely grown. No variety in the survey can be singled out as the most or least infested. In infested ears larvae were without exception detected in the lowest grains.

Fig. 2. Distribution of wheat midge larvae in the field. a) *S. mosellana* on wheat in 1985 (N = 66), b) *S. mosellana* on wheat in 1986 (N = 79), c) *C. tritici* on wheat in 1986 (N = 79), d) *S. mosellana* and *C. tritici* on wheat in 1987 (N = 82) and e) *S. mosellana* on barley in 1987 (N = 142). No infestation = open circle, less than the mean of 1 larvae / ear = small figure, more than the mean of 1 larvae / ear = big figure. The site of the maximum infestation is indicated.

Table 1. Occurrence of orange wheat blossom midge *S. mosellana* and yellow wheat blossom midge *C. tritici* in the samples from spring and winter wheat in 1985 — 87. Highly infested = over the mean of 1 larvae / ear.

	Spring wheat		Winter wheat	
	Orange	Yellow	Orange	Yellow
1985				
Infested samples %	80	—	*	*
Highly infested %	20			
Maximum mean no larvae / ear	13			
Mean no larvae / ear among infested samples	1.8			
1986				
Infested samples %	23	41	44	59
Highly infested %	3	8	17	15
Maximum mean no larvae / ear	1	3	11	7
Mean no larvae / ear among infested samples	0.25	0.4	1.1	0.9
1987				
Infested samples %	48	—	58	*
Highly infested %	21		8	
Maximum mean no larvae / ear	41		29	
Mean no larvae / ear among infested samples	1.3		2.5	

* occasional observations

Timing and distribution of orange wheat blossom midge infestation in the field

Adult *S. mosellana* emerged and started to fly, in 1985 on the first week of July, in 1986 on the third week of June and, in 1987 on the second week of July. The relation between soil temperature and development velocity counted according to the regression presented by KATAYMA (1987) provided the correct approximation of larval development during the experimental years (Fig. 3). The cumulative daydegrees used in prognoses for German wheat blossom midge populations (BASEDOW and GILLICH 1982) gave about a three-week longer development time and is therefore not valid for Finland. The standard cumulative daydegrees for cultivated plants, counted over 5 °C in Finland, reached the value of 370

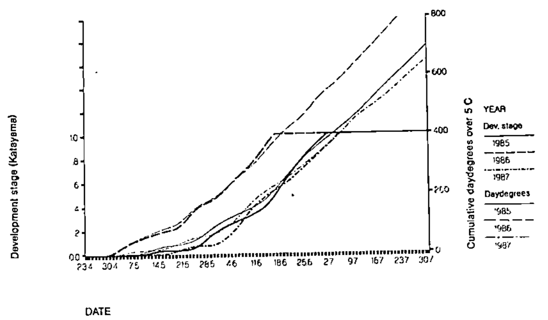

Fig. 3. Development of *S. mosellana*, according to the regression of KATAYAMA (1987), in conditions at Anjalankoski, in 1985 — 1987.

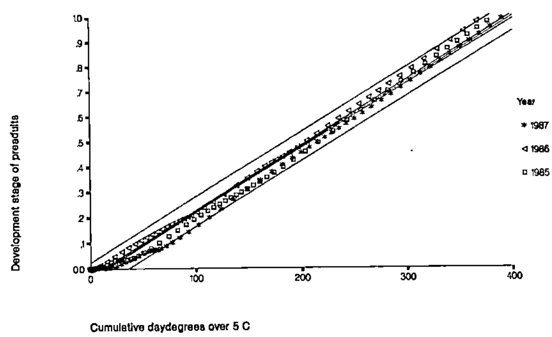

Fig. 4. Relation between pace of development of *S. mosellana* (counted by KATAYAMA 1987) and accumulation of daydegrees over 5 °C at Anjalankoski.

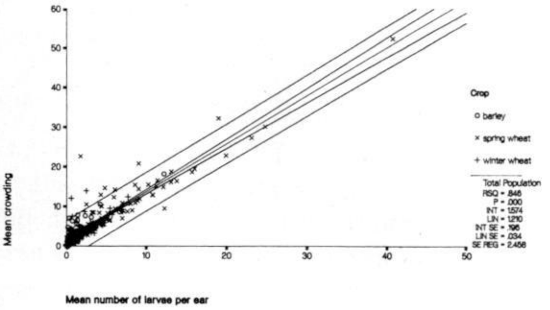

Fig. 5. Relation between mean crowding (LLOYD 1967) and the mean number of *S. mosellana* larvae / ear (Lloyd's aggregation index) on spring and winter wheat, and barley.

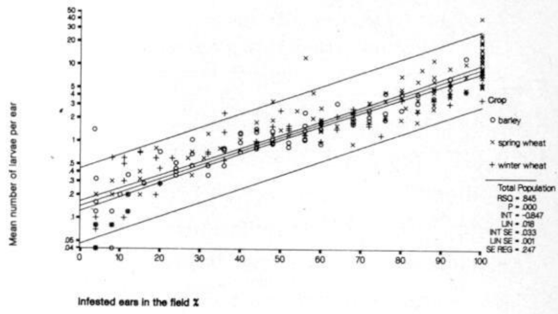

Fig. 8. Relation between the mean number of *S. mosellana* larvae / ear and proportion of infested ears.

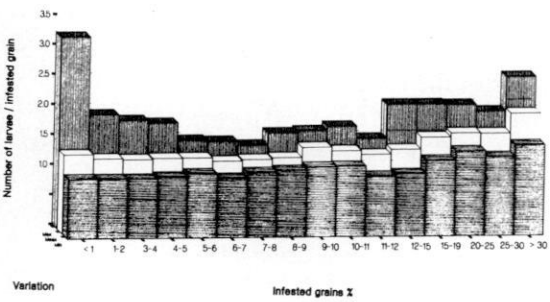

Fig. 6. Mean number of *S. mosellana* larvae / grain at various levels of infestation.

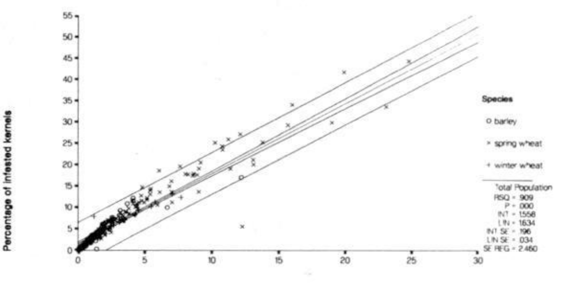

Fig. 7. Relation between mean number of *S. mosellana* larvae/ear and proportion of injured grains in the yield of wheat and barley. Estimates of the power function given by OLFERT et al. (1985) (solid circles) are given, by using 30 as a rough estimate of the number of grains per ear.

— 400 °C, at the start of the midge flight (Fig. 3). The pace of midge development (Fig. 4) correlated strongly with the air temperature.

The distribution of midge larvae in the field was nearly random. Lloyd's aggregation index (LLOYD 1967) was 1.21 ± 0.034 and did not significantly vary between the different host plants (Fig. 5). Larvae had distributed over the field before the number of larvae per ear started to increase exponentially (Fig. 8). As opposite to this, aggregation in ears was strong to variable in parts of the ear, as described above. However, the number of larvae / infested grain increased very slowly from 1 to 2 as infestation grew heavier, between 1 — 30 larvae / ear (Fig. 6). The variation around the mean was highest at the lowest and highest infestation levels. The absolute maximum number of larvae per one ear was 6, in a highly infested ear. There was a feasible linear correlation between the mean number of larvae / ear, on the scale of 0 — 25 larvae / ear, and the final proportion of injured grains (Fig. 7). The correlation was slightly better ($r = 0.966$) when the proportion of infested grains (p) was transformed to a logit scale, $\ln (1 / (1 - p))$.

DISCUSSION

The orange wheat blossom midge was shown to have been common in Finland since the early 1980's. Gradation had most probably begun at the end of 1970's, simultaneous to the incidence of high midge populations in Poland (GOLEBIOWSKA 1979). The reason for the increase of midge populations can only be speculated. Midges have been shown to migrate long distances, from Central Europe to Sweden, for instance (SVÄRDSON 1940). In 1978 and 1982, aphids from the south arrived in Finland (personal observation). In June and July, southern air streams are typical in Finland thus favoring southern migration.

BASEDOWs report (1972) about midge adjustment to early blossoming rye as well as the high rate of the development of the Finnish midge populations described in this study provide valuable clues about the great capacity of wheat midges to acclimatize to a new habitat. Carryover ability, essential to save population over a sequence of adverse environmental conditions (TAKAHASHI 1977), was apparent in 1986, in the population in southeastern Finland.

S. Mosellana infested spring and winter wheat depending on the local and annual conditions. The coincidence of egg laying and ear emergence was partial for the both wheat types in the warm year of 1986. In 1985 and 1987, winter wheat mostly escaped infestation by flowering before midge flight. However, spring wheat was frequently infested. *C. tritici,* which emerges earlier and lives a slightly shorter time than the orange midge (BASEDOW 1972), was able to infest wheat effectively only in 1986, and at that time especially winter wheat. In the other years adult midges were most apparently flying in the field during the time between the flowering of winter wheat and ear emergence of spring wheat. They were too late to infest winter wheat and too early to infest spring wheat.

The phenomenon of midge larvae in the ears has been observed with *C. tritici* and thought to depend on the packing of spikelets in an ear; the highest spikelets being preferred for oviposit (ÅKERMAN 1917). The ears of spring wheat are fairly compact and the lowest spikelets might be easiest for proper access by *S. mosellana*'s short ovipositor. In winter wheat ears spikelets are more directed outwords. The opening of the flag leaf shealth during ear emergence is the reason behind asymmetrical aggregation of larvae in an ear (HENNING 1913). Long awns were most possibly the reason for the larval aggregation in the lowermost grains in barley ears. All the grains higher up in an ear are covered by the awns of the lower grains and may be difficult to oviposit.

The 65 % ear attack represented 3 % grain attack and 90 — 100 % ear attack represented 8 grain attack upwards, equally as described by BARNES (1932) from England. The mean number as well as the absolute maximum number of larvae / infested ear in our material (Fig. 8) remained lower than that reported from Saskatchewan (OLFERT et al. 1985). However, we never found as high populations as those in Canada, either. In any case, as the midge population increased, infestation in our fields was distributed more rapidly to new ears and the percentage of infested grains increased more quickly, than in Canada. This might be a function of growing conditions. Our small, forest-surrounded field plots might be easier to fly onto and seek new ears than open prairie. Another possible reason might be a difference in the rate of wheat ear development and the uniform appearance of our cropstand. Our cultivars are fast maturing and the cropstand is very uniform being mainly formed by main tillers (mean number of tillers 1.2)

For advisory practices, the earliest possible sign of initiated infestation as well as, in a damage situation, a reliable estimate of the larvae population in a field are valuable. According to our material and the equations presented by WILSON and ROOM (1983), a sample of 400 ears per field would indicate an infestation of a minimum mean of 0.01 larvae / ear, with 95 % confidence. (A deviation of 100 % from the mean is accepted.) The same number of ears could be used, with the confidence of 95 %, for obtaining an estimate of a mean number of larvae / ear, on the level of 1 larvae / ear upwards, when a deviation of 17 % from mean is accepted.

The cumulative daydegrees over 5 °C was found to give feasible prognoses for the predult development of *S. mosellana.* It can be said therefore that the critical number remained nearly standard during the three climatically very different years. The method of soil temperature measurement is, naturally more exact but is not a procedure used by simple weather recording stations. The first warning of midge flight could be issued at the point when cumulative 350 ° C daydegrees has been attained. However, the major problem here is, that the effect of soil moisture, found to be an important factor at the end of larval development by BASEDOW (1972), is ignored. The phenomenon that midges did not appear in the infested area of southeast Finland in 1986 most obviously resulted from the early spring drought, which induced continued diapause. For prognosis, the continuation of the pupal development in soil should therefore be checked. The optimal time for that could, according to the developmental rhythm described by BASEDOW (1972), be when cumulative daydegrees over 5 ° C have reached the value of about 150.

Acknowledgement — I thank Jari Haukka M. Sc. for checking the statistical methods and Prof. Martti Markkula and Gun-Britt Husberg M. Sc. for reading the manuscript. Thanks are due to the State Granary, to the staffs of the Agricultural Advisory Centres for providing sample material and to my assistants for patiently counting the larvae.

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SELOSTUS

Tähkäsääski ja vehnäsääski maassamme vuosina 1981—1987

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Maatalouden tutkimuskeskus

Tähkä- ja vehnäsääski ovat viljojen yleisiä tuholaisia kaikkialla vehnänviljelyalueella. Tuhot ovat kuitenkin niin ajoittaisia, että sääskien merkitys on ehditty välillä lähes unohtaa. Meilläkin 1980-lukua edeltävät tiedot sääskistä ovat 1930-luvulta. Vuonna 1983 sääskituhot itäisellä Uudellamaalla olivat yllättäen niin huomattavat, että sääskien yleisyyden ja merkityksen selvittäminen tuli ajankohtaiseksi ja oli torjunnan ohjauksen kannalta välttämätöntä.

Sääskien aikaisempaa esiintymistä pyrittiin arvioimaan tarkastamalla Valtion Viljavaraston viljaotannan aineistoa vuosilta 1981 ja -83. Varsinainen sääskitoukkien levinneisyys selvitettiin vuosina 1985—87 tarkastamalla tähkänäytteitä, jotka oli otettu tuleentumisen alkuvaiheessa syys- ja kevätvehnäpelloilta sekä, vuonna 1987 myös ohrasta. Samoina vuosina tehtiin havaintoja sääskien lentoajasta ja muninnan ajoittumisesta, tarkimmin Maatalouden tutkimuskeskuksen Kymenlaakson tutkimusasemalla.

Tähkäsääsken vioitusta todettiin jo vuoden 1981 sadosta, tosin vain 29 %:ssa näytteistä vioitettujen jyvien määrän jäädessä enimmilläänkin alle 3,2 %. Pari vuotta myöhemmin korjatuista näytteistä vioitusta löytyi jo 66 %:ssa, ja neljänneksessä näistä vioittuneita jyviä oli yli 10 %. Pahimmin vioittuneet näytteet olivat peräisin itäiseltä Uudeltamaalta.

Tähkäsääsken toukkia esiintyi vuoden 1985 levinneisyystarkastuksessa eniten edelleen itäisellä Uudellamaalla. Sääsken muninta osui heinäkuun alkuun ja munintakohteina olivat kevätvehnät. Vuonna 1986 tähkäsääskiä kuoriutui monin paikoin yllättävän vähän. Ilmeisesti kevätkuivuuden tähden suuri osa toukista jättäytyi lepotilaan. Aikuistuvat sääsket lähtivät lentoon aikaisin, jo kesäkuun kolmannella viikolla ja munivat syysvehniin. Lajikekoekentillä myöhäinen Linna-lajike vioittui pahiten. Ilmeisesti sen tähkintä osui kaikkein parhaiten yksiin sääskien muninnan kanssa. Vuosi 1986 oli ainoa kolmesta koevuodesta, jolloin vehnäsääskeä esiintyi runsaasti, erityisesti läntisellä Uudellamaalla. Vuoden 1987 alhaisissa lämpötiloissa tähkäsääskien aikuistuminen siirtyi heinäkuun ensimmäiselle viikolle, mutta myös viljojen kehitys viivästyi niin paljon, että sääsket pääsivät munimaan sekä syys- että kevätvehniin ja vieläpä ohraan. Kevätvehnistä suurimmat toukkamäärät löytyivät Kymenlaaksossa ja syysvehnistä Satakunnassa. (Voimakas esiintymä toistui Satakunnassa ja Sata-Hämeessä seuraavana vuonna 1988.) Ohrissa tähkäsääskeä esiintyi myös varsinaista vehnänviljelyaluetta pohjoisempana.

Kasvukauden tehoisan lämpösumman ja tähkäsääskien lentoonlähtöajan väliltä löytyi käytännön kannalta tärkeä yhteys. Sääsket ovat valmiita munintaan, kun lämpösumma lähestyy arvoa 400 ° C. Tämä johtopäätös on vedetty kolmen sääoloiltaan hyvin erilaisen vuoden tuoksista, ja sen vuoksi sitä voitaneen pitää varsin luotettavana. Pienilmastollisten erojen varalta sääskien tarkkailuun on ryhdyttävä lämpösumman 350 ° C ylittyessä.

Tähkäsääskitoukat jakaantuivat tasaisesti tähkien kesken. Sääskikannan kasvaessa toukkaisten tähkien osuus kasvoi ensin lähelle 100 %:a, ja vasta sitten toukkien määrä kussakin tähkässä lähti voimakkaaseen kasvuun. Kussakin tähkässä toukat olivat sijoittuneet vierekkäisiin jyviin. Jyvää kohden laskettu keskimääräinen toukkamäärä nousi lievästi sääskikannan vahvistuessa, mutta pysyi rajoissa 1—3, ja vioittuneiden jyvien osuus nousi sitten lineaarisesti toukkamäärän noustessa. Tässä tähkäsääski eroaa vehnäsääskestä, jonka toukkia saattoi olla jopa kaksikymmentä yhdessä jyvässä. Näiden tulosten perusteella voidaan laskea, että pellolta kerätystä 400 tähkän näytteestä saadaan osoitettua tähkäsääsken esiintymä, silloin kun toukkia on keskimäärin vasta 1 sataa tähkää kohden. Samansuuruisesta näytteestä saadaan luotettava arvio keskimääräisestä toukkamäärästä, kun toukkia on vähintään 1 tähkää kohden ja 17 %:n virhe keskiarvosta hyväksytään.

ANNALES AGRICULTURAE FENNIAE, VOL. 28: 97—102 (1989)

Seria ANIMALIA NOCENTIA N. 139 — Sarja TUHOELÄIMET n:o 139

Research note

PESTS OF CULTIVATED PLANTS IN FINLAND DURING 1988

SIRPA KURPPA

KURPPA, S. 1989. **Pests of cultivated plants in Finland during 1988.** Ann. Agric. Fenn. 28: 97 — 102. (Agric. Res. Centre, Inst. Pl. Protect., SF-31600 Jokioinen, Finland.)

Damage caused by insects and other animal pests to cereals, forage plants, root crops, vegetables, rape, sugar beet, apple, berries and other cultivated plants in Finland during 1988 is reported based on the results of questionnaire surveys.

The year up to August was exceptionally warm being dry in southern coastal areas, rainier further north and, from August on rainier throughout the country. The abundance of all pests, in terms of a five-point scale was 3.3 and equal to the highest value during the period from 1965 to 1984 obtained once before this during an aphid outbreak in 1973. The major pest was *Rhopalosiphum padi.* The mean severity of the damage was the highest since the start of these surveys in 1965. In addition to the overwintering population, a high number of aphids came to the country by southern winds. Aphids were responsible for a major barley yellow dwarf epidemic.

On root crops and vegetables *Delia antiqua, Psila rosae* and *Plutella xylostella* caused damage. *P. xylostella* was carried by wind to the country. In greenhouses *Frankliniella occidentalis* was injurious, especially in mixed cultivations of ornamentals and vegetables, but occurred also in 6 % of cucumber in pure vegetable crops. Locally heavy injuries to currants were caused by *Nematus ribesii, Pristiphora pallipes, Dasineura tetensi* and aphids.

Slugs, *Deroceras agreste* and *D. reticulatum* caused exceptional damage to vegetables and winter wheat. The postseasonal number of voles, *Arvicola terrestis* and *Microtus agrestis,* increased posing a major risk to orchards.

Index words: plant pest, severity of damage, *Rhopalosiphum padi, Delia antiqua, Psila rosae, Plutella xylostella, Frankliniella occidentalis, Nematus ribesii, Pristiphora pallipes, Dasineura tetensi, Microtus agrestis, Arvicola terrestis, Deroceras agreste, Deroceras reticulatum.*

INTRODUCTION

The present survey is based on replies to inquiries sent to about 300 advisers of Agricultural Advisory Centres. This network covers all 461 municipalities of the country. Inquiries were sent out three times, in May, June and in August. The percentages of respondents (municipalities represented) to each inquiry were: 43 % (40 %), 42 % (38 %), 34 % (35 %), respectively. The final regional coverage is shown in Fig. 1.

Each inquiry requested an estimate of the severity of damage caused by insects and other pests specified in the questionnaire. A scale of 0 — 10 was used to assess severity. In the autumn inquiry, advisers were also requested to give a general estimate of the pest situation throughout the growing season. For this purpose, a scale of 1 — 5 was employed: very sparse (1), sparse (2), normal (3), abundant (4), very abundant (5).

The summer was extremely warm. The mean effective daydegrees (daily sum of temperatures over 5 ° C) for a normal growing season was, already, reached around the 25 th of August. By the end of the season, October 15 th — 23 rd, this sum of temperatures attained a 25 % higher value than the mean national for 1931 — 60. Precipitation was very variable. In the south-eastern, coastal area practically no rain fell between cereal sowing and harvest. In other areas heavy rainshowers occurring with occasional thunderstorms watered the soil excessively. A few fields had to be resown due to the crusting effect by heavy rain. Higher than average precipitation was common in August and September throughout the country.

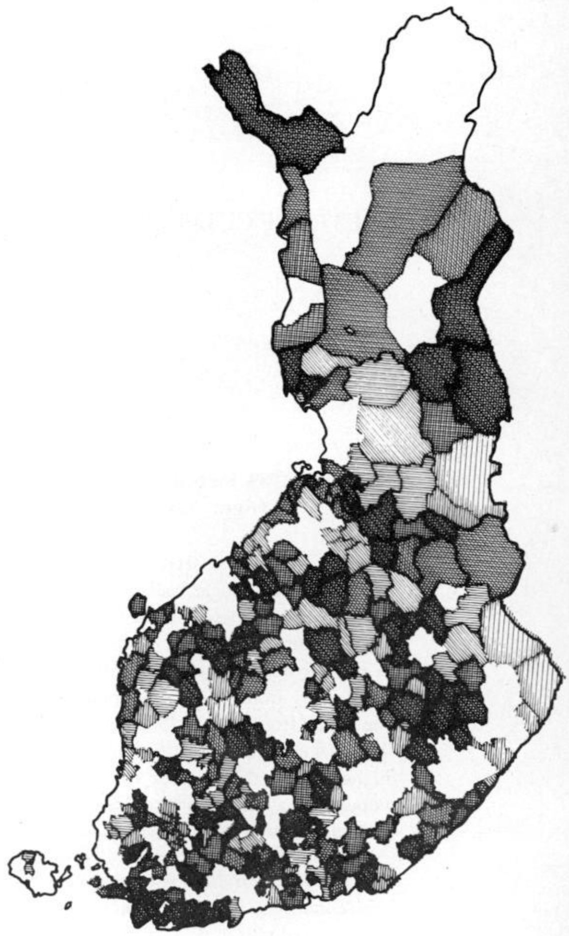

Fig. 1. Coverage of completed inquiries among municipalities in Finland. Replies were received in spring from the vertically striped areas and in autumn from the obligue striped area. Replies to all inquiries were received from the crisscrossing striped area, respectively.

RESULTS OF THE INQUIRIES

For the entire growing period the mean abundance of pests on the 1 — 5 scale was 3.3 being significantly higher than the mean abundance of 2.5 during the period 1965 — 84. The high mean value was based on the considerable abundance of certain single species, especially aphids. The previous high mean, 3.3 occurred in 1973 which was also a year of high aphid abundance.

In February a forecast for the summer abundance of the bird cherry oat aphid *(Rhopalosiphum padi)* was presented. Overwintering populations of the aphid were found to be very high, and the need for control was quite obvious. Only cold and rainy weather during the aphids' spring migration could have dampened the population. The aphids flew successfully onto cereals becoming the major pests of the season. In addition to the domestic population, an abnormally high number of *R. padi* were brought by southeastern winds to Finland, already on the 22nd and 25th of May. These aphids were carriers of barley yellow dwarf virus, which caused an extra pressure for early chemical control. Control in one or two applications, was common throughout the main cereal growing area.

The orange wheat blossom midge *(Sitodiplosis mosellana)* was absent in dry areas but occurred occasional in abundance in the southwestern inland area, where rain had fallen at the beginning of June.

The severity index for the rape blossom beetle *(Meligethes aeneus)* was equal to the mean for 1965 — 84, but the beetle was much less abundant than the year before and at the beginning of the decade. The population was most possibly decreased, excessively, when the beetle larvae were killed in high numbers by lady bird *(Coccinella septempunctata)* adults en route from cereal fields to other crops, after the aphids.

All pests were less abundant on sugarbeet than on the average in 1965 — 84. The same was true for the pea moth *(Cydia nigricana)*.

Onion, carrot rust and cabbage flies *(Delia antiqua, Psila rosae* and *Delia radicum & floralis)* were fairly common on vegetable crops, the severity of the first two being above the average. Also damage caused by the cabbage moth *(Plutella xylostella)*, increased slightly from the previous year exceeding the average. This pest is known to be carried by wind to our country. Major numbers of them appeared last time in 1978 a year also remembered for its aphid outbreak. Other insects occurred in low numbers on vegetables.

The apple sucher, *Psylla mali*, was found to occur steadily in orchards and the fruit tree red spider mite, *Panonychus ulmi*, was noted to have slightly increased from the previous year (Tuomo Tuovinen, oral comm.) but damage was minor. Similarly low was the damage by the apple fruit miner *(Argyresthia conjugella)* and the apple moth *(Cydia pomonella)*, even though some of the moths were able to form an exceptional second generation. Vole populations seemed to be on the increase from their low in 1987. The abundance of both vole species: the field vole *(Microtus agrestis)* and the water vole *(Arvicola terrestis)* clearly exceeded the average in 1965 — 84 and might result in substantial damage next year (Sampo Kulmala, oral comm.).

Aphids were the most prevalent of all pests on berries. Curled leaves caused by the permanent current aphid *(Aphis schneideri)*, were especially common. The gooseberry sawflies *(Nematus ribesii* and *Pristiphora pallipes)* caused major damage locally (e.g. Irmeli Markkula, oral comm.). In addition to those pests mentioned in the inquiry, the importance of the black currant leaf midge *(Dasineura tetensi)* seemes to be steadily increasing (Tuomo Tuovinen, oral comm.).

Damage caused by the raspberry beetle *(Butyrus tomentosus)* and the strawberry blossom weewil *(Anthonomus rubi)* also needed control (Tuomo Tuovinen, oral comm.), as usual.

As to pests occurring on several plants, the potato stem borer *(Hydraecia micacea)* increased its' importance.

Especially severe damage was occasionally caused by slugs in newly sown winter wheat. The high precipitation of the previous summer had been found to increase slug populations (MARKKULA 1988). In the inquiry the field slug *(Deroceras agreste)* is mentioned but according to extra field observations and descriptions given by farmers by phone, the damage was caused by the grey field slug *(Deroceras reticulatum)*. This species overwinters as an adult and the winter 1987 — 1988 obviously favoured its survival. The highest damage to winter rye fields was 8 — 10 ha on a heavy soil. High organic matter contents and direct drill increased damage.

Surveys on *Frankliniella occidentalis*

An additional survey was conducted on the western flower thrips *F. occidentalis*, which was noted to be widely distributed throughout Finnish greenhouse cultivations during the previous year. In 1988, cucumber was the focal crop and a survey was performed by the National Board of Agriculture's Plant Quarantine Service and the Agricultural Research Centre, Department of Pest Investigation.

Flower samples were received from 239 greenhouses growing cucumber. *F. occidentalis* was identified in 32 cultivations (13 %). Thrips was more common in cultivations comprising a wide selection of vegetable and ornamental plants (35 % infested) than in cultivations restricted to vegetables (6 % infested). The origin of the numerous infestations was thought to be the plant material obtained from various sources.

The mixed greenhouse cultivations seemed either to be targets of repeated thrips infestations or uncontrollable *F. occidentalis*. This was demonstrated by reinvestigating the greenhouses where infestations had been controlled in 1987. Most of these were found to be still infested in spring 1988 (BRAX and LINDQVIST 1989).

Table 1. Results of questionnaires. Severity of damage on a scale of 0 — 10. Frequency of damage calculated as the percentage of crops in which damage was observed.

	Number of observations 1988	Severity of damage 1988	Severity of damage 1965 — 84
CEREALS			
Rhopalosiphum padi (L.)	178	3.4	1.1
Phyllotreta vittula (Redtb.)	101	0.5	0.7
Oscinella frit (L.)	212	0.4	0.8
FORAGE PLANTS			
Nanna spp.	97	0.6	1.3
RAPE AND TURNIP RAPE			
Meligethes aeneus (F.)	121	1.6	1.6
Phyllotreta spp.	86	0.8	

SUGAR BEET			
Lygus rugulipennis Popp.	80	1.2	1.6
Pegomya betae (Curt.)	152	1.0	1.6
Chaetocnema concinna (March.)	167	1.0	1.4
Aclypea opaca (L.)	66	0.6	1.2
PEA			
Cydia nigricana (F.)	55	1.3	1.7
ROOT CROPS AND VEGETABLES			
Delia antiqua (Mg.)	94	2.0	1.5
Plutella xylostella (L.)	85	1.9	1.7
Delia radicum (L.) and *D. floralis* (Fall.)	87	1.6	1.8
Phyllotreta spp. on crucifers	167	1.0	1.6
Psila rosae (F.)	96	1.0	0.8
Trioza apicalis (Först.)	96	0.7	1.3
Phaedon cochlearie (F.)	68	0.3	0.9
APPLES			
Microtus agrestis (L.)	127	1.9	1.2
Lepus europaeus Pallas and *L. timidus* L.	122	1.5	1.8
Arvicola terrestris (L.) root damages	101	1.0	0.7
Cydia pomonella (L.)	60	1,0	2,0
Argyresthia conjugella Zell.	55	1.0	2.7
Aphis pomi (Deg.)	48	0.9	1.2
Panonychus ulmi (Koch.)	90	0.8	1.1
Psylla mali (Schmidbg.)	81	0.8	0.8
Yponomeuta padellus malinellus Zell.	37	0.4	1.2
BERRIES			
Aphididae on *Ribes* spp.	116	2.7	1.6
Nematus ribesii (Scop.) and *Pristiphora pallipes* Lep.	90	1.7	1.5
Tarsonemus pallidus Bks.	93	1.5	1.9
Byturus tomentosus (Deg.)	78	1.5	1.5
Anthonomus rubi (Abst.)	86	1.4	1.4
Pachynematus pumilio Knw.	83	1.4	1.2
Cecidophyopsis ribis (Westw.)	158	1.2	2.0
Lampronia capitella Cl.	126	0.9	1.7
Zophodia convolutella (Hbn.)	63	0.5	0.8
PESTS ON SEVERAL PLANTS			
Deroceras agreste (L.) etc.	103	1.9	1.3
Hydraecia micacea (Esp.)	74	1.6	1.1

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SELOSTUS

Viljelykasvien tuhoeläimet 1988

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Maatalouden tutkimuskeskus

Kasvukauden poikkeuksellinen lämpimyys paransi tuhoeläinten lisääntymismahdollisuuksia. Tuomikirvoja ja yleensäkin kirvoja oli runsaasti ja eräillä perhoslajeilla, mm. omenakääriäisellä syntyi toinen sukupolvi kesän aikana. Tuomikirvan lisäksi kaalikoita kulkeutui maahamme etelätuulien mukana. Varsinaiset eteläiset tuholaislajit eivät päässeet, kesän lämpimyydestä huolimatta, lisääntymään.

Peltomyyrän kanta alkoi nousta edellisen vuoden minimistä ja myyrien runsaus antoi aihetta odottaa runsaita tuhoja — vuoden 1989 kevättalvella. Etanat olivat poikkeuksellisen haitallisia syysvehnässä (kts. myös KURPPA 1989).

ANNALES AGRICULTURAE FENNIAE, VOL. 28: 103—111 (1989)

Seria ANIMALIA NOCENTIA N. 140 — Sarja TUHOELÄIMET n:o 140

CONTROL OF ORANGE WHEAT BLOSSOM MIDGE, *SITODIPLOSIS MOSELLANA* (Gehin), WITH PYRETHROIDS

SIRPA KURPPA and GUN-BRITT HUSBERG

KURPPA, S. & HUSBERG G. — B 1989. **Control of orange wheat blossom midge, *Sitodiplosis mosellana* (Gehin), with pyrethroids.**
Ann. Agric. Fenn. 28: 103—111. (Agric. Res. Centre, Inst. Pl. Protect., SF-31600 Jokioinen, Finland.)

Six pyrethroids were found to be as effective as fenitrothion and parathion in controlling ovipositing orange wheat blossom midges. The mean efficacy of one and two applications was 70 % and 85 %, respectively. Spraying had to be started immediately after midges appeared in the field at ear emergence. Repeated, application was necessary if the first application had been performed at very early ear emergence and oviposition prolonged. Cropstand development should be uniform to facilitate treatment of all ears at the optimum time. Midge larvae aggregated on late emerging ears. The yield response with one larva per ear was 98 kg / ha, i.e. about 2.5 % of the mean yield. The control threshold of one midge per 6 — 7 plants is proposed for Finnish growing conditions.

Index words: orange wheat blossom midge, *Sitodiplosis mosellana*, pyrethroids, chemical control, bifenthrin, cyhalothrin, cypermethrin, deltamethrin, fenvalerate, permethrin, yield loss, control threshold.

INTRODUCTION

In the 1980s, the orange wheat blossom midge, *Sitodiplosis mosellana*, has been the major pest of wheat in southeast Finland. It has gained economic importance, particularly in 1983, 1985 and 1987. The highest yield losses, 30 — 40 % of the grain yield, occurred in 1983, before the initiation of chemical control.

The natural insecticides: pyrethrum, derris and nicotine, paradichlorbentzol as well as arsenic were the first to be tested for the control of egg laying midges (MÜHLOW and SJÖBERG 1937). Organocloride compounds were tested in the 1950s and DDT proved to be effective (WAEDE 1957). Later, BASEDOW and SCHÜTTE (1973) obtained good results with methoxychlor and malathion, but poor results with parathion. In Saskatchewan, Canada, dimethoate, methoxychlor and chlorpyrifos are registered for aircraft application and permethrin for ground application only (HARVEY 1985). In addition, efforts to control larvae in soil have been made using various insecticidal, disinfective and fertilizing compounds, of which calcium cyanamide proved to be the best (MÜHLOW 1936). In Sweden, pyrethroids have recently been compared in pest control experiments on cereals with reasonably low wheat blossom midge infestations (LARSSON 1984).

A good knockdown effect as well as a certain residual effect is expected from a chemical compound used in controlling adult midges. The wheat ear is sensitive to midge attack for a period of about five days between the time when the first florets become visible and anthesis. A contact effect by one application with organophosphorus compounds was found to be sufficient by BASEDOW and SCHÜTTE (1973). The Canadians have recommended using systemic and other insecticides with a long residual effect (HARVEY 1985) in order to target both adult midges and eggs. The effect of the new pyrethroids has not been reported on any wider scale. In this paper 6 pyrethroids are compared with two organophosphates. In addition, the optimal spraying time and need for repeated spraying was investigated.

MATERIAL AND METHODS

Experiments comparing the efficacy of different pyrethroids were performed by the Kymenlaakso Research Station of the Agricultural Research Centre. One experimental site was a private field situated in Lapinjärvi, at Sestu, about 50 km from the station, and another a field at the Experimental Farm of the University of Helsinki at Viikki, about 100 km from the station. The experimental area was comprised of four blocks (replicates), 12.5 × 34 meters, situated in a queue one after the other. Thus the whole length of the area was 136 meters. The experimental plots, 2 × 12.5 m, were randomized across the four blocks. Insecticides as listed in Tables 1 and 2 were applied with a propane-operated knapsack compression sprayer, at a pressure of 3 bars. The

Table 1. Control of *Sitodiplosis mosellana* in spring wheat at Lapinjärvi, Sestu. Variety was Kadett, sowing date May 12 th, weed control: Hormoprop 3.0 l / ha in 250 l water, on June 18 th, culm stabilizer + fungicide treatment: CCC + Tilt 250 EC, 0.5 + 0.5 l / ha, June 30 th. Date of insecticide application July 7 th (at development stage 52).

Treatment * treated reference	g a.i/ha — DOSE KG/HA L/HA	S.m. adults	S.m. eggs/ ear	S.m. larvae/ear	Injured grains/ ear	Effect % of injured grains of untreated 1—2	Yield kg ha^{-1}
Untreated 1	—	100 ± 5	7.7 ± 3.1	2.5 ± 1.4	2.1 ± 1.1	—	3677 ± 204
Untreated 2	—	53 ± 32	6.8 ± 2.4	3.4 ± 0.5	2.4 ± 0.1	—	3633 ± 156
Bifenthrin	15						
TALSTAR	0.15	3 ± 5	1.8 ± 0.7	1.2 ± 0.3	1.0 ± 0.3	29 — 61	3870 ± 197
Cyhalothrin	10						
KARATE	0.2	1 ± 1	2.2 ± 0.8	1.7 ± 0.5	1.4 ± 0.5	32 — 42	4183 ± 262
Cypermethrin	50 — 20						
RIPCORD	0.5	2 ± 2	3.1 ± 1.6	1.4 ± 0.4	1.1 ± 0.4	38 — 54	4060 ± 245
RIPCORD	0.2	3 ± 3	2.4 ± 1.1	1.3 ± 0.2	1.0 ± 0.3	31 — 58	4117 ± 169
Deltamethrin	5						
DECIS EC 25	0.2	9 ± 9	3.7 ± 1.2	1.8 ± 0.9	1.6 ± 0.7	26 — 39	4060 ± 121
Fenvalerate	100						
SUMICIDIN 10 FW	1.0	11 ± 3	3.7 ± 2.2	1.7 ± 0.2	1.3 ± 0.2	26 — 44	4120 ± 257
Permethrin	100						
LUXAN PERMETHRIN	0.4	0.5 ± 0.5	2.5 ± 1.6	1.5 ± 0.3	1.4 ± 0.3	24 — 44	4487 ± 67
* Fenitrothion	500						
FOLITION	1.0	8 ± 3	3.0 ± 1.4	2.1 ± 0.6	1.3 ± 0.3	25 — 46	4043 ± 155
* Parathion	150						
BLADAN E 605	3.0	6 ± 3	4.0 ± 1.2	2.0 ± 0.4	1.5 ± 0.4	28 — 41	4303 ± 103
F (treatments)				4.80 ***	56.7 ***	N.S. -4.54 **	N.S.
Min. sign. diff.				1.2	0.9	— -43	

entire plot was sprayed. The quantity of water was 200 l/ha for pyrethroids and 400 l/ha for the other compounds. In Viikki, the surrounding areas were not sprayed. In Sestu, the surrounding areas were sprayed with deltamethrin 2 days after the experimental application except for the 5 m border surrounding the plot. Details on the other applications are presented in Tables 1 and 2.

Additional experiments on private farms were organized in the area of the country's highest midge infestation. Here, the experimental plots were much larger, from 0.05 to 0.1 hectares. Due to economic reasons the surrounding areas of the experimental areas were always treated. Applications were performed with a normal farm sprayer.

The developmental stages of wheat (GS) were those according to ZADOKS et al. (1974). Midge eggs were counted from 25 ears per plot sampled randomly after anthesis, at the wheat stage 62—63, and larvae were counted from 50 ears taken at the early dough stage, 72. All grains in the ears were always checked. During larvae counting grain injuries were also recorded. All experiments except that in Viikki were harvested with an experimental combine harvester. The yield was dried and sorted. Injuries were checked again in the sorted yield, and the 1 000 grain weight measured for uninjured and injured material. The bread making quality of the damaged material is discussed in another paper.

Table 2. Control of *Sitodiplosis mosellana* in spring wheat, of the Research Farm of the University of Helsinki. Variety was Tapio, sowing date May 28th, weed control: Actril S 2.5 l/ha in 300 l water/ha, June 23rd. First insecticide application in all blocks, July 23rd and second in blocks 2 and 4, only, July 27th (at development stages 58 and 60, respectively).

Treatment * treated reference	g a.i/ha — DOSE KG/HA L/HA	One application			Two applications		
		S.m. larvae/ear	Injured grains/ ear	Effect % of injured grains of untreated 1—2	S.m. larvae/ear	Injured grains/ ear	Effect % of injured grains of untreated 1—2
Untreated 1	—	4.2±0.4	3.2±0.2	—	4.2±0.4	3.2±0.2	—
Untreated 2	—	3.8±0.7	3.0±0.6	—	3.8±0.7	3.0±0.6	—
Bifenthrin	15						
TALSTAR	0.15	1.86±0.4	1.6±0.2	54—42	0.5±0.0	0.5±0.0	84—83
Cyhalothrin	10						
KARATE	0.2	1.0±0.7	0.8±0.6	78—58	1.1±0.8	0.8±0.6	70—73
Chypermethrin	50—20						
RIPCORD	0.5	1.5±0.3	1.3±0.1	64—54	0.5±0.3	0.4±0.3	84—86
RIPCORD	0.2	3.3±1.7	2.5±1.2	33—22	1.1±0.6	1.0±0.5	65—68
Deltamethrin	5						
DECIS EC 25	0.2	2.3±0.4	2.0±0.3	41—29	1.5±0.4	1.3±0.3	57—52
Permethrin	100						
LUXAN PERMETHRIN	0.4	1.3±0.1	1.1±0.2	70—56	1.0±0.0	0.8±0.0	74—66
* Fenitrothion	500						
FOLITION 50	1.0	1.0±0.6	0.9±0.4	74—74	0.1±0.0	0.1±0.0	96—95
* Parathion	150						
BLADAN E 605	3.0	0.8±0.2	0.6±0.1	82—74	0.0±0.0	0.0±0.0	100—100
F (treatments)					9.08***	9.54***	8.91***- 6.86***
Min. sign. diff. (between treatments)					2.2	1.5	41—47
F (no of treatments)					7.88**	11.8***	8.93**- 13.10**
Min. sign. diff. (between no of treatments)					0.57	0.42	11—14

Efficacy of pyrethroids in controlling *S. mosellana*

The efficacy of the six pyrethroids varied between the two experimental sites (Tables 1 and 2). In Sestu, the effect was not good in any of the treatments (Table 1). In this experiment spraying was followed by rain, first after 2 hours as a shower and on the following day continuous rain throughout the whole day. In addition, as this experiment was sprayed when only about 10 % of ears were visible (stage 51), a large area of the untreated surface of each ear thus became visible a few days after the treatment. Midge oviposition was, exceptionally, prolonged to more than three weeks, and 1.1 to 5.9 eggs per ear were counted on treated plots after anthesis. As no efficacy by pyrethroids against the eggs could even be expected (Table 1), an improved effect by the applications was therefore not attainable.

The wheat in Viikki had reached a higher stage of development, 58, by the time when the first midges appeared. The first treatment alone produced a better effect than that in Sestu (Table 2). Because of the late application very little, new untreated ear surface appeared after application. When the same ears were treated a second time the effect on the number of injured grains was nearly complete, at least with reference organophosphorus compounds (Table 2). These gave a significantly better mean efficacy than pyrethroids ($P<0.05$). In Viikki there was no problem due to rain during the application process.

Correct spraying time and the need for repeated spraying

Midges arrived in most fields before the ear emergence of spring wheat. Generally, about a 70 % efficacy was obtained if a field was sprayed at the time when the first ears emerged (GS 51) and when midge oviposition was in process (Table 3). In Kadett 1 the effect was decreased to 66 %, but the spraying of this field was adversely affected by rain. In 1986, however, midges had finished their oviposition by the time of Kadett 2 ear emergence, and an excellent effect was obtained with the earliest possible application at GS 51 of the wheat (Table 3).

Normally, if the midge population was high, a repeated spraying was necessary to cover the ear surface newly emerged from the sheath. The effect of two applications was about 75 — 85 % (Table 3), if the first application had been successful. The third application produced only a small additional effect.

In Tapio 3 (Table 3) the midges appeared slightly later than in other fields. Consequently, spraying commenced when the ears were completely out, at stage 58. The efficacy of the first application with deltamethrin was, however, not more than 50 % and with two applications during a 5-day period an effect of 75 % was obtained (Table 3). Flowering started immediately thereafter. Thus the 10 — 25 % loss in the total effect must have resulted from infestations initiated before the first application.

If the application was delayed even closer to flowering (GS 61), the effect was nullified (Table 3).

The importance of migration from a strongly infested neighboring plot became obvious in the results of Kadett 3. The efficacy of the two applications (GS 53 + 55) on the 20 m-wide border of the field just beside the earlier (1986) infested area was significantly lower than the efficacy attained in the field further away (Table 3, Kadett 3, the third and fourth result).

Table 3. Control of *S. mosellana* on private farms in southeastern Finland: Hindersby, Lappträsk and Tavastby, Pernå. Decis EC 25, 0.2 l / ha, was sprayed in 200 l water / ha with a normal tractor compression sprayer. The results of Ulla 2, Kadett 2 and 4 are from 1986, the others from 1987.

Variety / exp. no	Application time	Effect %	Mean no of larvae / ear treated	Mean no of larvae / ear untreated	Lloyd patchiness index untreated / treated
Tapio 1	51	74	9.2	2.4	1.3 / 5.5
Tapio 2	51 + 57	75	16.0	4.0	1.2 / 2.2
Ulla 1	51	73	11.0	3.0	1.3 / 1.3
	51 + 55	81	11.0	2.1	/ 3.8
	51 + 55 + 59	87	11.0	1.4	/ 2.2
Ulla 2	51 + 55	76	5.7	1.5	
Kadett 1	51	66	5.0	1.7	1.4 / 1.4
	51 + 58	72	5.0	1.4	/ 5.3
Kadett 2	51	89	0.9	0.1	
Kadett 3	53	59	3.4	1.4	1.4 / 2.3
	55	41	3.4	2.0	/ 1.5
	53 + 57	74	3.4	0.9	/ 2.9
	53 + 57 *	29	3.4	2.4	/ 1.7
Reno	51 + 59	85	20.0	3.0	1.1 / 1.7
Tapio 3	58	50	4.0	2.0	1.4 / 1.6
	58 + 60	75	4.0	1.0	/ 2.1
Luja	60	0	4.0	5.0	1.7 / 1.9
Kadett 4	61	0	10.6	12.2	

* area with strong migration from the neighboring field

Aggregation of midge larvae among ears in treated areas

Midge larvae were slightly aggregated in certain ears in the pyrethroid treated plots. The mean of LLOYD'S (1967) patchiness index was 1.67 in Sestu and 2.37 in Viikki (the index is 1 if distribution is random). A significant difference ($P<0.01$) between the number of applications was found in Viikki. The patchiness index in areas treated once was 1.96 ± 0.19 and in areas treated twice 2.84 ± 0.21. The most effective pyrethroid, cyhalothrin, differed significantly from all other treatments in both experiments. The patchiness index in cyhalothrin-treated plots in Sestu was 3.15 ± 1.61. The index in Viikki was 1.92 ± 0.28, for one treatment, and 5.36 ± 0.83 for two treatments. In Viikki, the other treatments that caused higher aggregation were as follows:

	Treated once	Treated twice
bifentrin	2.28 ± 0.62	3.64 ± 0.40
cypermethrin (0.2 l / ha)	3.38 ± 1.11	4.06 ± 0.61
permethrin	2.41 ± 0.16	3.47 ± 0.01

Aggregation was normally concentrated in late emerging ears. The larvae were significantly ($P<0.05$) less aggregated in the fenitrothion and parathion treatments than in pyrethroid treated areas.

Midge larvae were randomly distributed in the untreated areas of the farm fields. Lloyds patchiness index varied between 1.4 ± 0.2. In the treated areas aggregation was clearly intensified (Table 3).

Yields

The ear-feeding aphid, *Sitobion avenae,* infested the control experiments at the same time as the midges. The mean yield increase due to aphid control in the experiment in Sestu was calculated to be 30 ± 11 kg / ha ($P<0.05$) per aphid on an ear at stage 72.

The yield loss caused by *S. mosellana* depended on the number of larvae per ear, the number of grains per ear, plus the weight loss per injured grain. For the control experiment in Sestu the mean effect of one larva per ear on the yield was calculated to be 86 ± 5 kg / ha and the effect of one infested grain per ear 98 ± 7 kg / ha. This was 2.4 % of the mean control yield (= 4 060 kg / ha, 4 277 kg / ha minus the mean yield loss due to aphids, 217 kg / ha). A rough estimate of the total number of grains per ear was 32. The yield responses gained in the farm experiments were comparable to this in the first and second applications.

When injured grains are sorted from uninjured the yield loss is composed of the weight loss of injured grains. Again, this, depends on variety and growing conditions. Normally, at least 30 % of the injured grains were lost during harvest. The mean weight of harvested injured grains varied between 60 and 70 % of the mean weight of healthy grains. Thus the proportional weight loss of the total yield could be roughly estimated to be half of the mean proportion of injured per ear (Table 4, Ulla).

Table 4. Control of *S. mosellana* on private farms in the southeast of Finland: Hindersby, Lappträsk and Tavastby, Pernå. Decis EC 25, 0.2 l / ha, was sprayed in 200 l water / ha with a normal tractor compression sprayer. Ulla 1 results are from 1986, the others from 1987.

Variety	Appl.	Mean no of larvae / ear	Mean no of injured grains / ear	Prop. of injured grains in ears %	Prop. of injured grains in yield %	Mean yield kg / ha	Change in yield % of treated
Ulla 1	Untreated	5.7	4.8	16	16	3348 ± 22	
	Treated 2 ×	1.8	1.8	6	6	3504 ± 22	4
Tapio	Untreated	16.0	10.3	34	—	2359 ± 104	
	Treated 2 ×	4.0	3.2	11	—	3051 ± 107	23
Ulla 2	Untreated	10.8.	7.0	23	—	2825 ± 72	
	Treated 1 ×	3.0	2.4	8	—	3295 ± 83	14
	Treated 2 ×	2.1	1.5	5	—	3485 ± 60	19
	Treated 3 ×	1.7	1.4	5	—	3235 ± 135	13
Kadett	Untreated	4.9	3.6	12	—	3664 ± 99	
	Treated 1 ×	1.7	1.6	5	—	4017 ± 80	9
	Treated 2 ×	1.4	1.2	4	—	4465 ± 125	18

DISCUSSION

The efficacy of the pyrethroids tested was good in dry application conditions. Our results were significantly better than those reported by ELLIOT (1988). If rain interrupted application, a dry period of two hours did not seem to be adequate for pyrethroids or for fenitrothion or parathion to make good contact with the plant surface. In such a case spraying should be repeated.

Observation of midge oviposition and its coincidence to ear emergence is essential when defining application time. At the time of ear emergence, spraying should be started immediately when ovipositing midges appear and their number can be expected to override the control threshold. Accurate observation of midges is especially important if midges arrive during the later part of ear emergence. Thus, if the application is delayed by one day, a good control effect can not be obtained even with a repeated application later. According to this data it is not possible to wait until the time when ear emergence is completed as recommended by BASEDOW and SCHÜTTE (1973). A local forecast of midge occurrence would be of great help in timing the applications.

The first application seems to be worth repeating in the case of a high midge population and if most of the ears have been in the boot stage during the first treatment. The economics of a second application are mainly based upon the improvement in wheat quality. Injured grains spoil the yield quality for bread making and, therefore these should be eliminated from the yield. In Finland the often rainy harvesting conditions intensify water absorbance and secondary infections in injured grains. In 1987, the effect on cereal aphids was obtained by a second application and thus the actual yield was increased considerably. If cereal aphids arrive earlier, as they normally do, they can be controlled by an application at stage 51.

Uniform ear emergence throughout a field is essential, so that all ears can be treated at the optimum time. In the controlled areas midge larvae were shown to aggregate to certain ears, aggregation being the more intense the more effective the treatment was. Normally, late emerging ears maintain infestation and these should be eliminated somehow, by avoiding late tillering, for example.

The yield response, 98 kg / ha / infested grain, is slightly less than that reported from Canada (OLFERT et al. 1985). The proportional yield loss caused by a certain number of larvae per ear in Finland is over two times higher than the effect by the same number of larvae in Central Europe, reported by (LÜBKE and WETZEL 1984). This variation results from the difference in ear size and consequently yield level. In addition, the proportion of injured grains passing through harvesting and sorting into the final yield may vary.

The control threshold is given as the number of ovipositing midges per number of ears and has settled to one midge per three ears in Germany and elsewhere (LESCAR 1977). If we calculate 30 eggs per female and a 50 % egg mortality, (mean in 1987, variation 20 % — 80 %) and a ratio of females:males 3:2, the threshold result in the number of 3.3 injured grains per ear, which is about 10 % of the grains injured. Thus the unavoidable quantitative yield loss would be as high as 5 %, with 6 — 7 % injured grains in the yield. A yield of this quality has been reported, in some cases, to be unacceptable for human consumption (NIJVELDT and BOKHORST 1973). If, instead, the injury of 4 — 5 % of grains is accepted, the control threshold should be one midge per 6 — 7 ears, which is the recommendation of the practical advisory service in Canada (HARVEY 1985). The cost of the attainable yield increase, in this case, can be expected to cover the cost of pyrethroid application i.e. about 100 — 150 FMK per hectare at the 1988 Finnish cost level.

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SELOSTUS

Pyretroidien käyttö tähkäsääsken, *Sitodiplosis mosellana* (Gehin), *torjuntaan.*

SIRPA KURPPA ja GUN-BRITT HUSBERG

Maatalouden tutkimuskeskus

Tähkäsääski ehti aiheuttaa itäisen Uudenmaan vehnänviljelijöille jopa 30—40 % sadonmenetyksiä vuosina 1983 ja 1985 ennen kuin sääsken torjunta aloitettiin vuonna 1986, lähinnä Keski-Euroopassa käytettäviin ohjeisiin perustuen. Samaan aikaan aloitetuissa torjuntakokeissa verrattiin eri pyretroidivalmisteiden tehoa, ja pyrittiin määrittämään meidän kasvuoloissamme paras torjunta-aika ja uusintaruiskutusten tarve sekä torjunnan vaikutus satoon.

Kokeiltujen, kuuden pyretroidivalmisteen tehoaineina olivat: bifentriini, deltametriini, fenvaleraatti, permetriini, syhalotriini ja sypermetriini. Näiden välillä ei havaittu merkittäviä eroja sääsken torjuntatehossa. Pyretroidit eivät myöskään poikenneet olennaisesti kahden vertailussa käytetyn orgaanisen fosforiyhdisteen: fenitrotionin ja parationin tehosta.

Koeruuduissa, joihin tuli helposti uusia sääskiä ympäristöstä, yhdellä onnistuneella ruiskutuskerralla saatiin noin 60 %:n teho laskettuna tähkiä vioittavien toukkien määristä. Toinen ruiskutuskerta paransi tehon noin 75 %:ksi. Viljelijöiden pelloilla tehdyissä koko peltolohkon käsittävissä ruiskutuksissa yhdellä käsittelykerralla saatiin jo noin 70 %:n teho ja se parani toisella käsittelyllä noin 85 %:ksi. Näille lohkoille uusia sääskiä tuli pääasiallisesti vain kasvualustasta.

Oikea ruiskutusaika voitiin määrittää ainoastaan sääskien munintaa seuraamalla. Sääskien ilmaannuttua torjunta oli aloitettava heti kun tähkät tulivat esiin. Muutoin sääsket ehtivät munia, eikä hyvää torjuntatulosta saatu edes uusintaruiskutuksen avulla. Jos kasvusto on jo tähkällä kun sääsket aikuistuvat, torjunta on ajoitettava vieläkin tarkemmin heti ensimmäisten sääskien ilmaantumiseen. Ruiskutuksen uusinnalla oli olennainen merkitys, kun sääskikanta oli runsas, käsittelemättömällä alueella likipitäen 20 toukkaa / tähkä, tai jos kasvusto oli ruiskutettu ensimmäisen kerran niin varhain, että runsaasti uutta tähkäpintaa oli paljastunut tupesta ja samalla sääskien muninta oli pitkittynyt. Toisen ruiskutuskerran taloudellisuus perustuu sadon laatuvaurioiden torjumiseen. Jos ensimmäinen käsittely tehtiin vasta vehnän kukintavaiheessa mitään torjuntatehoa ei havaittu.

Ruiskutetuilla alueilla sääskitoukat olivat keskittyneet tiettyihin, yleensä kehityksestä myöhässä oleviin tähkiin. Kasvuston tasaisuudella on torjunnan onnistumisen kannalta tärkeä merkitys, ettei pellolla olisi tällaisia tähkiä, joita ei voida ruiskuttaa niiden alttiissa vaiheessa. Ne keräävät toukkia ja ylläpitävät sääskikantaa alueella.

Yhden tähkäsääskitoukan aiheuttama sadonalennus oli 98 kg / ha eli noin 2.5 % noin 4 000 kg hehtaarisadosta, kun vioittuneet jyvät lajiteltiin pois sadosta. Kevyimmät vioittuneet jyvät, noin 30 %, joutuivat hukkaan jo puidessa ja suurempien 1 000 jyvän paino oli 60 — 70 % terveiden jyvien painosta. Lajittelemattoman sadon suhteellinen sadonmenetys oli siten noin puolet suhteellisesta vioittuneiden jyvien määrästä.

Jos torjuntakynnykseksi valitaan 5 % sadonmenetyksen aiheuttava tuholaismäärä, sääskiä tulisi olla vähintään yksi 6 — 7 tähkää kohden, jotta kynnys ylittyisi. Torjuntakynnys on siten puolta alempi kuin Keski-Euroopassa, mutta sama kuin Kanadassa. Syy tähän eroon löytyy satotasoista, sekä siitä, että meillä vioittuneiden jyvien aiheuttama sadon laadun menetys on sateisten korjuusäiden tähden otettava huomioon.

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Seria ANIMALIA NOCENTIA N. 141 — Sarja TUHOELÄIMET n:o 141

FREE AMINO ACIDS IN THE PSYLLID *TRIOZA APICALIS* FÖRST. (HOMOPT., TRIOZIDAE) AND IN CARROT LEAVES

SEPPO LAUREMA

LAUREMA, S. 1989. **Free amino acids in the psyllid *Trioza apicalis* Först. (Homopt., Triozidae) and in carrot leaves.** Ann. Agric. Fenn. 28: 113 — 120. (Univ. Helsinki, Dept. Agric. Forest Zool., SF-00710 Helsinki, Finland.)

Free amino acids in extracts of the carrot psyllid, *Trioza apicalis*, as well as in its honeydew and carrot leaves were determined by thin-layer and automatic ion-exchange chromatography. The total concentration of amino compounds in adult psyllids was ca. 74 µmoles / g fr. wt. (0.92 %), and in nymphs 57 µmoles / g fr. wt. (0.72 %). Predominant free amino acids in the psyllids were proline and alanine. Relatively abundant were also glutamine, glutamic acid, methionine sulphoxide, arginine, taurine, and in the nymphs tyrosine. The abundance of proline suggests its importance in the energy metabolism of psyllids. No distinctly phytotoxic amino compounds were detected in the insects.

Amino acids accumulate in carrots infested by the psyllid. In the leaves of healthy carrots the total concentration of free amino acids was 10.1 µmoles / g fr. wt. (0.13 %), but in the leaves of infested carrots 62.2 µmoles / g fr. wt. (0.84 %). The predominant compounds in healthy and infested leaves were asparagine and glutamine. In the honeydew of psyllids concentration of amino acids was ca. 3 %.

Index words: carrot psyllid, free amino acids, honeydew, carrot toxaemia, *Trioza apicalis*, *Daucus carota*.

INTRODUCTION

The psyllid *Trioza apicalis* Först. is a common insect pest on cultivated carrots, *Daucus carota* L., in many areas of Northern and Central Europe (RYGG 1977). The nymphs and adults of the psyllid suck up sap from carrot leaves causing both retardation of growth and curl in developing leaves. The damage is systemic, and is evidently mainly caused by the toxic salivary secretions of the insect pest (LASKA 1964, MARKKULA et al. 1976).

The toxic principle in the saliva of the carrot psyllid is unknown. Amino acids, indolylacetic acid and enzymes known to occur in the saliva of Hemiptera can evidently cause local effects in plants (MILES 1972, 1987, CARTER 1973), but it is uncertain if such compounds can also have systemic effects in plants. In any case, indolylacetic acid or a related phytohormone does not seem to be responsible for the damage caused by *T. apicalis* in carrot (MARKKULA and LAUREMA 1971).

Investigation of ^{14}C-labeled *T. apicalis* indicated that the salivary secretions contained three common sugars and inositol, evidently arising from the host plant (MARKKULA et al. 1976). Evidence was also found for an unidentified compound which seemed to be related to amino acids or amines. Therefore, a closer investigation of amino compounds in the psyllid was performed.

A reason for the investigation of carrot leaves was the finding that concentrations of nitrogenous compounds in the roots of infested carrots were increased (LAUREMA 1979). Free amino acids are important nutrients for phloem feeding insects, and the development of these insects is often found to be dependent on the level of nitrogenous compounds in their host plant. There is also evidence that some of these insects can induce changes in their host plant which improve its nutritional quality for the insect pest. However, only in a few cases has the accumulation of free amino acids been definitely established (HODKINSON 1974, KLINGAUF 1987).

MATERIAL AND METHODS

Hibernated adult psyllids were collected by means of a hand aspirator from carrot fields near Helsinki in the early summer when the seedlings were at the one to three leaf stage. The psyllids were further reared to second generation adults in cages in a greenhouse or in a field.

The hibernated psyllids in Table 1 were taken from a rearing in the greenhouse on 8 and 11 July 1986, when the females were egg-laying. The nymphs and honeydew were collected from the same rearing in the end of August. The new generation adults were collected from cages in the field on 2 September.

The hibernated adults weighed on the average 323 and 517 μg and the new generation adults 254 and 289 μg, males and females respectively. The nymphs representing the last larval instars weighed on the average 236 μg.

Before extraction the insects were weighed while alive and then killed by refrigeration at –25 °C. Extraction of the insects was performed with 76 % (w / w) ethyl alcohol. About 30 mg fr. wt. psyllids were boiled for 2 min in 1 ml of alcohol and extracted in a glass homogenizer at room temperature three times with similar volumes of 76 % alcohol. The extracts were separated by centrifugation at 1 000 xg for 15 min and the combined supernatants reduced to dryness in a rotary evaporator at 40 °C. The residue was mixed with 500 μl of distilled water and centrifuged at 12 000 xg for 15 min. The centrifuged water solution was used for thin-layer and ion-exchange chromatography.

The honeydew of the psyllids was collected from aluminium foil placed below the leaves of infested carrots in the greenhouse. The honeydew particles were dried over anhydrous $CaCl_2$, dissolved in 10 % ethyl alcohol (ca. 10 mg / ml) and the solution cleared by filtration through a membrane filter (Millipore GS). The filtered solution was evaporated to dryness and dissolved in a small volume of distilled water for analysis. Honeydew weight did not essentially change during drying with $CaCl_2$.

The samples of young carrot leaves (2.5 g fr. wt. each) shown in Table 1 originated from an experiment in which the psyllids were reared on carrots (variety Nantes Markthallen) in an insectary for 2 months. Carrot leaves were extracted with boiling 76 % ethyl alcohol as in the case of insects, but the extracts were further purified by ion-exchange on a Dowex-50 H^+ column before analysis of amino acids.

The analyses of amino acids by thin-layer and ion-exchange chromatography were performed as described by HELIÖVAARA and LAUREMA (1988).

For quantitative analyses the water solutions of amino acids were treated with 2.5 % (w / v) 5-sulphosalicylic acid and LiOH before loading into a LKB-Biochrom 4150 Alpha amino acid analyser. To check the effect of the extraction procedure some samples of psyllids were also analysed directly after homogenization in cooled sulphosalicylic acid.

Methionine sulphoxide for reference in the chromatography was prepared from L-methionine (Fluka, puriss.) by oxidation with H_2O_2 in glacial acetic acid. The resolution of the diastereoisomeric sulphoxides was performed as picrates (GREENSTEIN and WINITZ 1961).

RESULTS

The total concentration of free amino acids in the samples of adult carrot psyllids varied from 69.9 to 78.8 μmoles / g fr. wt. (0.85 — 0.96 % by weight). The concentrations were slightly higher in the new generation adults, and also higher in females than in males. In nymphs the total concentration was lower than in adults, ca. 57 μmoles / g fr. wt. (0.72 %) (Table 1).

The predominant free amino acids in the psyllids were proline and alanine. In adult psyllids there was a fair abundance also of glutamine, glutamic acid, methionine sulphoxide, arginine, histidine and taurine. The result suggested some differences in the relative concentrations of amino acids between males and females. Especially in the hibernated psyllids the concentration of taurine was higher and that of methionine sulphoxide lower in males than in females. In nymphs the concentrations of tyrosine and glutamic acid were relatively higher and those of methionine sulphoxide, taurine, glutamine, alanine and proline lower than in adults. In the psyllids also occurred an unidentified compound which eluted after α-aminoadipic acid and S-methylcysteine in front of proline.

In the sample of healthy carrot leaves the total concentration of free amino acids was ca. 10.1 μmoles / g fr. wt. (0.13 %), and in the leaves of infested carrots 62.2 μmoles / g fr. wt. (0.84 %), or about six times higher. The predominant compounds in healthy and infested leaves were asparagine and glutamine. The increase of concentrations in the infested carrots was most prominent in the case of arginine, asparagine, aspartic acid, glutamine, lysine and histidine (Table 1).

In the honeydew of psyllids the total concentration of free amino acids was ca. 3 % (226 μmoles / g), and the predominant compounds were glutamine, glutamic and aspartic acid.

Table 1. Free amino acids and related compounds in extracts of the carrot psyllid *Trioza apicalis* Förster, in its honeydew and carrot leaves. The concentrations are expressed as μmoles / g fresh weight. The concentrations of the unknown compound were estimated using α-alanine as reference.

\+ = present as a trace or not determined quantitatively
— = not present in detectable amount
ND = not determined

Compound	Carrot psyllids: Hibernated adults ♂♂	Hibernated adults ♀♀	New generation adults ♂♂	New generation adults ♀♀	Nymphs	Honeydew	Carrot leaves: Healthy	Infested	Ratio infested / healthy
O-Phosphoserine	0.30	0.64	0.24	0.31	0.21	0.57	—	—	—
Taurine	5.70	2.83	4.85	3.86	1.20	—	—	—	—
O-Phosphoethanolamine	+	0.47	0.68	+	0.31	1.88	—	—	—
Urea	0.78	+	+	+	1.86	—	—	—	—
Aspartic acid	0.13	0.15	0.13	0.21	0.24	21.15	0.36	3.49	9.7
Methionine sulphoxide	3.42	5.33	7.14	7.41	1.92	0.46	—	—	—
Threonine	1.84	1.90	0.87	1.01	1.52	6.77	0.58	1.39	2.4
Serine	1.02	1.20	0.58	0.67	1.68	12.09	0.63	1.86	3.0
Asparagine	+	+	+	+	+	+	1.52	21.97	14.5
Glutamic acid	2.89	5.14	3.64	3.45	7.21	44.14	0.70	2.85	4.1
Glutamine	6.42	5.74	6.49	6.82	2.09	85.92	1.92	15.85	8.2
α-Aminoadipic acid	—	—	—	—	—	0.69	0.06	0.21	3.6
unknown	0.12	0.26	0.13	0.75	0.37	—	—	—	—
Proline	17.32	23.08	21.30	22.52	12.92	6.39	0.85	1.18	1.4
Glycine	1.49	2.00	0.89	0.85	1.91	5.88	0.06	0.13	2.0
α-Alanine	14.77	12.81	14.04	15.20	7.62	9.26	0.61	1.74	2.8
α-Aminobutyric acid	—	—	—	—	+	0.09	—	—	—
Valine	1.45	1.34	1.09	1.09	2.40	10.65	0.77	1.78	2.3
Cystine	—	—	—	+	—	0.25	—	—	—
Methionine	—	+	0.22	0.20	—	1.46	—	—	—
Cystathionine	0.14	0.21	0.21	0.21	0.20	—	—	—	—
Isoleucine	0.28	0.75	0.37	0.37	0.78	4.98	0.51	1.17	2.3
Leucine	0.54	1.25	0.53	0.61	1.08	2.28	0.39	1.11	2.9
Tyrosine	1.26	1.27	0.83	0.91	4.07	1.45	0.11	0.16	1.5
β-Alanine	+	+	+	0.25	+	+	—	—	—
Phenylalanine	0.37	0.45	0.01	0.14	0.67	3.64	0.13	0.42	3.2
β-Aminoisobutyric acid	—	+	—	+	—	—	—	—	—
γ-Aminobutyric acid	0.24	0.13	0.35	0.41	0.17	0.42	0.51	1.94	3.8
Ethanolamine	—	+	0.93	3.68	0.37	—	0.17	0.45	2.7
Ammonia	1.25	0.67	0.75	0.73	0.52	1.37	ND	ND	—
Ornithine	0.09	0.24	0.05	0.07	0.17	0.06	—	—	—
Lysine	0.70	1.17	0.77	0.83	0.54	0.50	0.06	0.47	8.2
1-Methylhistidine	+	+	0.28	0.25	0.05	0.76	—	—	—
Histidine	2.74	1.35	2.72	2.46	2.21	1.42	0.09	0.52	5.7
Tryptophan	0.25	0.33	0.28	0.31	0.15	0.99	0.05	0.20	4.0
Anserine	+	0.95	—	—	0.76	—	—	—	—
Arginine	4.44	2.98	3.03	3.22	1.81	0.46	0.08	3.33	42.2
Total μmoles / g fr. wt	69.95	74.65	73.40	78.79	56.90	225.52	10.15	62.24	6.1
(mg / g fr. wt)	(8.53)	(9.38)	(9.13)	(9.57)	(7.20)	(30.55)	(1.29)	(8.41)	(6.5)

DISCUSSION

Studies on the free amino acids of insects indicate that the composition of the amino acid pool is typical of each species and developmental stage, but generalisations concerning higher categories are difficult to make (CHEN 1962, 1985, FLORKIN and JEUNIAUX 1974). So far, only few species of the Hemiptera and apparently no psyllids have been studied in detail.

The total concentration of free amino acids in the adults of *T. apicalis* seems to be at the same level as that in the pine bark bug (*Aradus cinnamomeus* Panzer) but in the haemolymph of Heteroptera the concentrations evidently are lower (HELIÖVAARA and LAUREMA 1988). In aphids concentrations of free amino acids ranging from 0.3 to over 1 per cent of fresh weight have been reported (AUCLAIR 1960, RILLING et. al. 1974, CHEN and FU 1981). PFEIFFER and BURTS (1984) found that the total concentration of free amino acids in the pear psylla *P. pyricola* Först. depends on the nitrogen fertilization of pear trees.

As in many other insects the predominant free amino acid in *T. apicalis* is proline. Proline is a source of energy in insects, but the efficiency by which they use proline varies in different taxonomic groups (BURSELL 1981). The metabolism of proline is linked to α-alanine, and the abundance of these amino acids in *T. apicalis* suggests the importance of the proline-alanine cycle in psyllids. A similar predominance of proline and alanine has been found in the tse-tse flies *(Glossina),* which use proline as the main fuel for flight (TOBE 1978).

In aphids proline does not seem to be especially abundant, and there is evidence that aphids and planthoppers mainly use lipids or carbohydrates during flight (LIQUIDO and IRWIN 1986). According to WILLIAMS and LINDNER (1965), the predominant free amino acid in the pear psylla *(P. pyricola)* is α-alanine. However, the amount of proline is difficult to evaluate by the paper chromatographic method which they used.

A characteristic constituent in the amino acid pool of *T. apicalis* is methionine sulphoxide, which does not commonly occur in large amounts in insects. In the ion-exchange chromatography its retention time was identical to that of L(+)-methionine sulphoxide. The same stereoisomeric form was detected in *Phormia regina* Meigen by LUCAS and LEVENBOOK (1966).

The amount of methionine sulphoxide in insects appears to be higher in females (CHEN 1958), whereas more taurine has been found in males (HILCHEY et. al. 1957). The abundance of tyrosine in the nymphs of *T. apicalis* is evidently connected with its function in the formation of the new cuticle during ecdysis (FLORKIN and JEUNIAUX 1974, CHEN 1985).

The investigation of carrot leaves demonstrated the accumulation of amino acids in infested carrots. So far distinct increases in free amino acids have been found in the host plants of a planthopper (CAGAMPANG et al. 1974) and two species of aphid (POEHLING 1985, DORSCHNER et al. 1987), but evidence of the accumulation of soluble nitrogenous compounds has been also found in other cases including psyllid infested plants (HODKINSON 1974). However, none of the cases studied before seemed to be typically systemic.

The accumulation of soluble nitrogenous compounds in infested plants has been generally associated with the degradation of leaf proteins, although the mechanism by which it takes place is obscure. Proteolytic enzymes in the saliva of insects evidently can release nitrogenous compounds into the feeding site, but such enzymes hardly can explain the extensive accumulation of amino acids in the whole plant. Other mechanisms, such as some kind of induced senescence seem to be operative (DORSCHNER et al. 1987).

The early symptoms of psyllid toxaemia in carrots do not resemble senescence, but rather a disturbance of growth. A cause for the accumulation of amino acids could then be the hindrance in growth and protein synthesis. Asparagine, glutamine and arginine are known to accumulate in plants in which protein synthesis is hindered by a deficiency of mineral elements (STEWART and LARHER 1980).

The unknown compound previously found in the salivary secretions of *T. apicalis* was not detected in the extracts of whole psyllids. None of the compounds identified in the psyllid is typically phytotoxic and most of them were also found in healthy carrot leaves. The amount of methionine sulphoxide in the psyllids seems to correlate with their phytotoxicity, which is highest in the females and lowest in the nymphs (MARKKULA et al. 1976). However, the sulphoxide in itself is hardly toxic to plants and was not detected in the salivary secretions of ^{14}C-labeled psyllids.

Honeydew is the sugary excretion of phloem feeding insects which generally contains amino acids derived from the host plant (HODKINSON 1974, MAURIZIO 1985). The total content of free amino acids in the honeydew of *T. apicalis* seems to be at the same level as that generelly found in honeydews.

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SELOSTUS

Porkkanakempin ja porkkanan lehtien vapaat aminohapot

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Porkkanakemppi, *Trioza apicalis*, on tunnettu porkkanassa esiintyvä tuhohyönteinen, joka aiheuttaa lehtien käpertymisen ja heikentää kasvua. Vioituksen katsotaan suurelta osin johtuvan kempin syljessään erittämästä toksiinista. Tutkimuksessa on pyritty selvittämään toksiinin kemiallista luonnetta ja sen vaikutusta tutkimalla kempin ja porkkanan lehtien sisältämiä vapaita aminohappoja.

Porkkanakempeissä todettiin yli 30 erilaista aminoyhdistettä, joista runsaimpia olivat proliini ja alaniini. Melko runsaina esiintyivät myös glutamiini, glutamiinihappo, metioniinisulfoksidi, argiini ja tauriini. Proliinilla on eräille hyönteisille tärkeä merkitys energian lähteenä, ja on todennäköistä, että sillä on sama tehtävä myös porkkanakempissä. Tässä suhteessa kemppi näyttää eroavan kirvoista ja olevan lähempänä erilaissiipisiä (Heteroptera).

Metioniinisulfoksidin määrä kempeissä näyttää olevan yhteydessä niiden aiheuttaman vioituksen voimakkuuteen, mutta ei ole kuitenkaan varmaa liittyykö se kemppien erittämään toksiiniin. Kempeissä ei todettu mitään kasveihin selvästi haitallisesti vaikuttavia aminoyhdisteitä.

Porkkanan lehdistä löydettiin noin 20 vapaata aminohappoa, joista runsaimpina esiintyivät glutamiini ja asparagiini. Glutamiinia oli eniten myös kemppien erittämässä mesikasteessa. Kempin vioittamien porkkanoiden lehdissä aminohappojen pitoisuus oli selvästi lisääntynyt. Aminohappojen lisääntyminen vioituksen seurauksena ilmeisesti edistää kemppien kehitystä, mutta ihmisen kannalta sillä tuskin muuten on suurempaa merkitystä.

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Seria AGROGEOLOGIA ET -CHIMICA N. 151 — Sarja MAA JA LANNOITUS n:o 151

GROWTH OF RYE GRASS, BARLEY AND OATS IN SOILS AMENDED WITH ASHES OF WOOD, BARK, PEAT AND COAL

INTO SAARELA

SAARELA, I. 1989. **Growth of rye grass, barley and oats in soils amended with ashes of wood, bark, peat and coal.** Ann. Agric. Fenn. 28: 121-132. (Agric. Res. Centre, Inst. Crop and Soil, SF-31600 Jokioinen, Finland.)

The effects of ashes of different fuels on the growth of plants were studied in four pot experiments and in two field experiments during 1980 — 1986. Nutrient deficient acid soils were used in the pot experiments in order to display the all-round soil amending and fertilizing effects of ashes in plant growth. Ashes were compared with lime and soluble P and K sources. Good growth obtained on the initially very infertile soils indicated the considerable potential value of ashes in plant production. However, the variable composition of ashes should be taken into account when amending soils with them. Wood ash was both an efficient liming agent and nutrient rich fertilizer. Bark ash was more diluted especially in K. This soluble macronutrient occurred in very small amounts in the ashes of fossil fuels. Peat ashes had a substantial P content. Coal ash was poor in nutrients, but it caused symptoms of B toxicity at large rates. Ashes were rather effective P sources in peat soils in the pot experiments, but under field conditions wood ash P was less efficient compared to P in single superphosphate. A wood ash rich in K did not increase the grain yield of barley in a clay field as much as the muriate of potash did. According to an additional experiment comparing different K and Cl compounds in barley, the inferiority of wood ash seemed to be a result of a beneficial effect by Cl in muriate of potash. Severe Cu and Mo deficiencies found in plants growing on peat treated with wood and bark ashes indicated a poor status of these micronutrients in Finnish soils and their inavailabilities in acid peat amended with ash.

Index words: ashes, soil amendment, infertile peat, plant growth.

INTRODUCTION

The mineral elements taken up from the soil are concentrated in the ash when plant material is decomposed by burning. Ashes have long been used to improve soil fertility. Earlier, they were produced in small amounts by numerous minor heating units, and were thus most important in horticulture (LUNDEN 1925). Nowadays wood chips are also burned in larger central heating systems and the bark of industrially processed wood has become an important source of nutrient rich ash. The total amount of wood and bark ashes produced annually in Finland was estimated to be 80 000 tons (HAKKILA and KALAJA 1983). Peat and coal ashes are formed in large quantities by power plants. Their values as soil amendments are known to be rather low (LUNDEN 1925, ADRIANO et al. 1980), but these ashes may also occur in mixtures with wood and bark ashes. The production of ashes from cereal straw has not increased as steeply as at the beginning of this study when energy prices were high.

Wood ash has been recognised as a valuable potassium fertilizer (SHUTT 1925, LUNDEN 1925), but its phosphorus was known to be present in sparingly soluble compounds and thus less effective (LUNDEN 1925, SALOHEIMO 1952). Because wood and bark ashes contain large percentages of calcium and magnesium carbonates or oxides, they are efficient liming agents (SALONEN 1966, SIMOJOKI 1976). In spite of their potential value as soil amendments, ashes are still largely disposed of as a waste and possibly not without risk of environmental pollution. The aim of this study was to investigate the effects of ashes on soils and plants and so promote their recycling in plant production. The main idea was to test ashes as all-round soil amendments in acid infertile soils. The effects on plant growth and nutrient availability of ten ash samples were investigated in four pot experiments and two field experiments. The yield results from the six experiments are presented in this paper.

MATERIAL AND METHODS

Ashes. The investigated material (Table 1) included one straw ash sample obtained by burning a bale of rye straw on a granitic rock, one wood ash (2) collected from small brick ovens and one wood ash (7) from a chips-burning central heating plant. The industrial bark ashes 3 and 8 were dry and well burned, 5 was wet and rich in organic residues. One peat ash (4) originated from a small unit, another peat ash (9) and one coal ash (6) from large power plants. One bark ash (10) was pressed into hard pellets 10 mm in diametre with waste cellulose pulp by the Teachnical Research Centre of Finland. The ignition loss is the reduction of weight at 550 °C. Acid neutralization capacity was determined by boiling 3 — 10 g of ash in 150 ml of 0.5 M HCl for 45 min and titrating the residual acid with 0.1 M NaOH. The contents of mineral elements were determined from HCl-$HClO_4$-HF extract (ANON. 1986, p. 37) by plasma emission spectrometry, except Cd by flameless AAS.

Soils. Acid and nutrient deficient soils were selected for pot experiments (Table 2). One humified *Carex* peat (1) originated from Pelsonsuo, Kainuu, one slightly humified *Carex* peat (2) from Jokioinen and a *Sphagnum* peat (3) was an unhumified commercial product. The loamy clay (F1) and clayey mull (F2) fields are situated in Jokioinen. Soil pH was measured from a 1:2.5 suspension, macronutrients were extracted in acid ammonium acetate, and micronutrients and Cd in an acid ammonium acetate EDTA solution, except B in boiling water (ANON. 1986).

Pot experiments. In the first pot experiment

Table 1. Properties of ashes.

Type and number	Ignition loss, %	Neutralization capacity, % Ca	Ca	Mg	K g / kg	P	Fe	Mn	Zn	Cu	B mg / kg	Mo	Cd
Straw ash 1	—	10.8	32	7	240	11.0	3.1	1.0	400	390	80	—	—
Wood ash 2	2.8	38.3	252	42	116	17.7	3.0	12.3	2920	178	500	1.2	0.9
Bark ash 3	4.4	22.6	189	16	35	8.3	18.9	7.2	275	75	170	3.5	0.5
Peat ash 4	3.4	4.2	40	6	12	11.1	100.0	0.9	154	73	47	9.9	0.3
Bark ash 5	45.0	21.1	166	11	21	6.7	6.5	8.1	1920	90	200	1.2	5.4
Coal ash 6	3.6	4.6	26	12	20	1.2	57.7	0.7	225	86	170	5.4	0.4
Wood ash 7	11.9	31.4	213	32	86	17.5	10.2	13.0	1240	163	420	2.7	2.1
Bark ash 8	5.2	28.2	237	28	51	13.5	14.8	10.8	248	86	220	1.9	0.2
Peat ash 9	6.3	6.6	82	14	12	12.4	202.0	1.8	308	67	86	11.2	3.1
Bark ash 10	32.5	23.0	211	19	29	12.7	8.7	6.1	686	77	200	3.3	4.6

Table 2. Properties of soils.

Type and number	Depth cm	Organic matter, %	pH (in H_2O)	Extractable content mg / l soil										
				Ca	Mg	K	P	Fe	Mn	Zn	Cu	B	Mo	Cd
Carex peat 1	(pot)	78	3.8	465	43	15	1.6	2530	9.5	3.9	0.4	0.22	0.01	0.01
Carex peat 2	(pot)	72	4.9	2150	450	48	0.6	1520	30.0	0.6	2.3	0.55	0.16	0.17
Sphagnum peat 3	(pot)	97	3.7	250	60	25	3.7	147	5.1	2.7	0.2	0.16	0.08	0.06
Loamy clay F1	0-25	5.2	6.4	2150	390	180	17.0	360	92	2.7	5.1	0.85	0.07	0.08
	25-40	1.8	6.9	2650	1010	185	2.2							
Clayey mull F2	0-25	32.0	5.4	2900	260	165	6.1	1220	47	3.6	6.6	0.68	0.06	0.14
	25-40	38.0	5.1	2300	320	110	2.5							

(P1) carried out in 1980, four different ashes were studied as amendments in a infertile peat soil (1) with Italian rye grass as the test plant. Graded levels of lime, phosphorus, potassium and chloride were included for comparison. Four treatments were performed with each ash, using two amounts and complementary P or PK applications. The grass was cut four times at the beginning of heading. The same acid *Carex* peat was also used in the second pot experiment (P2) in which barley and oats were grown in successive years. Several ashes were applied at two levels according to their acid neutralization capacity which was determined chemically. Excessive Mn and B applications were included. The third pot experiment (P3) was particularly aimed at testing P availability, and ashes were exceptionally applied annually in order to demonstrate the effect of excessive amounts of ash. Overly as well as suboptimal rates were also included in the fourth pot experiment (P4) which was particularly conducted for testing the bark ash pellets (10).

The volume of soil in a pot was five litres in each experiment. Lime and ashes as well as nurtient solutions were thoroughly mixed into the soil before sowing in May. 250 mg of rye grass seeds and 25 pieces of barley (var. Pomo) and oat (var. Nasta) seeds were sown per pot. The pots were kept under a net-walled glass shelter and irrigated daily. Ripened cereals were cut at 2 cm in August or early September, dried at 105 °C, threshed and weighed.

Field experiments. The effects of increasing amounts of wood ash (7) were compared to ground limestone and single superphosphate and muriate of potash in two field experiments (F1 and F2) with barley in 1982 — 1984. The lime and ash were spread onto levelled soil in the first spring and incorporated to 0 — 7 cm by harrowing, and to 22 cm by ploughing in the autumns of 1982 and 1983. The P and K fertilizers were drilled in rows 12,5 cm apart and 8 cm below the surface. Normal rates of barley seeds (500 m^{-2}, var. Pomo except at F2 in 1983 — 1984 Arra) and ammonium nitrate lime (F1 at 100 kg N and F2 at 50 kg N per hectare) were combidrilled (ELONEN 1983) in May. Grain yields were harvested by a plot combine in late August or early September. All pot and field experiments were established with four replicates and their results computed by the analysis of variance, and the least significant differences at the five per cent risk level were calculated for treatment comparisons.

RESULTS

Rye grass on acid *Carex peat*

The humified *Carex* peat used in the pot experiment P1 was very infertile. Liming as well as an application of both phosphorus and potassium were required for normal growth (Table 3). The properties of the ashes as liming agents and P and K sources could thus come into effect. The very acid peat had also a great buffer power against pH increases, and so even the limed treatments were quite acid. The yields of the first cut indicated that the soil acidity in the unlimed pots depressed growth most strongly in the early stage. According to the soil pH values, straw ash was an inefficient liming agent, but it produced the best yields of the experiment.

In the pots treated with straw or wood ashes, growth was quite normal in the absence of applied P, and the effects of complementary P were relatively small (Table 3). These ashes had thus been effective sources of P to rye grass in the acid peat. In the pots treated with bark and peat ashes, growth was largely regulated by K supply and so the supply of P could not be estimated from the yield data.

A suboptimal K supply was most detrimental for the last yield, because this nutrient was so mobile in the peat that most of the exchangeable pool had been taken up earlier. In the bark (3) and peat (4) ashes a major part of the K was in an sparingly soluble form, but it did not seem to have particularly supported late growth (Table 3). In this extremely K deficient peat those ashes were thus inferior because of their low content of available K.

In the first cut the wood ash (1) was superior to soluble fertilizers, excluding a treatment with potassium carbonate. Because the carbonate ion is

Table 3. Effects of lime and soluble P and K on soil pH and dry matter yield of rye grass on acid *Carex* peat (1) in pot experiment P1.

Treatment	Lime and ash additions, g / pot Material	Soluble nutrients * $Ca(H_2PO_4)_2 \cdot H_2O$ mg P / pot	KCl mg K / pot	Soil pH in 0.01 M $CaCl_2$	Dry matter yield g / pot 1st cut	4th cut	1+2+3+4 cuts
L0	—	400	2000	3.3	5.4	5.3	57.4
L1	15 g Ground limestone	400	2000	3.9	15.2	9.2	68.2
L2	30 g Ground limestone	400	2000	4.7	16.9	10.2	73.4
P0	18 g $CaCO_3$	0	2000	4.2	7.7	3.9	28.7
P1	18 g $CaCO_3$	200	2000	4.4	15.1	8.3	63.6
P2(K_2)	18 g $CaCO_3$	400	2000	4.2	16.4	8.6	69.8
K0	18 g $CaCO_3$	400	0	3.7	4.0	—	5.7
K1	18 g $CaCO_3$	400	1000	4.2	16.6	1.6	42.8
K2,5	18 g $CaCO_3$	400	2500 1)	3.9	16.0	16.1	84.8
$K_2 \cdot 2\,Cl$	18 g $CaCO_3$	400	2000 2)	4.3	15.2	10.7	75.7
$K_2 \cdot SO_4$	18 g $CaCO_3$	400	2000 3)	4.3	17.4	8.0	70.9
$K_2 \cdot CO_3$	18 g $CaCO_3$	400	2000 4)	4.1	18.2	6.1	64.3
SA10	10 g Straw ash 1	—	—	3.5	10.2	2.6	49.4
SA10P	10 g Straw ash 1	200	—	3.4	12.5	2.8	52.3
SA20	20 g Straw ash 1	—	—	3.4	16.0	7.1	80.8
SA20P	20 g Straw ash 1	200	—	3.3	17.9	9.8	91.1
WA10	10 g Wood ash 2	—	—	3.6	14.9	—	36.6
WA10P	10 g Wood ash 2	200	—	3.7	14.9	—	39.3
WA20	20 g Wood ash 2	—	—	4.4	18.1	4.8	64.3
WA20P	20 g Wood ash 2	200	—	4.4	19.3	5.4	67.5
BA20	20 g Bark ash 3	—	0	3.9	8.4	—	19.1
BA20PK	20 g Bark ash 3	200	500	3.8	14.2	—	32.5
BA40	40 g Bark ash 3	—	0	4.3	11.3	1.8	30.4
BA40PK	40 g Bark ash 3	200	500	4.6	15.7	2.7	45.5
PA80	80 g Peat ash 4	—	0	3.8	6.4	—	10.0
PA80PK	80 g Peat ash 4	200	500	3.7	11.7	—	25.7
PA160	160 g Peat ash 4	—	0	4.1	8.4	—	14.1
PA160PK	160 g Peat ash 4	200	500	4.0	12.0	—	29.1
LSD 0.05				0.22	1.9	1.8	4.7

1) 1000 + 500 + 500 + 500 as KCl
2) 2000 K in KCl + equal amount of Cl in $CaCl_2$ and $MgCl_2$ (eq Ca = eq Mg)
3) as K_2SO_4
4) as K_2CO_3
* Mg 200, Mn 16, Cu 13 and Zn 11 mg / pot, as sulphates (290 mg S), 3.5 mg B as H_3BO_3 and Mo 5 mg as Na_2MoSO_4 per pot in each treatment without ash.
N fertilization 1000 mg to first and 500 mg / pot to subsequent crops as NH_4NO_3.

labile in acid soil, it did not increase the osmotic tension of soil water as much as the chloride did. The excess chloride depressed early growth but increased later growth, obviously through a saving of potassium (Table 3). The results suggest that a low chloride content of the potassium source may be beneficial also for plants not known to be sensitive to chloride. By the straw and wood ash treatments growth declined more steeply than by corresponding levels of K in soluble salts, because the ashes did not supply sulphur sufficiently. The S deficiency was diagnosed from the yellowish colour of the grass and confirmed by a vigorous revival of growth with applied S after the experiment proper.

Table 4. Effects of lime and ashes and soluble fertilizers on grain and straw yields of barley and oats on acid *Carex* peat (1) in pot experiment P2.

Treatment	Lime and ash additions, g 2 pot material	To 1st crop (mg / pot) In soluble chemicals[1] P	K	Mg	Mn	B	Dry matter yield g / pot Barley 1981 Grain	Barley 1981 Straw	Oats 1982 Grain	Oats 1982 Straw	Barley 1983[3] Grain	Barley 1983[3] Straw
L1F1	24 g gr. limestone	200	1000	200	10	2	30.9	51.7	33.9	57.2	61.9	53.9
L1Mn+	24 g gr. limestone	400	2000	400	150	2	30.9	56.1	29.3	72.3	65.3	56.6
L1B+	24 g gr. limestone	400	2000	400	10	15	28.8	56.0	34.0	63.3	62.1	51.9
L2F1	48 g gr. limestone	200	1000	200	10	2	24.8	43.0	26.6	53.2	55.9	51.9
L2F2	48 g gr. limestone	400	2000	400	10	2	35.4	59.3	28.2	64.7	54.6	49.8
L2Mn+	48 g gr. limestone	400	2000	400	150	2	24.5	49.4	35.7	59.6	63.7	55.5
L2B+	48 g gr. limestone	400	2000	400	10	15	32.5	58.5	27.0	63.3	63.7	57.6
A1WA2	21 g wood ash 2	200	0	0	0	0	27.0	55.9	17.8	83.3	5.7	62.8
A1PA4	70 g peat ash 4[2]	0	1000	200	10	2	24.5	46.3	33.2	62.4	61.3	54.1
A1BA5	40 g bark ash 5	200	1000	0	0	0	19.3	50.2	11.9	79.9	6.8	48.6
A1CA6	174 g goal ash 6	200	1000	0	0	0	19.9	46.1	22.6	71.1	64.5	48.4
A2WA2	42 g wood ash 2	100	0	0	0	0	29.5	55.0	9.3	89.1	23.7	35.1
A2BA3	70 g bark ash 3	0	1000	0	0	0	37.2	55.8	19.6	64.1	61.2	52.9
A2BA3P	70 g bark ash 3	200	1000	0	0	0	39.6	61.0	15.7	83.9	66.7	58.0
A2BA5	80 g bark ash 5	100	1000	0	0	0	40.6	59.6	32.0	54.8	31.6	33.4
A2CA6	348 g coal ash 6	0	1000	0	0	0	23.9	44.1	18.1	59.6	70.6	54.7
A2CA6P	348 g coal ash 6	200	1000	0	0	0	19.6	47.5	18.9	73.5	74.1	59.3
LSD 0.05							7.5	10.4	8.0	8.2	12.7	10.3

1) Chemical compounds added: H_3PO_4, K_2CO_3, $MgSO_4$, $MnSO_4$ and H_3BO_3 in solution. To L and PA4 pots applied Cu, Mn and Zn 10 mg, B 2 mg and Mo 1 mg.
2) 18 g $CaCO_3$ and 70 g peat ash
3) Cu applied as basic fertilization to all treatments, 20 mg per pot as $CuSO_4$. To each pot added as basic fertilization (mg):
1981 1000 N as NH_4NO_3 and 100 S as H_2SO_4
1982 1500 N and 100 P as NH_4NO_3 and $(NH_4)_2$ HPO_4, 1000 K as KCl and 100 Mg and 130 S as $MgSO_4$
1983 1500 N and K and 300 P as NH_4NO_3, $(NH_4)_2$ HPO_4 and KNO_3, 200 Mg and 260 S as $MgSO_4$

Barley and oats on acid *Carex peat*

In the second pot experiment on the infertile *Carex* peat, soil pH and K levels were raised to a reasonable level and a small amount of S was applied throughout all the treatments in order to display the effects of P and other properties of ashes. In the first year a complementary P application did not significantly increase the barley yields obtained by bark (3) and coal (6) ashes (Table 4). Also, the peat ash (4) was an effective P source to barley. The P amount 100 mg per pot applied to oats in the second year was suboptimal, but severe growth disturbances did not, in the absence of analytical data, allow the comparison of the treatments as P sources.

Coal ash (6) was so inefficient as a liming agent that very large amounts should be applied to attain the effects equivalent to the other materials studied. Although its B content was not particularly high (Table 1), this ash caused severe toxicity symptoms in barley in 1981, which were similar to those that appeared by the excess B treatments. Yellow chlorosis and brown necrotic spots appeared in the leaves beginning at the tips, as shown in a preliminary Finnish report (SAARELA 1982). Weaker symptoms of a similar type appeared by the wood ash (2). In the first year at the higher level (A2), the coal ash clearly hampered growth and the wood ash produced slightly smaller seed yields compared to the bark ashes (3 and 5) which supplied less B (Table 4).

It is sometimes hypothesized that plant ashes contain all the essential mineral nutrients in balanced proportions, and are thus excellent sources of micronutrients. The results of the pot experiment P2 surprisingly were quite contrary to this hypothesis, since no ash sample maintained normal growth in the absence of applied micronutrients. In the second year the leaves of oats were chlorotic and late tillering was vigorous by all of the ash treatments excluding the peat ash with applied micronutrients. Seed yields were also poor (Table 4). The symptoms suggested Cu deficiency, but this nutrient restored normal growth only with the coal ash and with one of the bark ashes (3) when applied to barley in the third year. Later on, it was found that the other deficient micronutrient was Mo, which was in accordance with the poor Mo status of the soil (Table 2) and with the low Mo contents of the wood (2) and bark (5) ashes (Table 1).

Oats and barley on P deficient *Carex peat*

The relatively good yields obtained on this P deficient soil indicated that the wood (7) and bark (8) ashes did supply P to oats and barley also in a neutral medium. These ashes, however, tended to be slightly inferior to peat ash (9) and to the limed control treatment L2 in producing dry matter (Table 5). The largest yield reductions occurred with bark ash in the first year and with the lower rate of wood ash in the third year. The tested peat ash was less efficient in raising soil pH than the chemical determination suggested and thus the soil treated with it remained acid. Another possible reason for the better growth obtained with this material was a more favourable nutrient composition.

Barley and oats on infertile *Sphagnum peat*

The acid peat used in the pot experiment P 4 was so infertile that even the more tolerant plant, oats, grew very poorly in the unlimed control pots. Only this plant was able to form grains by the minor amount (5 g) of ground limestone or wood ash (7), which was superior at this suboptimal level (Table 6). When larger amounts were applied, wood ash caused smaller yields than lime. In the second year in oats, the ash brought about growth disturbances by a largely excessive rate only, when the pH rose to 9.6.

Bark ash pellets (10) were very ineffecient soil amendments for barley in the first year. Even their weak effect was delayed, as indicated by the low dry matter percentages at cutting (Table 6).

Table 5. Effects of repeated application of lime and ashes on grain and straw yields of oats and barley on P deficient *Carex* peat (2) in pot experiment P3.

Treatment	Lime and ash applied annually g / pot Material	Soluble nutrients* annually mg / pot P	K	Soil pH in H_2O 1983	Dry matter yield mg / pot Oats 1982 Grain	Straw	Barley 1983 Grain	Straw	Oats 1984 Grain	Straw
L1	18 g gr. limestone	150	1000	6.3	36.2	56.5	52.3	46.4	65.0	72.3
L2	36 g gr. limestone	300	2000	7.1	49.6	69.8	68.5	49.4	66.8	75.4
WA1	18 g wood ash 7	0	0	6.3	44.3	68.4	52.0	48.3	38.9	49.5
WA2	36 g wood ash 7	0	0	7.4	44.9	71.1	51.9	53.1	46.9	57.2
BA2	36 g bark ash 8	0	0	7.5	19.2	87.3	48.9	49.3	52.4	64.4
PA2	180 g peat ash 9	0	500	5.8	43.9	68.6	62.3	53.2	59.9	69.7
LDS 0.05					6.0	8.0	8.1	11.8	6.4	10.5

* As K_2HPO_4 and KCl, in 1984 1000 mg K per pot with peat ash
Micronutrients to control treatments with lime in 1982 and 1983, and to all experiment in 1984
Basic fertilization to each pot (mg):
1500 N and 100 S as NH_4NO_3 and $(NH_4)_2$ SO_4

Table 6. Effectes of increasing rates of lime and ashes on soil pH, grain and straw yields and dry matter percentage at cutting of barley and oats on infertile *Sphagnum* peat (3) in pot experiment P4.

Treatment	Lime and ash additions g / pot Material	Soil pH in H_2O 1985	Barley 1985 Dry matter g / pot Grain	Straw	% DM	Oats 1986 Dry matter g / pot Grain	Straw	% DM
Control	— —	3.8	0	0.6	—	0.2	6.3	18
L1 / 4	5 g gr. limestone	4.4	0	8.1	48	19.1	59.4	32
WA1 / 4	5 g wood ash 7	4.6	0	8.8	35	32.6	57.0	40
BA1 / 4	10 g bark ash 10	4.4	5.0	12.7	35	20.4	42.8	41
L1	20 g gr. limestone	5.5	41.8	46.9	75	61.1	66.6	52
WA1	20 g wood ash 7	5.8	34.5	49.2	65	63.1	71.3	48
BA1	40 g bark ash 10	4.8	15.5	21.5	45	59.3	59.3	51
L4	80 g gr. limestone	7.2	46.9	52.1	80	57.5	65.4	49
WA4	80 g wood ash 7	8.6	35.1	46.9	39	55.3	59.2	42
BA4	160 g bark ash 10	5.4	25.2	34.1	44	67.4	80.2	46
WA8	160 g wood ash 7	9.6	4.0	19.2	27	7.8	15.7	28
BA8	320 g bark ash 10	6.6	33.2	40.2	49	67.4	73.0	43
BA1-P	40 g bark ash 10	4.0	0.7	1.9	17	13.8	17.5	50
BAILI-P	40 g BA + 20 g lime	5.7	6.0	10.6	30	8.6	9.4	44
BAILI	40 g BA + 20 g lime	5.7	44.4	49.5	74	65.2	68.6	48
LSD 0.05			6.8	4.3	8	4.9	5.0	3

Basic fertilization (mg / pot): 1985 and 1986 1500 N and K, 400 P as KNO_3, $(NH_4)_2$ HPO_4 and NH_4NO_3, 1 Mo as Na_2MoO_4. Cu, Zn, Mn and Fe 20 in 1985 and 10 in 1986, Mg 400 in 1985 and 200 in 1986 as sulphate, Cl 120 in 1985 and 60 in 1986 as NaCl, B 2 in 1985 and 1 in 1986 as H_3BO_3.

Table 7. Effects of wood ash, ground limestone and fertilizers on yields of barley in clay and mull soils (TGW = weight of 1000 grains, HLW = weight of hectolitre grains).

Treatment	Lime and ash applied at start t/ha Material	Annual fertilization kg/ha* P	K	Grain yield 1982 kg/ha	1983 kg/ha	1984 kg/ha	Mean yield grain kg/ha	protein kg/ha	Mean quality of grain moisture %	TGW g	HLW kg
				Loamy clay (F1)							
Control	—	—	—	5470	4630	3750	4620	72.8	19.1	31.4	66.6
P	—	60	—	5510	4640	4140	4760	73.0	19.1	31.4	66.4
K	—	—	80	5900	5020	4630	5184	76.3	19.6	33.0	66.8
PK*	—	60	80	5850	4690	4600	5050	74.1	19.3	32.7	66.5
L6PK*	6 t limestone	60	80	5930	4750	4680	5120	77.0	18.8	32.6	66.4
WA3	3 t wood ash 7	—	—	5520	4610	3690	4610	68.8	18.5	31.3	66.4
WA6	6 t wood ash 7	—	—	5550	4710	4060	4770	72.3	18.3	31.2	66.3
WA12	12 t wood ash 7	—	—	5740	4810	3900	4820	74.1	18.4	31.5	66.7
LSD				290	270	370	160	5.0	0.5	0.8	0.5
				Clayey mull (F2)							
Control	—	—	—	4620	3330	1270	3070	60.5	24.4	26.5	59.0
P	—	60	—	5680	3940	2260	3960	75.7	20.7	28.7	62.1
K	—	—	80	4960	3790	1760	3500	67.2	23.3	27.7	60.4
PK*	—	60	80	5690	3830	2460	3990	77.0	22.0	28.0	61.6
L6PK*	6 t limestone	60	80	5780	3900	2590	4090	79.8	22.0	29.0	60.9
WA3	3 t wood ash 7	—	—	4880	3490	1310	3220	64.2	24.1	26.7	59.7
WA6	6 t wood ash 7	—	—	5060	3680	1320	3350	66.2	23.7	26.6	60.1
WA12	12 t wood ash 7	—	—	4960	3950	1630	3510	70.4	23.2	27.2	60.6
WA6P	6 t wood ash 7	60	—	5990	4330	2610	4310	84.6	20.8	28.5	62.6
LSD				270	400	250	180	4.5	1.7	1.0	0.8

* P and K not applied in 1983

In the second year oats grew well in the pots treated with the pellets, though soil pH values were low. The poor growth in the first year saved nutrients for the succeeding crop, which was probably the main reason for the superiority of this treatment in the second year. The inefficiency of the pellets as a liming agent was also confirmed by the combined ash and lime treatments, and the absence of applied P revealed the inavailability of P in the pellets (Table 6). Pieces 10 mm in diametre did not dissolve in the acid peat, but maintained their original shapes, and even hardened during the two experimental season. This was obviously a result of the acting of the Ca rich material as mortar and forming $CaCO_3$.

Barley in clay and mull fields

In the rather fertile loamy clay field the effect of wood ash (7) on the grain yield of barley was significant only by the highest rate, which increased the average of three years by 200 kg / ha (Table 7). The inefficiency of liming and P application was in accordance with the good pH value and P status of this soil. The significant increases in grain yields caused by drilled muriate of potash were unusually large compared to the results of other recent Finnish experiments. The wood ash used contained very large amounts of K (258 kg in 3 t, 516 kg in 6 t and 1032 kg in 12 t), but it was significantly inferior to the fertilizer salt. During the first year the largest rate of ash very distinctly stimulated early growth, but finally caused earlier ripening without a corresponding increase in grain yield. The ash treatments accordingly decreased the percentage of grain moisture at harvest (Table 7). They did not increase the thousand seed weight as did the muriate of potash.

In the moderately acid clayey mull field the grain yield of barley responded quite weakly to liming and K application, but the effect of single superphosphate was substantial being + 890 kg / ha on average over the three year period (Table 7). The wood ash caused significant increases in grain and protein yields when applied at 6 or 12 t / ha, but 3 t /ha was inefficient. The effect of P fertilization was not reduced with the ash treatment, and the best result was obtained by combined treatments with wood ash and P fertilizer. The moisture of grain at harvest was decreased and the grain quality was improved most efficiently by P fertilizer (Table 7). The total content of P in the wood ash doses of 3, 6 and 12 t / ha were 53, 105 and 210 kg / ha. The inferiority of the wood ash in supplying P to barley thus indicated a poor availability, which resulted from an inadequate solubility or from the unfavourable method of ash application.

DISCUSSION

Plant ashes, which are efficient liming agents containing the essential mineral elements taken up from the soil, are theoretically valuable amendments in Finnish soils, which are generally both acid and deficient in mineral nutrients. The recycling of ashes in plant production is also an ecologically safe way to get rid of these waste products. Wood and bark ashes are efficient agents for improvement of the productivity of peat land forests, but the spreading of ash in forested land is restricted due to technical difficulties (HAKKILA and KALAJA 1983).

The experimental results obtained in the present study confirmed the potential value of ashes in amending agricultural soils, but did not support the hypothesis of a balanced supply of different nutrients by ashes. Deficiencies of some nutrients in soils treated with ash caused severe growth disturbances in plants. The macronutrient potassium, which is a chemically soluble element and mobile in the biosphere, was deficient in peat and coal ashes, and even bark ashes had probably lost a major part of their original content (HAKKILA and KALAJA 1983). The deficiencies of the micronutrients copper and molybdenum in soils amended with wood and bark ashes were possibly reflections of the inherently poor status of these nutrients in Finnish soils. Another explanation is the generally known poor availability of Cu in organic soils and Mo in acid soils. The detrimental effects of boron by coal and wood ashes indicated the high toxicity of this nutrient in excessive amounts. The absolute contents of B were not as high as the contents of Mn and Zn, which appeared to be nontoxic.

The ashes from fossil fuels have occasionally decreased plant growth if applied in very large amounts (e.g. KICK and GROSSE-BRAUCKMAN 1961, KATZUR and GORA 1986). In agreement with the results of the present study, the most phytotoxic element in coal ashes has frequently been boron (ADRIANO et al. 1980, AITKEN and BELL 1985). Even quite heavy treatments with coal ash have increased yields (ADRIANO et al. 1980, KATZUR and GORA 1986), as did the coal ash in the pot experiment P3 of this study in the third year. The possible harmful effects of peat ash on plants seems to be unknown, but the results presented here and reported earlier agree on its quite low contents of nutrients and relatively weak efficiency as a liming agent (LUNDEN 1925, JOKINEN 1982, HAKKILA and KALAJA 1983, RINNE 1983).

In earlier Finnish experiments wood ash has been a good potassium fertilizer in a peat soil (SALOHEIMO 1952), and wood and bark ashes have produced equal or better yields than the usually used ground limestones which were compared to them (SALONEN 1966, SIMOJOKI 1976, RINNE 1983). One possible reason for the superiority of ashes occasionally found may be their low-Cl potassium as in the pot experiment P1. In addition to Cl sensitive crops, this advantage is most probable in intensive ley cropping on K deficient soils, where large rates of K are required (SAARELA 1983). In the loamy clay field wood ash stimulated early growth of barley in the application year, but efficiently only by the largest rate. The temporarily improved growth factor is unknown, but evidently it was some physical soil property. The dark ash may have increased soil temperature, which should be assessed in additional experiments.

The K rich wood ash was significantly inferior to the muriate of potash in barley on the loamy clay field. The effects of the form and application method of potassium fertilizer were studied in another experiment on similar soil adjacent to the F1. The muriate of potash (KCl) was compared with K_2SO_4 and NaCl, each both drilled into rows and broadcast onto the soil. The best response in the grain yield (+13 %) was obtained by the drilled muriate of potash. Broadcasted KCl as well as the drilled and broadcast NaCl caused smaller increases in yield, but K_2SO_4 was inefficient irrespective of the application method (SAARELA 1987). The inferiority of the wood ash in barley on the loamy clay soil thus seemed to have been a result of its suboptimal chloride content. Soluble anions such as chloride may improve the availability of cations in soils by increasing their concentrations in soil solution, but further studies are required to clarify the mechanisms.

The experiments presented in this paper preliminarily elucidated the functioning of different ashes as sources of nutrients to plants. The ashes of wood, bark and peat have not been the subject of extensive international research as have coal ashes. Additional investigation would therefore be highly relevant in order to successfully use these ashes in plant production under variable edaphic and technical conditions. The availabilities of different nutrients in ashes could be assessed more precisely by means of analytical studies, which would allow the tracing of even such elements that are not critical to the plant under the particular conditions.

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SELOSTUS

Raiheinän, ohran ja kauran kasvu puun, kuoren, turpeen ja kivihiilen tuhkalla parannetuilla mailla

INTO SAARELA

Maatalouden tutkimuskeskus

Eri polttoaineiden tuhkien vaikutusta kasvien kasvuun tutkittiin neljällä astiakokeella ja kahdella kenttäkokeella vuosina 1980 — 1986. Astiakokeisiin valittiin happamia, niukkaravinteisia maita, jotta tuhkien monipuolinen maanparannus- ja lannoitusvaikutus olisi ilmennyt koekasvien kasvussa. Tuhkia verrattiin kalkkiin ja helppoliukoisiin P- ja K-lannoitteisiin.

Heikossa kasvukunnossa olleilla mailla saavutettu hyvä kasvu osoitti tuhkien olevan potentiaalisesti arvokkaita materiaaleja kasvintuotannossa. Eri tuhkalajien vaihteleva koostumus tulisi kuitenkin ottaa käyttökohteiden ja -määrien sekä tarvittavan täydennyslannoituksen suunnittelussa huomioon. Puun tuhka oli tehokasta kalkitusainetta ja runsasravinteista peruslannoitetta. Kuoren tuhka oli laimeampaa varsinkin kaliumin osalta. Fossiilisten polttoaineiden tuhkassa tätä helppoliukoista makroravinnetta oli hyvin vähän. Turpeen tuhka sisälsi jonkin verran fosforia. Kivihiilen tuhka oli niukkaravinteista ja aiheutti suurina määrinä boorimyrkytysoireita. Aluksi kokeiltu oljen tuhka osoittautui kaliumrikkaaksi lannoitteeksi, mutta kalkitusaineena melko heikkotehoiseksi.

Tuhkat olivat suhteellisen tehokkaita turvemaan fosforilannoitteita astiakokeissa. Kenttäolosuhteissa puun tuhkan fosfori oli ohran lannoituksessa selvästi huonompaa verrattuna sijoitetun superfosfaatin fosforiin. Runsaasti kaliumia sisältävä puun tuhka ei lisännyt ohran jyväsatoa savimaan kenttäkokeessa yhtä paljon kuin kalisuola. Erillisen K- ja Cl-yhdisteiden vertailukokeen mukaan puun tuhkan huonommuus näytti johtuvan kalisuolan kloorin edullisesta vaikutuksesta. Puun ja kuoren tuhkaa saaneella turpeella todettu kuparin ja molybdeenin puutos osoitti näiden hivenaineiden niukkuutta Suomen maaperässä ja huonoa saatavuutta tuhkalla käsitellystä happamasta turpeesta.

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EFFECT OF DIDIN (DICYANDIAMIDE) ON THE FERTILIZER VALUE OF COW SLURRY FOR BARLEY

ERKKI KEMPPAINEN

KEMPPAINEN, E. 1989. **Effect of Didin (dicyandiamide) on the fertilizer value of cow slurry for barley.** Ann. Agric. Fenn. 28: 133 — 150. (Agric. Res. Centre, Kainuu Res. Sta., SF-88600 Sotkamo, Finland.)

Cow slurry was spread at different times of the year with or without Didin in six field experiments in southern Finland in 1983 — 1987. Four experiments were carried out on a sandy clay soil and two on a sand soil. In September and in late May slurry was applied both by broadcasting and by injection but in November — December and April — early May only surface application was used. The rate of cow slurry ranged from 50 to 67 m^3 / ha and that of Didin from 11 to 30 kg / ha in different years. In addition two pot experiments were carried out in which the most economical time for Didin treatment in autumn was more thoroughly examined.

In most experiments Didin improved the fertilizer value of autumn applied slurry significantly. The best effect by Didin was obtained when it was added to slurry injected in September, followed by a cool autumn with relatively little precipitation. Didin did not have any effect on slurry applied in November — December. When added to slurry applied in spring, Didin had a considerably positive effect only during the exceptionally cool growing season of 1987. The lower rates of Didin (11 — 13 kg / ha) seemed to be more economical compared to higher rates.

At best, when added to slurry injected in September, one kilogram of Didin produced as high a yield increase as 2.6 kg of nitrogen in artificial fertilizer applied in spring. On average, however, the benefit by Didin was significantly smaller. The price of Didin in Finland is 3 — 4-fold compared to the cost of nitrogen in most commonly used artificial fertilizers.

Didin was found to retard the nitrification of slurry ammonia and prevent an increase in the nitrate content of deeper soil layers. In southern Finland, Didin can be advantageously used until the beginning of November.

Spring application of slurry appeared to be much more effective compared to autumn application. Furthermore, injection was found to be a superior method compared to surface application. Yield increases by injection averaged 310 kg / ha of barley grain in the case of slurry application in autumn and 350 kg / ha in the case of spring application. Injection was especially effective in autumn on sand soil but in spring on sandy clay soil.

Index words: nitrification inhibitor, slurry, dicyandiamide, injection, surface application.

INTRODUCTION

Autumn is an unfavourable time for slurry application. In Finland, the efficiency of autumn spread slurry ranges from 25 to 40 % compared to that applied in spring (KEMPPAINEN 1985). However, about one-third of all livestock manure produced in Finland must be spread in autumn due to limited storage capacities and the restrictions placed on winter application. In addition to the poor fertilizer effect by slurry applied in autumn, environmental pollution resulting from nitrate leaching is considered to be a serious disadvantage.

The nitrification of manure ammonia has been shown to be strongly dependent on soil temperature (AMBERGER 1985). The higher the temperature, the faster ammonia nitrifies. In practice, the critical soil temperature in autumn is 4—5 °C, below which nitrification proceeds rather slowly. In southern Finland this soil temperature is reached on average in the beginning of November, although annual variation is considerable.

Several chemicals have been examined in order to retard ammonia nitrification (CORNFORTH and CHESNEY 1971, BUNDY and BREMNER 1974, AMBERGER 1981, MALHI and NYBORG 1983, KJELLERUP 1986). Of these, Didin (dicyandiamide) is regarded as the most promising additive. It has been shown to retard nitrification effectively thus increasing yields, improving slurry nitrogen efficiency and reducing nitrate leaching (AMBERGER and GUTSER 1979, GUTSER 1981, KUNZE and SCHEFFER 1981, SOLANSKY 1981, 1982, AMBERGER 1982, AMBERGER et al. 1982a, 1982b, GÖRLITZ 1983, KJELLERUP 1986, 1987, de la LANDE CREMER 1986). Nitrogen losses through denitrification, nitrite accumulation into soil and nitrate accumulation into horticultural crops have also been reduced with Didin (KICK and MASSEN 1973, BUNDY and BREMNER 1974, HARTMAN 1982, VILSMEIER and AMBERGER 1982).

Soil temperature is considered to be the most important factor determining the efficiency of Didin. In a warm soil, Didin decomposes quickly thus losing its nitrogen-preserving effect already in early autumn (VILSMEIER 1981, KJELLERUP 1987). In a cool soil, on the other hand, ammonia oxidation proceeds so slowly that it is preserved even without a nitrification inhibitor (KJELLERUP 1987). Thus the time period in which Didin application is profitable in autumn may be rather short. On coarse soils especially in rainy summers, however, Didin may produce significant positive effect even by slurry application in spring (GÖRLITZ 1983).

Another factor that determines the efficiency of Didin is the leaching of the nitrification inhibitor itself. Didin has been found to be washed out through the soil even faster than ammonia (BOCK et al. 1981). According to de la LANDE CREMER (1986) however, use of Didin is the most profitable on coarse soils and the least efficient on heavy soils.

The objective of this study was to examine the efficiency and profitability of Didin as a cow slurry additive in the northern climate of Finland. A special task was to determine the optimal rate and application period for Didin application in the autumn.

MATERIAL AND METHODS

Field experiments

Six field experiments were carried out at Jokioinen (60° 49' N, 23° 30' E) in 1983 — 1987. Four experiments were located on sandy clay soil at Ojainen and two experiments on sand soil (0.2 — 0.6 mm) at Rehtijärvi. Both soils were rather fertile (soil analysis according to VUORINEN and MÄKITIE 1955, nutrients mg / l):

	pH	Ca	K	Mg	P
Ojainen	6.2	2700	310	550	30
Rehtijärvi	6.2	1280	235	90	26

Cow slurry was spread with or without Didin at four different times of the year (September, November — December, April — early May, late May). In September and in late May two methods of slurry application were used: surface application and injection. Following slurry application in September, the field was ploughed after 2 — 3 weeks. Following slurry application in late May, slurry was incorporated into the soil by harrowing after 2 — 3 days. In November — December and in April — early May slurry was applied only by surface application without incorporation into the soil until late May. In the first experimental year (growing season 1984), the rate of Didin applied with slurry was 30 kg / ha. In later years two different rates were studied: 13 and 26 kg / ha or 11 and 22 kg / ha.

Cow slurry was spread by a Finnish Teho-Lotina spreader equipped with six injection tines spaced about 50 cm apart (ANON. 1983). The spreader has a capacity of 6.8 m^3 and a working width of 3 m. For surface application, a specially designed iron plate was adjusted beneath the tines in order to improve the evenness of slurry distribution. Didin was added to a spreader containing 3 — 4 m^3 of slurry, and the slurry was mixed 3 — 5 minutes before application.

Barley (*Hordeum vulgare* var. Pomo) was grown on experimental plots, each 15 m long and 3 m wide. All of the experiments had four replicates. Information concerning the field experiments is presented in Table 1.

Barley grain yield was weighed and its nitrogen content determined by the Kjeldahl method. In addition, the content of nitrate and ammonium nitrogen in different soil layers (0 — 20, 20 — 40 and 40 — 60 cm) in spring was determined for plots with slurry application during the preceding September. Soil nitrogen content was determined photometrically by an AKEA-autoanalyzer. The statistical significance of yield increases etc. by Didin was tested by calculating the LSD value or the corresponding Tukey's HSD value with a 5 % risk (STEEL and TORRIE 1960).

Yield increases by Didin at different times of the year were compared to those by nitrogen in artificial fertilizer applied in spring. For this purpose, a second degree equation, presenting the effect of artificial fertilizer (nitrogen), was first calculated. The fertilizer value of Didin, as kg of nitrogen / kg of Didin, was then assessed from the yield curve. In experiments on the sandy clay soil at Ojainen in 1985 and 1986, however, yield increases by Didin were compared to those by soluble nitrogen in slurry applied in spring. This was because there were no treatments with artificial fertilizer in 1985, and in 1986 treatments with artificial fertilizer had to be disregarded because of mistakes in fertilizer spreading. Difficulties were also met in interpreting results because, in some experiments, the highest yields by slurry exceeded those by the highest rate of artificial fertilizer. Thus the values for Didin efficiency, as kg of N / kg of Didin, have to be regarded as approximate instead of accurate.

Pot experiments

In autumn 1984 a pot experiment was carried out in which the nitrification inhibiting effect of Didin was examined. Sandy clay soil was first

Table 1. Treatments with slurry and Didin in field experiments.

1984 Ojainen, sandy clay

Time of application	Method of application	Didin kg / ha	
15. 9. 1983	surface	0	30
15. 9. 1983	injection	0	30
25. 11. 1983	surface	0	30
13. 4. 1984	surface	0	30
16. 5. 1984	surface	0	30
16. 5. 1984	injection	0	30

controls: unfertilized, 250 and
500 kg NPK (20-4-8) / ha

rate of slurry: 50 m³ / ha

nutrients in slurry:

N total	139 kg / ha
N soluble	73 kg / ha
P	27 kg / ha
K	175 kg / ha
sowing time	19. 5.
harvesting time	23. 8.

1985 Ojainen, sandy clay

Time of application	Method of application	Didin kg / ha		
7. 9. 1984	surface	0	13	26
7. 9. 1984	injection	0	13	26
20. 12. 1984	surface	0	13	26
16. 5. 1985	surface	0	13	26
24. 5. 1985	surface	0		
24. 5. 1985	injection	0		

control: unfertilized

rate of slurry: 50 m³ / ha

nutrients in slurry:

N total	87 kg / ha
N soluble	52 kg / ha
P	15 kg / ha
K	119 kg / ha
sowing time	27. 5.
harvesting time	30. 8.

1986 Ojainen, sandy clay and Rehtijärvi, sand

Time of application	Method of application	Didin kg / ha		
12. 9. 1985	surface	0	11	22
12. 9. 1985	injection	0	11	22
5. 12. 1985	surface	0	11	22
9. 5. 1986	surface	0	11	22
19. 5. 1986	surface	0		
19. 5. 1986	injection	0		

controls: unfertilized, 250 and
500 kg NPK (20-4-8) / ha *

rate of slurry: 67 m³ / ha

nutrients in slurry:

N total	161 kg / ha
N soluble	84 kg / ha
P	33 kg / ha
K	178 kg / ha
sowing time	23. 5.
harvesting at Ojainen	25. 8.
at Rehtijärvi	11. 9.

1987 Ojainen, sandy clay and Rehtijärvi, sand

Time of application	Method of application	Didin kg / ha		
29. 9. 1986	surface	0	11	22
29. 9. 1986	injection	0	11	22
12. 12. 1986	surface	0	11	22
19. 5. 1987	surface	0	11	22
26. 5. 1987	surface	0		
26. 5. 1987	injection	0		

controls: unfertilized, 250 and
500 kg NPK (20-4-8) / ha

rate of slurry: 67 m³ / ha

nutrients in slurry:

N total	154 kg / ha
N soluble	75 kg / ha
P	30 kg / ha
K	178 kg / ha
sowing time	28. 5.
harvesting at Ojainen	21. 9.
at Rehtijärvi	22. 9.

*) At Ojainen due to mistakes
only unfertilized control

placed into six-liter plastic pots, 5 kg of soil per pot, and the soil watered almost to field capacity. Five different fertilizing treatments were used: unfertilized, cow slurry 3 dl / pot and in addition to cow slurry 67 mg, 133 mg or 200 mg Didin / pot. The slurry application rate, as calculated on the basis of soil surface area, corresponded to 96 m^3 / ha. Application rates of Didin corresponded to 0.22 kg, 0.44 kg and 0.66 kg / m^3 of slurry. Slurry was mixed carefully throughout the soil. Each treatment had two replicates.

The subexperiments were performed four times during autumn 1984: 21.8., 21.9., 21.10. and 21.11., respectively. Each time the pots were immediately transferred to the field and placed into holes dug in the soil. The pots were protected against the rain by a loose plastic film and stored in the field until the soil froze. Soil samples were taken on 10.1.1985 and then photometrically analyzed for ammonium and nitrate nitrogen using an AKEA-autoanalyzer.

An almost similar pot experiment was carried out in autumn 1985, but then the rate of cow slurry was 2 dl / pot (64 m^3 / ha) and the respective rates of Didin 0.20, 0.40 and 0.60 kg / m^3 of slurry. The number of replicates was three and the subexperiments were established on 26.8., 16.9., 8.10., 29.10. and 19.11.1985. The pots were kept at soil temperature until the frost, and soil samples were taken on 14.1.1986.

Weather conditions

Information on the weather conditions at Jokioinen in 1983 — 1987 is presented in Appendices 1 and 2. In 1984, 1985 and 1986 the mean air temperature during the growing season almost equalled the long-term average but the summer of 1987 was significantly cooler. In all experimental years, precipitation during May — August exceeded the long-term average.

The mean air temperature in autumn 1983 (September — November) equalled the long-term average. In comparison, autumn 1984 was significantly warmer but the autumns of 1985 and 1986 were significantly cooler. The varying air temperature in different years was reflected in the soil temperatures, as can be seen in Appendix 2. Precipitation in September — November was higher than the long-term average in 1983, 1984 and 1986 but lower in 1985.

RESULTS

Effect of Didin on barley yield in field experiments

Barley grain yields and their nitrogen contents (N uptake) are presented in Tables 2 — 13. Didin addition improved the fertilizer value of slurry significantly in five experiments out of six. The effect of Didin was optimal when used with slurry injected in September. When used with slurry in November — December the effect of Didin was insignificant. With slurry application in spring, Didin had a statistically significant effect only on the sandy clay soil at Ojainen in 1986 and 1987. Besides, the effect in 1986 was only slight.

In most cases, a smaller rate of Didin (11 or 13 kg / ha) proved to be more cost efficient compared to a higher one (22 or 26 kg / ha). Only when added to the slurry broadcast in September, did an increasing rate of Didin raise barley yields without exception.

Didin did not have a clear effect on the nitrogen percentage in the barley grain yield. In some experiments Didin seemed to raise the nitrogen percentage, but in others the reverse was true. Nitrogen uptake by the grain yield was positively affected by Didin.

Table 2. Barley grain yields in the field experiment on sandy clay soil at Ojainen in 1984, kg / ha (85 % DM). Cow slurry was applied at a rate of 50 m³ / ha.

Time of application	Method of application	Didin, kg / ha		LSD (P =0.05)
		0	30	
15. 9. 1983	surface	2150	2810	600
"	injection	2200	3500	330
25. 11. 1983	surface	3050	3020	770
13. 4. 1984	surface	2050	1780	530
16. 5. 1984	surface	3430	3310	300
"	injection	3650	3630	245
Unfertilized		2120	—	
250 kg NPK / ha in spring		3690	—	
500 kg NPK / ha in spring		3480	—	

Table 3. Nitrogen uptake by barley grain in the field experiment on sandy clay soil at Ojainen in 1984, kg / ha.

Time of application	Method of application	Didin, kg / ha		LSD (P =0.05)
		0	30	
15. 9. 1983	surface	35	45	13
"	injection	34	54	5
25. 11. 1983	surface	48	46	12
13. 4. 1984	surface	34	29	10
16. 5. 1984	surface	53	51	5
"	injection	55	57	6
Unfertilized		33	—	
250 kg NPK / ha in spring		56	—	
500 kg NPK / ha in spring		60	—	

Table 4. Barley grain yields in the field experiment on sandy clay soil at Ojainen in 1985, kg / ha (85 % DM). Cow slurry was applied at a rate of 50 m³ / ha.

Time of application	Method of application	Didin, kg / ha			HSD (P =0.05)
		0	13	26	
7. 9. 1984	surface	1410	1520	1970	350
"	injection	1780	2350	2150	400
20. 12. 1984	surface	1860	2030	2070	260
16. 5. 1985	surface	3130	3190	2870	420
24. 5. 1985	surface	2770	—	—	
"	injection	3260	—	—	
Unfertilized		1590	—	—	

Table 5. Nitrogen uptake by barley grain in the field experiment on sandy clay soil at Ojainen in 1985, kg / ha.

Time of application	Method of application	Didin, kg / ha 0	13	26	HSD (P = 0.05)
7. 9. 1984	surface	22	23	32	9
"	injection	29	38	33	8
20. 12. 1984	surface	30	33	33	5
16. 5. 1985	surface	49	50	44	7
24. 5. 1985	surface	45	—	—	
"	injection	50	—	—	
Unfertilized		26	—	—	

Table 6. Barley grain yields in the field experiment on sandy clay soil at Ojainen in 1986, kg / ha (85 % DM). Cow slurry was applied at a rate of 67 m³ / ha.

Time of application	Method of application	Didin, kg / ha 0	11	22	HSD (P = 0.05)
12. 9. 1985	surface	1290	1670	1970	330
"	injection	1570	2090	2220	240
5. 12. 1985	surface	1580	1680	1680	300
9. 5. 1986	surface	2430	2580	2440	140
19. 5. 1986	surface	1940	—	—	
"	injection	2290	—	—	
Unfertilized		1250	—	—	

Table 7. Nitrogen uptake by barley grain in the field experiment on sandy clay soil at Ojainen in 1986, kg / ha.

Time of application	Method of application	Didin, kg / ha 0	11	22	HSD (P = 0.05)
12. 9. 1985	surface	23	30	36	5
"	injection	28	39	43	5
5. 12. 1985	surface	27	29	29	5
9. 5. 1986	surface	49	50	49	3
19. 5. 1986	surface	39	—	—	
"	injection	46	—	—	
Unfertilized		22	—	—	

Table 8. Barley grain yields in the field experiment on sand soil at Rehtijärvi in 1986, kg / ha (85 % DM). Cow slurry was applied at a rate of 67 m^3 / ha.

Time of application	Method of application	Didin, kg / ha 0	11	22	HSD (P =0.05)
12. 9. 1985	surface	2760	3120	3220	530
"	injection	3200	3540	3310	230
5. 12. 1985	surface	2810	2880	2950	420
9. 5. 1986	surface	3650	3770	3640	660
19. 5. 1986	surface	3490	—	—	
"	injection	3770	—	—	
Unfertilized		2350	—	—	
250 kg NPK / ha in spring		3670	—	—	
500 kg NPK / ha in spring		3840	—	—	

Table 9. Nitrogen uptake by barley grain in the field experiment on sand soil at Rehtijärvi in 1986, kg / ha.

Time of application	Method of application	Didin, kg / ha 0	11	22	HSD (P =0.05)
12. 9. 1985	surface	46	51	53	12
"	injection	51	64	58	12
5. 12. 1985	surface	44	45	47	7
9. 5. 1986	surface	65	67	62	16
19. 5. 1986	surface	65	—	—	
"	injection	68	—	—	
Unfertilized		34	—	—	
250 kg NPK / ha in spring		61	—	—	
500 kg NPK / ha in spring		75	—	—	

Table 10. Barley grain yields in the field experiment on sandy clay soil at Ojainen in 1987, kg / ha (85 % DM). Cow slurry was applied at a rate of 67 m^3 / ha.

Time of application	Method of application	Didin, kg / ha 0	11	22	HSD (P =0.05)
29. 9. 1986	surface	1540	2040	2230	390
"	injection	1890	2430	2690	460
12. 12. 1986	surface	2200	2210	2460	410
19. 5. 1987	surface	2690	3360	3250	390
26. 5. 1987	surface	2830	—	—	
"	injection	3660	—	—	
Unfertilized		1550	—	—	
250 kg NPK / ha in spring		3330	—	—	
500 kg NPK / ha in spring		3920	—	—	

Table 11. Nitrogen uptake by barley grain in the field experiment on sandy clay soil at Ojainen in 1987, kg / ha.

Time of application	Method of application	Didin, kg / ha 0	11	22	HSD (P =0.05)
29. 9. 1986	surface	21	29	31	8
"	injection	27	33	38	8
12. 12. 1986	surface	31	31	37	8
19. 5. 1987	surface	39	53	47	11
26. 5. 1987	surface	40	—	—	
"	injection	56	—	—	
Unfertilized		22	—	—	
250 kg NPK / ha in spring		52	—	—	
500 kg NPK / ha in spring		66	—	—	

Table 12. Barley grain yields in the field experiment on sand soil at Rehtijärvi in 1987, kg / ha (85 % DM). Cow slurry was applied at a rate of 67 m³ / ha.

Time of application	Method of application	Didin, kg / ha 0	11	22	HSD (P =0.05)
29. 9. 1986	surface	2210	2530	2600	920
"	injection	2590	2590	2590	300
12. 12. 1986	surface	2490	2540	2500	280
19. 5. 1987	surface	2860	3030	2920	540
26. 5. 1987	surface	2920	—	—	
"	injection	2840	—	—	
Unfertilized		2010	—	—	
250 kg NPK / ha in spring		2840	—	—	
500 kg NPK / ha in spring		2820	—	—	

Table 13. Nitrogen uptake by barley grain in the field experiment on sand soil at Rehtijärvi in 1987, kg / ha.

Time of application	Method of application	Didin, kg / ha 0	11	22	HSD (P =0.05)
29. 9. 1986	surface	37	43	46	16
"	injection	46	47	46	5
12. 12. 1986	surface	40	43	41	7
19. 5. 1987	surface	47	52	51	9
26. 5. 1987	surface	52	—	—	
"	injection	50	—	—	
Unfertilized		33	—	—	
250 kg NPK / ha in spring		43	—	—	
500 kg NPK / ha in spring		50	—	—	

Table 14. Substitution coefficients representing the yield increasing value of Didin, expressed as kg of nitrogen in artificial fertilizer applied in spring / kg of Didin.

Time of application	Method of application	1984 Ojainen	1985 Ojainen		1986 Ojainen		1986 Rehtijärvi		1987 Ojainen		1987 Rehtijärvi	
		Didin, kg / ha										
		30	13	26	11	22	11	22	11	22	11	22
September	surface	0.5	0.1	0.3	1.2	0.9	1.2	0.7	1.0	0.7	1.5	0.9
"	injection	1.2	0.8	0.3	2.6	1.9	1.5	0.2	1.2	1.0	0	0
Nov. — Dec.	surface	0	0.3	0.2	0.5	0.2	0.2	0.2	0	0.3	0.3	0
April — May	surface	0	0.4	0	1.6	0.1	0.9	0	2.1	0.9	1.8	0.5

The efficiency of slurry nitrogen, as calculated on the basis of nitrogen recovery in the grain yield, was positively affected by Didin. However, much of the slurry nitrogen seemed to be lost following the autumn application in spite of the Didin addition. The efficiency of total nitrogen in slurry injected in September without Didin averaged 5 %, that of slurry injected in September with Didin 11 % and that of slurry at its best in spring without Didin 20 %, with only a slight variation between the six experiments.

The value of Didin at different times of the year, as expressed as kg of nitrogen needed less in spring fertilization per kg of Didin, is presented in Table 14. Optimally, in combination with slurry injected in September, one kg of Didin corresponded to 2.6 kg of nitrogen in artificial fertilizer applied in the spring. On average, however, the value of Didin in combination with slurry injected in September was significantly less, about 1.5 kg of N / kg of Didin.

The effect of Didin varied considerably in different years. The year 1986 with a good effect by Didin was preceded by a cool autumn with low precipitation and early frost and snowcover. Nineteen-eighty-five, showing only a minor effect by Didin on the yield, again, was preceded by a warm and rainy autumn.

Notes on barley yields on plots without Didin

Time and application method seemed to have a different effect on the fertilizer value of slurry in the two different experimental soils. As the yield from unfertilized plots each year is expressed as 100, the average relative yields were as follows (2 experiments / site):

	sandy clay 1986 — 1987	sand 1986 — 1987
autumn, surface appl.	101	114
autumn, injection	124	133
spring, surface appl.	169	147
spring, injection	210	151
unfertilized yield, kg / ha	1400	2180

Autumn application of slurry produced higher yields on the sand soil at Rehtijärvi compared to the sandy clay soil at Ojainen even though the unfertilized yield at Rehtijärvi was rather high. In the case of spring application the reverse was true; far higher relative yield increases were obtained at Ojainen compared to Rehtijärvi.

Considering all six experiments, the advantage by slurry injection compared to surface application averaged 310 kg / ha of grain yield (85 % DM) for autumn applications and 350 kg / ha for spring applications. On the sandy clay soil in

1986 — 1987 the advantage by injection averaged 320 kg / ha in autumn and 590 kg / ha in spring. On the sand soil the corresponding figures were 410 kg / ha and 100 kg / ha. Yield increases by injection were rather high, indeed. As assessed from the yield curves, they corresponded to nitrogen in artificial fertilizer applied in spring as follows (kg N / ha):

		autumn appl.	spring appl.
sandy clay	1984	1	11
sandy clay	1985	5	29
sandy clay	1986	15	27
sand	1986	19	19
sandy clay	1987	7	34
sand	1987	29	< 0

Moreover, it is probable that the apparently negative effect of injection on the sand soil in spring 1987 was only due to overfertilization resulting in a falling yield curve (see yields by NPK treatments in Table 12).

Soil mineral nitrogen

Ammonium and nitrate nitrogen content in spring in plots fertilized with slurry in September is shown in Tables 15 — 19. Didin addition seemed to preserve slurry nitrogen in the soil layers examined, especially ammonium nitrogen in the uppermost layer (0 — 20 cm). In the sand soil at Rehtijärvi Didin increased ammonium content also at the depth of 20 — 40 cm, but had no effect on the NH_4-N content at 40 — 60 cm. Ammonium contents at the depth of 40 — 60 cm were about equal in all plots whether manured or not.

Didin did not affect soil nitrate content as clearly as it affected ammonium content. However, it can vividly be seen that in the sand soil at Rehtijärvi Didin prevented the increase of nitrate content in deeper soil layers.

Table 15. Amount of mineral nitrogen, kg / ha in the uppermost soil layer (0-20 cm) in the sandy clay soil at Ojainen 28. 5. 1985. 50 m³ / ha of cow slurry was applied 7. 9. 1984.

Didin kg / ha	Method of application	NO_3-N	NH_4-N	NO_3-N + NH_4-N
0	surface	17	5	22
26	"	18	6	24
0	injection	19	6	25
26	"	29	16	45
Unfertilized		14	6	20

Table 16. Amount of mineral nitrogen, kg / ha in different soil layers (0-20 cm, 20-40 cm, 40-60 cm) in the sandy clay soil at Ojainen 14. 5. 1986. 67 m³ / ha of cow slurry was applied 12. 9. 1985.

Didin kg / ha	Method of application	NO_3-N				NH_4-N				NO_3-N + NH_4-N			
		0-20	20-40	40-60	0-60	0-20	20-40	40-60	0-60	0-20	20-40	40-60	0-60
0	surface	11	7	3	21	3	2	1	6	14	9	4	27
22	"	13	8	2	23	6	5	1	12	19	12	4	35
0	injection	13	7	3	23	3	2	1	7	17	9	5	31
22	"	17	7	3	27	12	3	1	17	29	10	4	43
Unfertilized		9	6	2	17	3	3	2	8	12	9	3	24

Table 17. Amount of mineral nitrogen, kg / ha in different soil layers (0-20 cm, 20-40 cm, 40-60 cm) in the sand soil at Rehtijärvi 19. 5. 1986. 67 m^3 / ha of cow slurry was applied 12. 9. 1985.

Didin kg / ha	Method of application	NO_3-N				NH_4-N				NO_3-N + NH_4-N			
		0-20	20-40	40-60	0-60	0-20	20-40	40-60	0-60	0-20	20-40	40-60	0-60
0	surface	9	9	10	28	4	4	1	9	13	13	11	36
22	"	10	6	6	21	8	15	4	27	17	20	10	48
0	injection	9	10	8	28	4	3	2	8	13	13	10	36
22	"	11	7	4	21	9	30	4	42	20	37	7	63
Unfertilized		8	7	3	17	6	3	4	13	14	10	7	31

Table 18. Amount of mineral nitrogen, kg / ha in different soil layers (0-20 cm, 20-40 cm, 40-60 cm) in the sandy clay soil at Ojainen 12. 5. 1987. 67 m^3 / ha of cow slurry was applied 29. 9. 1986.

Didin kg / ha	Method of application	NO_3-N				NH_4-N				NO_3-N + NH_4-N			
		0-20	20-40	40-60	0-60	0-20	20-40	40-60	0-60	0-20	20-40	40-60	0-60
0	surface	7	5	3	14	6	2	1	8	12	6	4	23
11	"	7	5	4	17	9	5	2	15	16	10	6	32
22	"	6	5	4	15	18	2	2	22	24	7	5	37
0	injection	11	5	5	21	9	2	1	12	20	7	6	33
11	"	15	6	6	27	12	2	1	15	26	8	7	41
22	"	9	6	4	18	31	4	1	36	40	9	5	54
Unfertilized		5	4	3	12	4	1	1	7	9	5	4	19

Table 19. Amount of mineral nitrogen, kg / ha in different soil layers (0-20 cm, 20-40 cm, 40-60 cm) in the sand soil at Rehtijärvi 8. 5. 1987. 67 m^3 / ha of cow slurry was applied 29. 9. 1986.

Didin kg / ha	Method of application	NO_3-N				NH_4-N				NO_3-N + NH_4-N			
		0-20	20-40	40-60	0-60	0-20	20-40	40-60	0-60	0-20	20-40	40-60	0-60
0	surface	11	14	9	34	5	4	1	10	16	17	10	43
11	"	10	6	5	22	26	13	2	41	36	19	7	63
22	"	8	6	6	21	25	10	2	37	33	17	8	58
0	injection	11	14	10	34	20	11	2	33	30	25	12	67
11	"	11	10	6	26	37	26	2	65	48	36	8	91
22	"	9	7	5	21	24	12	2	37	33	18	7	58
Unfertilized		7	6	4	17	4	3	2	9	11	9	6	27

Pot experiments

Didin clearly retarded the nitrification of ammonium nitrogen in slurry during both experimental years (Tables 20 — 21). Without a Didin addition, the ammonium nitrogen of slurry applied until the end of September was practically totally nitrified before winter. With a Didin addition, nitrification could be retarded, and the later the autumn the lower the rate of Didin needed.

A difference between the two experiments can also be seen, which probably results from variable weather conditions. Ammonium nitrogen in slurry without Didin applied on 29. 10. 1985 was preserved well (89 % of mineral nitrogen as NH_4-N) whereas that in the slurry applied on 21. 10. 1984 was significantly poorer (25 % as NH_4-N). In 1984 there was a warm period from the middle of October until the middle of November with a soil temperature above 5 °C at the depth of 20 cm (Appendix 2). In 1985, the soil temperature at the depth of 20 cm dropped below 5 °C already on 26. 10. and stayed low throughout

Table 20. Percentage of ammonium nitrogen of total mineral nitrogen in soil in the pot experiment on 10. 1. 1985.
Rate of slurry was 3 dl / pot. Nitrogen amounts in control pots were subtracted before calculating the percentages.

Didin, mg / l	Date of manuring in autumn 1984			
of slurry	21.8.	21.9.	21. 10.	21.11.
0	0	0	25	91
222	59	83	100	100
444	76	97	100	100
667	100	100	100	100

Table 21. Percentage of ammonium nitrogen of total mineral nitrogen in soil in the pot experiment on 14. 1. 1986.
Rate of slurry was 2 dl / pot. Nitrogen amounts in control pots were subtracted before calculating the percentages.

Didin, mg / l	Date of manuring in autumn 1985				
of slurry	26. 8.	16. 9.	8. 10.	29.10.	19. 11.
0	2	5	19	89	86
200	5	45	68	100	100
400	33	100	81	100	100
600	64	84	100	100	100

DISCUSSION

In accordance with the literature, Didin preserved slurry nitrogen in the soil, and its effect was also seen in the higher grain yield of barley (AMBERGER 1981, AMBERGER et al. 1982a, 1982b, GÖRLITZ 1983, KJELLERUP 1986, 1987).

The effect of Didin was generally optimal when used with slurry injected in September. This is also logical, because slurry injection prevents ammonia volatilization. The effect of Didin on broadcast slurry is smaller simply because a portion of the ammonia is already lost by volatilization. Another factor strengthening the positive interaction between slurry injection and Didin addition is that Didin, as well as other nitrification inhibitors, increases ammonia volatilization (CORNFORTH and CHESNEY 1971, BUNDY and BREMNER 1974, RODGERS 1983, PRAKASA and PUTTANNA 1987).

The fact that Didin did not have any influence when applied with slurry in November — December results only from the low soil temperature which preserved ammonium nitrogen as such. This could be verified by the pot experiments. Slurry broadcast late in the autumn also always produced higher grain yields compared to slurry broadcast in September.

In two experiments, yield increases by Didin were found also with a spring application of slurry, notably in the experiment on sandy clay soil at Ojainen in 1987. This may be due to the exceptionally cool growing season when barley growth was extremely late compared to normal summers. In 1987 barley was harvested about one month later than normally. It is probable that Didin then prevented nitrate leaching during the growing season (MASON 1987). The fact that the effect of Didin was then greater on the sandy clay soil at Ojainen compared to the sand soil at Rehtijärvi, however, indicates that Didin can also prevent denitrification (VILSMEIER and AMBERGER 1982).

In some experiments, slight yield reductions by Didin applied with slurry in the spring were observed. In fact, dicyandiamide has been shown to be toxic to plants, retarding their early growth (MASON 1987). The same phenomenon could also be seen in preliminary pot experiments carried out at Jokioinen. In those experiments higher rates of Didin were clearly toxic to Italian ryegrass, but the effect vanished as soon as Didin decomposed in the soil. The transient toxic effect of Didin should be borne in mind if it is to be used in the spring.

The effect of Didin applied with slurry in September varied considerably in different experimental years. The best effect by Didin was found during a relatively cool autumn with slight precipitation in 1985. In the relatively warm autumn of 1984 the effect of Didin was considerably less due to its fast decomposition and / or its leaching. The results correspond well to those of BOCK et al. (1981).

According to this study, an advantage by Didin in southern Finland can be obtained with slurry application until the beginning of November. The lower rate of Didin (11 — 13 kg / ha) appeared to be more cost efficient compared to the higher (22 — 26 kg / ha). The recommended application rate in Finland, 15 kg / ha seems justified also on the basis of these results.

Didin was not found to be more effective on the sand soil at Rehtijärvi compared to the sandy clay soil at Ojainen, although this might be assumed (GÖRLITZ 1983, de la LANDE CREMER 1986). Leaching of Didin itself from the coarser soil may be an explanation (BOCK et al. 1981). On the other hand, it was peculiar that far higher yield increases by slurry applied in the autumn were obtained on sand soil compared to sandy clay soil. It is suggested that the significance of denitrification as a cause of nitrogen losses from slurry be examined more thoroughly in Finland. According to CHRISTENSEN (1983, 1985), nitrogen losses through denitrification from slurry clearly exceed those from artificial fertilizer.

Slurry injection, as compared to surface application, seemed to greatly improve the fertilizer value of slurry. The effect of injection in autumn was especially strong on the sand soil at Rehtijärvi, where it was assessed to correspond on average to 24 kg / ha of nitrogen in artificial fertilizer applied in spring. On the sandy clay soil at Ojainen the effect of injection in autumn corresponded to about 11 kg of N / ha. In spring, however, injection seemed to be more advantageous on sandy clay soil compared to sand soil. The effect of slurry injection compared to surface application at different times of the year on different soil types has not been studied earlier in Finland, nor much in other countries.

It can be deduced on the grounds of soil nitrogen determinations that Didin diminishes the leaching of nitrogen from slurry applied in autumn. Didin can be regarded as an environmentally advantageous additive also in Finland.

The profitability of Didin can be assessed by comparing yield increases by Didin to those by artificial fertilizer applied in spring. At its best, Didin used with slurry injected in September, corresponded to 2.6 kg of nitrogen / kg of Didin, but on average to about 1.5 kg / kg. As the price of Didin in Finland is 3 — 4-fold compared to that of nitrogen in most commonly used artificial fertilizers, its use as a slurry additive for the fertilization of barley does not seem justified.

However, Didin is a very promising additive and the results of this study by no means preclude its use in Finland. Because of its beneficial environmental effect the use of Didin might even be financially supportable. Besides, the efficiency of Didin should be examined also for other cultivated crops such as grasses and root crops. According to de la LANDE CREMER (1986) Didin may be especially effective when used with slurry to fertilize root crops. Experiments by GÖRLITZ et al. (1983), on the other hand, indicate an especially positive effect by Didin on winter cereals.

Although it was shown that Didin could not increase efficiency of slurry nitrogen sufficiently when used in autumn, the potential to preserve higher nitrogen amounts by Didin should be studied. Therefore, experiments with more concentrated slurries and manures should be carried out, for example with pig, poultry and fur animal manure.

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SELOSTUS

Didinin (disyandiamidi) vaikutus naudan lietelannan tehoon ohran lannoitteena

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Maatalouden tutkimuskeskus

Nitrifikaation estoaineen Didinin (disyandiamidi) vaikutusta naudan lietelannan tehoon ohran lannoitteena tutkittiin kuudessa kenttäkokeessa Jokioisilla vuosina 1983 — 1987. Koeruuduille levitettiin lietelantaa eri vuodenaikoina pintalevityksenä tai sijoittaen ilman Didiniä tai Didin-lisäyksen kanssa. Ensimmäisenä koevuonna Didinin määrä lietelannan ohella oli 30 kg / ha. Myöhempinä vuosina kokeiltiin kahta eri määrää (13 ja 26 kg / ha tai 11 ja 22 kg / ha). Kaksi kenttäkoetta tehtiin hienolla hiekalla ja neljä hietasavella. Kenttäkokeissa tutkittiin eri koetekijöiden vaikutusta ohran jyväsatoon ja sen typpipitoisuuteen sekä maan mineraalitypen määrään keväällä.

Lisäksi kahtena syksynä tehtiin astiakoe, jossa hietasavimaahan annettiin lietelannan ohella eri määriä Didiniä. Eri aikoina syksyä (elo — marraskuu) perustetut osakokeet säilytettiin pellolla maan routaantumiseen saakka. Astiakoemaista määritettiin nitrifioitumatta jääneen ammoniumtypen osuus maan mineraalitypen kokonaismäärästä.

Didin paransi useimmissa kenttäkokeissa syyskuussa levitetyn lietelannan lannoitusvaikutusta merkitsevästi. Paras vaikutus sillä oli viileänä ja verraten vähäsateisena syksynä syyskuussa sijoitetun lietelannan ohella annettuna. Marras — joulukuussa levitetyn lietelannan tehoon Didinillä ei juurikaan ollut vaikutusta. Keväällä levitetyn lietelannan ohella Didinillä oli huomattava vaikutus vain vuonna 1987, jolloin kasvukausi oli poikkeuksellisen viileä ja ohran kasvu tavanomaisesta hyvin paljon myöhässä. Pienempi määrä Didiniä (11 — 13 kg / ha) osoittautui suurempaa määrää (22 — 26 kg / ha) kannattavammaksi.

Syksyllä sijoitetun lietelannan ohella annettu pienempi Didin-määrä (11 — 13 kg / ha) vastasi lannoitusvaikutukseltaan kiloa kohden parhaimmillaan 2.6 kg, mutta keskimäärin 1.5 kg keväällä levitettyä typpeä. Didin on kilohinnaltaan kuitenkin 3 — 4-kertaa kalliimpaa kuin Y-lannoitteiden sisältämä typpi.

Astiakokeiden ja kenttäkokeiden maa-analyysien perusteella voitiin todeta, että Didin esti ammoniumtypen nitrifioitumista ja nitraatin kulkeutumista maassa. Didinillä lienee tästä syystä ympäristön pilaantumista estävä vaikutus myös Suomen oloissa. Astiakokeiden perusteella voitiin myös todeta, että nitrifikaation estoaineella voidaan saavuttaa hyötyä aina marraskuun alkuun levitetyn lietelannan ohella.

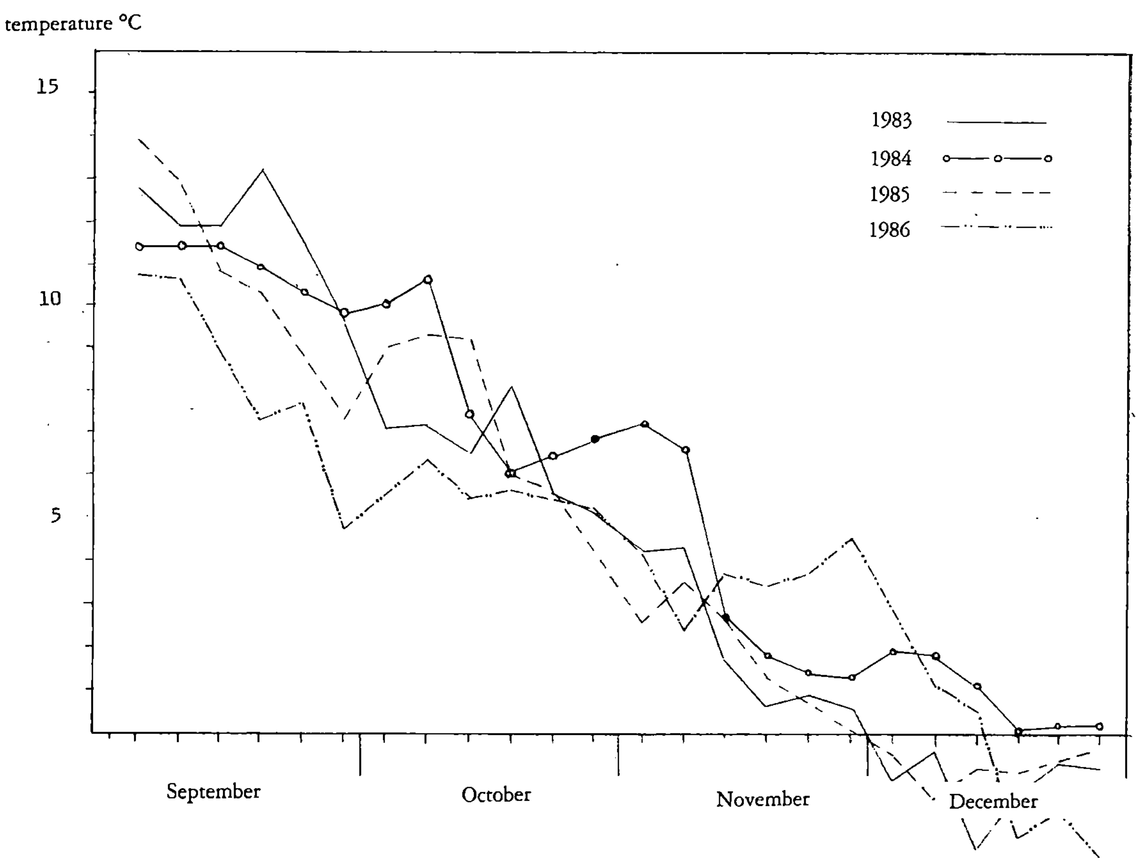
Keväällä levitetty lietelanta oli ohran lannoitteena huomattavasti syksyllä levitettyä tehokkaampaa. Edelleen lietelannan sijoitus osoittautui huomattavasti pintalevitystä tehokkaammaksi. Syyskuun levityksissä sijoitus antoi pintalevitykseen verrattuna keskimäärin 310 kg / ha sadonlisäyksen ja toukokuussa 350 kg / ha. Sijoituksella oli syksyllä erityisen edullinen vaikutus hiekkamaalla, keväällä taas savimaalla.

Table 1. Treatments with slurry and Didin in field experiments.

Appendix 1. Information on the weather at the Jokioinen observatory.

	1983	1984	1985	1986	1987	1931—1960
	Monthly precipitation, mm					
May	44	66	43	52	38	39
June	84	113	41	11	81	42
July	41	91	55	65	68	70
August	58	69	119	110	83	74
September	86	77	51	102	120	61
October	63	99	36	74	43	61
November	37	57	55	93	38	51
December	76	40	52	47	36	41
	Monthly mean temperature, °C					
May	11.0	12.0	8.6	10.5	7.6	8.8
June	13.3	13.1	13.2	16.3	12.1	13.7
July	16.6	14.8	15.3	16.2	14.8	16.2
August	15.0	13.8	15.5	12.9	11.7	14.7
September	11.0	9.2	8.9	6.4	8.4	9.7
October	5.4	6.6	6.4	5.2	6.4	4.3
November	-2.4	0.8	-2.0	3.4	-0.7	-0.1
December	-3.6	-2.3	-7.0	-8.3	-5.3	-3.5
	Beginning of persistent snow cover					
	7.12.	27.12.	23.11.	13.12.		

Appendix 2. Soil temperature in the depth of 20 cm at Jokioinen observatory in autumn 1983—1986.



ANNALES AGRICULTURAE FENNIAE, VOL. 28: 151—160 (1989)

Seria AGROGEOLOGIA ET -CHIMICA N. 153 — Sarja MAA JA LANNOITUS n:o 153

EFFECTS OF Mo FERTILIZATION ON TIMOTHY *(PHLEUM PRATENSE* L.) GROWTH IN PEAT SOIL.

LEILA URVAS

URVAS, L. 1988. **Effects of Mo fertilization on timothy *(Phleum pratense* L.) growth in peat soil.** Ann. Agric. Fenn. 28: 151 — 160. (Agric. Res. Centre, Inst. Crop and Soil., SF-31600 Jokioinen, Finland.)

In a pot experiment on Mo poor peat Mo fertilization doubled the yield of timothy. Total uptake of Mo by timothy was 10 to 19 times higher than that without Mo fertilization.

Mo fertilization seemed to restrain the relative uptake of K, Zn and Cu by timothy thus improving the Cu / Mo ratio of the crop.

It is possible to increase the Mo content of peat soil manyfold by Mo fertilization. Mo content of the peat soil receiving no Mo fertilization was the same before the experiment and after.

Index words: peat soil, molybdenum, timothy, micronutrient content.

INTRODUCTION

Molybdenum (Mo) is one of the nutrient elements considered to be essential for the growth of plants. The biological importance of Mo was understood, when BORTELS (1930) showed that the element was highly beneficial in the fixation of N_2 by nitrogen-fixing bacteria. The essentiality of Mo to higher plants was first demonstrated by ARNON and STOUT (1939). During the last two decades, the damage to plants caused by Mo deficiency has been studied all over the world (GUPTA and LIPSETT 1981). Mo has been found in at least five enzymes, three of which occur in plants (MARJANEN 1972). Plants need Mo for their protein metabolism. A high No_3 content has been found to increase Mo reguirements in soil (GUPTA and LIPSETT 1981). By liming and P fertilization it is possible to increase the solubility and availability of Mo in soil (MARJANEN et al. 1979). On the other hand, these measures also increase the leaching of Mo, thus reducing the total content of Mo in soil.

The range of 0,01 — 0,10 mg / l Mo in soil is considered to be normal in Finland (SILLANPÄÄ et al. 1975). During the 1970s no notable deficiency of Mo occurred in Finnish soils. Only two per cent of the soil material collected from throughout the country was below the concentration level of 0,01 mg / l, and most of the figures for Mo content fell within a fairly narrow range, 0,01 — 0,06 mg / l of soil (SIPPOLA and TARES 1978). The mean value for soluble Mo (0,047 ± 0,076 mg / l) was nearly the same as that previously observed (0,052 mg / l) in Finnish soils (SILLANPÄÄ et al. 1975). The mean Mo content in *Carex* peat soils was 0,06 ± 0,06 mg / l (SIPPOLA and TARES 1978).

The consequences of heavy N fertilization on grasslands, including the deprivation of potassium and some micronutrients became apparent in the 1970s (SILLANPÄÄ 1974). At the same time, the general use of combined fertilizers containing relatively more P than K as compared to the amounts taken up by timothy, has increased the P content in soil. Because P increases the solubility of Mo in soil and stimulates Mo uptake by plants (KABATA-PENDIAS and PENDIAS 1984), the Mo reserves of peat soils in northern Finland have decreased and deficiencies have begun to appear (MARJANEN et al. 1979). In addition, some experiments carried out in Karelia, in the USSR, have shown Mo fertilization to be essential to grasslands (KALININA et al. 1984).

In the 1970s Finnish timothy *(Phleum pratense* L.) contained Mo 0,36 — 0,67 mg / kg DM, according to PAASIKALLIO (1978) and 0,4 — 0,9 ppm according to YLÄRANTA and SILLANPÄÄ (1984). The international values range between 0,33 — 1,5 ppm (KABATA-PENDIAS and PENDIAS 1984). As reported by GUPTA and LIPSETT (1981) the deficiency limit of Mo for timothy might be 0,11 ppm. The toxic limit for cattle is 10 mg Mo / kg DM (ZAVADIL 1984). Such levels are unlikely in Finland, however.

The aim of this study was to investigate by means of a pot experiment the effects of Mo fertilization on the growth and mineral content of timothy grown on peat poor in Mo, as well as to determine its Mo content.

MATERIAL AND METHODS

Peat soil employed in the pot experiment originated from northern Finland from a field where timothy did not thrive. Its $pH(H_2O)$ was 4,5 and electrical conductivity 15,4 mS / cm. The peat soil contained the following amounts of macronutrients extractable by AAAc, i.e. acid ammonium acetate (VUORINEN and MÄKITIE 1955) and micronutrients soluble in AAAc-EDTA (LAKANEN and ERVIÖ 1971):

Calcium (Ca)	600	mg / l
Potassium (K)	78	"
Magnesium (Mg)	55	"
Phosphorus (P)	17,3	"
Zinc (Zn)	0,48	"
Boron (B)	0,8	mg / l
Manganese (Mn)	2,1	"
Iron (Fe)	862	"
Copper (Cu)	8,4	"
Molybdenum (Mo)	0,012	"

The experiment had four replicates. Each pot (Kick / Brauckmann's) contained seven litres of peat, treated by the following basic fertilization: 1 600 mg nitrogen as NH_4NO_3, phosphorus 500 mg as KH_2PO_4, potassium 1 900 mg as KH_2PO_4, KCl and K_2SO_4, magnesium 200 mg as $MgCl_2 \cdot 6H_2O$, sulphur 200 mg as K_2SO_4, copper 12 mg as $CuCl_2 \cdot 2H_2O$, zinc 6 mg as $ZnNa_2$ – EDTA, cobalt 3 mg as $CoCl_2 \cdot 6H_2O$ and manganese 12 or 24 mg as $MnCl_2 \cdot 2H_2O$.

Mo fertilization treatments were as follows:

Mo 0: no Mo added / pot
Mo 1: 4 mg Mo / pot as $Na_2MoO_4 \cdot 2H_2O$
Mo 2: 8 " " " " " "

As field applications, the amounts of Mo added corresponded to 2.9 (Mo 1) and 5.8. (Mo 2) kg / ha $Na_2MoO_4 \cdot 2H_2O$

After the fertilizers were mixed into the peat, the pots were filled and irrigated. Bothnia timothy was used as a test plant and sown onto the peat at the beginning of May. After sprouting the pots were transferred outdoors to an open growing frame. Deionized water was used for irrigation.

Three cuts were performed. One day after the first and second cuts the following nutrients were added to each pot: 800 mg N, 250 mg P, 950 mg K and 100 mg Mg.

Yields were weighed and the plant samples analyzed by the methods used by the Department of Soil Science, Agricultural Research Centre (SILLANPÄÄ 1982).

The results were tested by analysis of variance and the significance of differences between treatments by Tukey's t-test (HSD 5 %).

RESULTS

Timothy yields

The crop yield of the first timothy cut without Mo fertilization was only one third of those, receiving Mo fertilization (Table 1). In the second and third cuts the crops were about half of the Mo 1 and Mo 2 treatments.

Contents of mineral elements in timothy

The Mo contents of timothy in the crops of the first and second cuts were 10-fold in the Mo 2 treatment compared with that in the Mo 0 treatment (Fig. 1). The respective proportion in the third cut was one to three. The timothy crop of

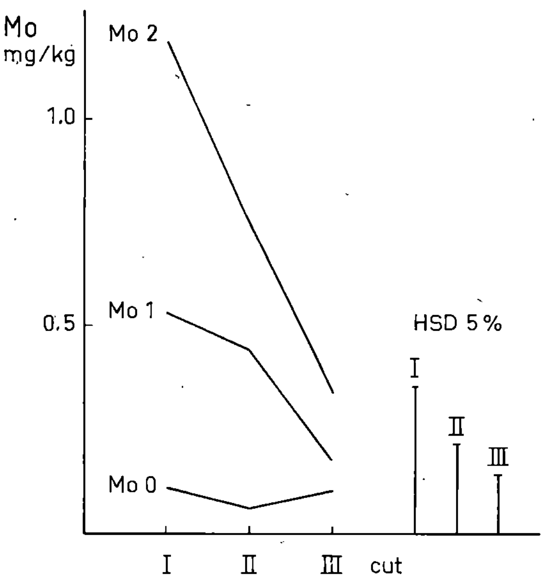


Fig. 1. Mo content of timothy (mg / kg DM) in three Mo-fertilization levels and three cuts.

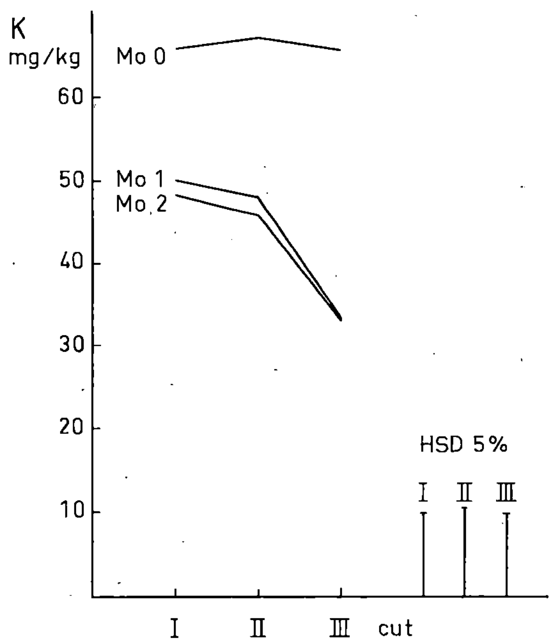


Fig. 2. K content of timothy (mg / kg DM) in three Mo-fertilization levels and three cuts.

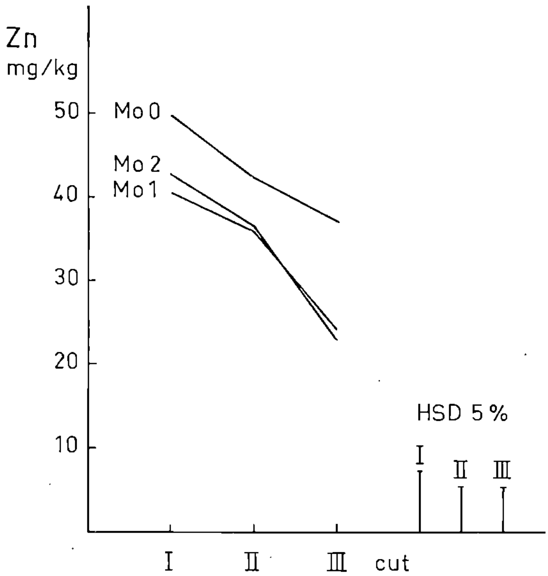


Fig. 3. Zn content of timothy (mg / kg DM) in three Mo-fertilization levels and three cuts.

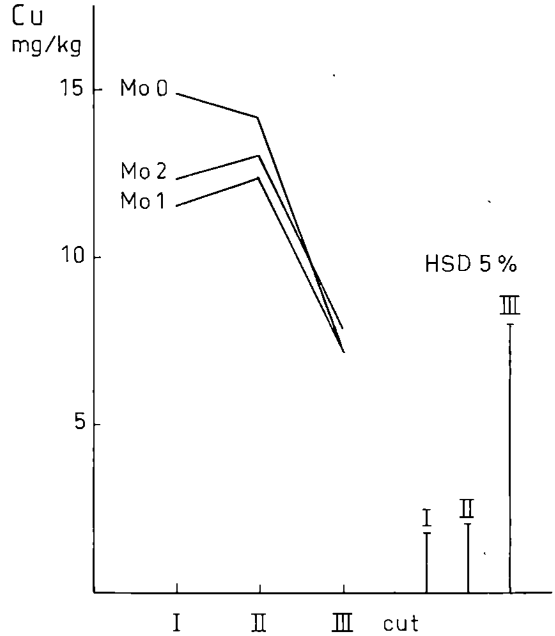


Fig. 4. Cu content of timothy (mg / kg DM) in three Mo-fertilization and three cuts.

the Mo 1 treatment had a molybdenum content about half that of the Mo 2 treatment. By the fertilized treatments, the Mo content of timothy appeared to be the lowest at the end of the growing season. The Mo content of the Mo 1 treatment was in the third cut nearly as low as that of the Mo 0 treatment.

Mo fertilization significantly decreased the potassium and cobalt contents of timothy in all three cuts (Fig. 2). A lowering effect on the zinc content of timothy can also be seen (Fig. 3). The copper contents of timothy were significantly smaller only in the crops of the Mo 1 treatment in the first cut, and the Mo 2 treatment in the first and second cuts (Fig. 4).

Mo fertilization does not seem to have any effect on the magnesium content of timothy and its effect on the calcium and phosphorus contents of timothy is not significant.

The molybdenum content of timothy was highest in the first cut and lowest in the third cut of every treatment. Likewise the copper and zinc contents of timothy decreased from the first cut to the third. The diminishing trend in potassium content was similar for Mo 1 and Mo 2 treatments.

Uptake of mineral elements

The uptake of molybdenum from Mo 0 peat was slight, but about the same in every cut (Table 1). The Mo uptake of the two Mo levels was proportionally equal. Mo levels in both Mo treatments decreased from the first cut to the last by nearly one fourth. The apparent recoveries of fertilizer molybdenum (Mo 1 — Mo 0 and Mo 2 — Mo 0) were 8.0 and 8.6 ‰, respectively. In peat, low in molybdenum, the higher rate of Mo fertilizer seemed to be more advisable than the lower.

Mo fertilization also increased the total uptake of Co, Cu, Fe, Mn and Zn, but clearly only in the first and second cuts.

Table 1. Yields (g / pot DM) of different Mo fertilization treatments and mineral element uptakes by the crops.

Element	Cut no	Mo 0	Mo 1	Mo 2	HSD 5 %
Dry matter	1 st	9.9	32.4	32.0	5.1
yield	2 nd	17.1	28.8	29.5	8.4
g / pot	3 rd	16.2	30.2	32.0	10.7
	Total	43.2	91.4	93.5	16.5
Mo uptake	1 st	1.1	17.4	38.4	19.7
µg / pot	2 nd	1.0	12.6	22.5	
	3 rd	1.1	5.1	10.9	
	Total	3.2	35.1	71.8	19.7
Cu uptake	1 st	145	372	393	59
µg / pot	2 nd	242	354	349	79
	3 rd	118	218	248	158
	Total	506	944	990	189
Zn uptake	1 st	480	1 309	1 365	162
µg / pot	2 nd	719	1 031	1 073	226
	3 rd	590	732	733	333
	Total	1 789	3 074	3 169	518
P uptake	1 st	82	211	213	24
mg / pot	2 nd	131	209	211	50
	3 rd	111	171	184	54
	Total	324	591	608	24
Ca uptake	1 st	21.8	90.9	104.9	32.4
mg / pot	2 nd	40.4	89.4	87.6	25.1
	3 rd	48.8	75.9	83.2	41.1
	Total	111.0	256.2	275.7	59.4
K uptake	1 st	636	1 619	1 545	200
mg / pot	2 nd	1 132	1 371	1 340	338
	3 rd	1 034	1 004	1 039	428
	Total	2 801	3 994	3 923	193
Mg uptake	1 st	18.6	62.8	68.0	14.2
mg / pot	2 nd	39.3	70.1	72.2	20.8
	3 rd	44.4	55.6	65.6	37.2
	Total	102.3	188.5	205.8	52.8
Co uptake	1 st	5.5	16.4	15.9	
µg / pot	2 nd	12.2	15.8	14.9	
	3 rd	15.5	10.5	11.4	
	Total	33	42.7	42.1	
Mn uptake	1 st	604	1 945	2 120	433
µg / pot	2 nd	1 014	2 077	2 073	551
	3 rd	913	1 249	1 431	695
	Total	2 530	5 270	5 625	1 204
Fe uptake	1 st	747	2 049	2 149	440
µg / pot	2 nd	1 001	1 760	1 752	347
	3 rd	1 328	1 718	1 819	852
	Total	3 076	5 527	5 719	1 140

Table 2. Mineral element contents of timothy grass *(Phleum pratense* L.).

Element	Cut no	Mo 0	Mo 1	Mo 2	HSD 5 %
Ca mg / g DM	1 st	2.2	2.8	3.2	0.6
	2 nd	2.4	3.1	3.0	0.4
	3 rd	2.9	2.5	2.6	0.6
Mg mg / g DM	1 st	1.9	1.9	2.1	0.2
	2 nd	2.3	2.4	2.4	0.4
	3 rd	2.6	1.8	2.0	0.7
K mg / g DM	1 st	65.9	50.0	48.4	9.8
	2 nd	67.1	48.1	45.8	10.4
	3 rd	65.6	33.5	33.0	9.8
P mg / g DM	1 st	8.5	6.5	6.7	1.3
	2 nd	7.7	7.3	7.2	0.9
	3 rd	7.2	5.7	5.8	1.4
Mo mg / kg DM	1 st	0.11	0.53	1.19	0.35
	2 nd	0.06	0.44	0.75	0.21
	3 rd	0.10	0.17	0.34	0.14
Cu mg / kg DM	1 st	14.8	11.5	12.3	1.7
	2 nd	14.3	12.4	11.9	2.0
	3 rd	7.2	7.2	7.8	8.0
Zn mg / kg DM	1 st	49.7	40.5	42.7	7.3
	2 nd	42.4	36.0	36.5	5.4
	3 rd	37.2	24.4	22.9	5.4
Co mg / kg DM	1 st	0.56	0.51	0.50	0.05
	2 nd	0.72	0.55	0.51	0.14
	3 rd	0.98	0.35	0.35	0.12
Mn mg / kg DM	1 st	62.2	59.9	66.0	8.6
	2 nd	60.0	71.8	70.5	7.2
	3 rd	56.0	41.4	44.4	11.6
Fe mg / kg DM	1 st	76.7	63.1	66.9	9.6
	2 nd	59.6	61.3	59.8	8.8
	3 rd	80.8	56.9	56.8	15.9

Effect of Mo fertilization on nutrient level in peat soil

The effect of fertilization on the soil is best seen in the soil of the Mo 0 treatment (Table 3), because growth and hence the uptake of nutrients were slight due to Mo deficiency. Especially the potassium and phosphorus contents of the Mo 0 treatment were higher compared to fertilized treatments. Heavy fertilization increased electrical conductivity by six units and pH decreased by 0.8 units in the Mo 0 treatment.

The Mo 0 treatment had the same Mo-level at the beginning and end of the trial (0.012 — 0.017 mg / l). Except for the good timothy crop of the Mo 1 and Mo 2 treatments, the Mo content of the

Table 3. pH and mineral element contents of peat soil before and after the pot experiment.

	At the beginning of the exp.	After growing season treatments Mo 0	Mo 1	Mo 2	HSD 5 %
pH (H_2O)	4.5	3.7	4.0	4.0	
El. cond. mS / cm x 10^{-1}	1.5	7.5	3.3	3.7	
Calcium mg / l	600	544	556	588	67
Potassium "	78	189	48	39	97
Magnesium "	55	101	90	86	10
Phosphorus "	17	62	37	29	9
Molybdenum mg / l	0.012	0.017	0.300	0.489	0.08
Cobalt "	0.11	0.53	0.56	0.53	0.08
Copper "	8.4	9.5	9.8	9.4	3.1
Iron "	862	759	760	722	82
Manganese "	2.0	3.1	2.4	2.7	0.8
Zinc "	0.48	1.02	0.76	0.74	0.22

Mo 1 treatment was 0.30 mg / l and that of Mo 2 0.49 mg / l. Besides molybdenum, the only other micronutrient whose content was affected by Mo fertilization was zinc. After three cuts there was no difference between the Zn content of the Mo 1 and Mo 2 treatments in soil, but the Zn content of Mo 0 was significantly higher than that of Mo fertilized pots.

DISCUSSION

The nutrient uptake of plants in a pot experiment is more effective than that in the field, because the water requirement of the plants is guaranteed by daily watering. The effect of Mo fertilization on the crop and on the Mo contents of timothy also are clearer because the peat used in this pot experiment was genuinely poor in molybdenum (0.012 mg / l). The average molybdenum content of Finnish peat soils is usually 0.06 mg / l (SIPPOLA and TARES 1978). Peat as poor in molybdenum as that used in the present study can only be found in Lapland from timothy fields, where heavy N-fertilization has been applied (MARJANEN et al. 1979, SILLANPÄÄ 1974).

Mo fertilization increased total timothy yields by 111 and 116 per cent in this pot experiment. In earlier studies, where mineral soils had sufficient molybdenum, the addition of molybdenum did not increase yields (JAAKKOLA 1972), but in perennial rye grass the uptake of molybdenum was greater with supplemental molybdenum than without it. In this study, also molybdenum uptake by timothy from peat was only 10 mg / pot, but that from Mo supplemented peat was 35 and 72 mg / pot. The differences are clear.

In consideration of the different yields by the various treatments the uptakes of macronutrients counted per pot differ considerably from each other (Table 1). The differences between the total amounts of Ca, Mg, K and P, taken up by the crops from Mo-fertilized pots and Mo 0-pots were greater than the corresponding HSD 5 %.

The differences between the Mo 1 and Mo 2 treatments were insignificant.

Not only the higher yields, but also the greater contents of molybdenum in timothy caused the differences in uptakes. The Mo content of the timothy crop of the Mo 0 treatment was below the proposed deficiency limit (0.11 ppm) for timothy (GUPTA and LIPSETT 1981), when the Mo contents of the Mo 1 and Mo 2 treatments were 0.38 and 0.76 mg / kg DM, respectively. Usually the molybdenum content of Finnish timothy grown in the field ranges between 0.4 to 0.7 mg / kg DM (PAASIKALLIO 1978). In another pot experiment the Mo content of timothy rose to 1.9 mg / kg DM (URVAS 1985) with the same fertilization as that in the present study. It appears to be easy to improve Mo uptake by Mo fertilization. The rate may range by up to 6 kg / ha sodiummolybdate depending on soil content without causing excessive levels in plants. Earlier recommendations were 1 kg Na_2 $MoO_4 \cdot 2H_2O$ (MARJANEN et al. 1979).

According to BERGMAN (1968) the relationship between the copper and molybdenum contents of timothy ranges from 15:1 to 45:1. The mean Cu / Mo ratio of Finnish timothy has been found to vary from 5.3 to 29.6 (PAASIKALLIO 1978). The highest ratios were in Lapland, where MARJANEN (1972) also found very high ratios, 150:1 or 200:1, in farms employing heavy N-fertilization. In this study, the Cu / Mo ratio varied from 72:1 to 238:1 in the Mo 0 treatment. In the timothy of the Mo 1 treatment it was 42:1 — 22:1 and in the Mo 2 treatment 23:1 — 10:1. The latter ratios correspond to normal ratios for Finnish timothy and recommendations concerning cattle feed. In animal husbandry it has been found that copper alleviates molybdenum toxity and by feeding supplemental Mo it is possible to diminish the transfer of Cu from the ewe to the lamb (GUPTA and LIPSETT 1981). In plants there exists a mutual antagonism between Cu and Mo with applications of one element depressing the uptake of the other (MACKAY et al. 1966).

Mo fertilization seemed to decrease the potassium contents of timothy. It is difficult to determine to what extent potassium fertilization can be used in peat soils poor in potassium, without also affecting the grass which already has an overly high K content (over 3 %). In practice, we have already found that with micronutrient fertilization the K content of timothy was decreased in one case where the amount of extra K fertilization was 200 kg / ha (SOINI and URVAS 1984). In light of these results showing that Mo fertilization decreased the K content of timothy, it might be possible to recommend Mo fertilization in order to limit excessive potassium uptake by timothy grass.

Molybdenum fertilization seems to have an effect on the uptake of zinc and cobalt by timothy. The total uptake of these elements increased, but their contents in timothy were lower in the fertilized treatments than in Mo 0.

In many heavily nitrogen fertilized peat soils in Lapland, the rather high phosphorus content has increased the solubility of molybdenum in soil and on the other hand stimulated Mo uptake by timothy resulting in a molybdenum deficiency over time. The peat used in this study had an adequate phosphorus level and was poor in molybdenum. When normal fertilization was applied, P contents became excessive, especially in the Mo 0 treatment (62 mg / l). That is one reason why the rise in electrical conductivity was too high.

The copper content of peat was 8.4 mg / l at the beginning of the experiment which indicates good Cu supply. This is most likely due to Cu fertilization. That accounts for the Cu / Mo ratio in timothy of the Mo 0 treatment being abnormally high. With Mo fertilization we could lower this ratio to normal and after the experiment also the molybdenum contents in soil increased to 0.3 and 0.5 mg / l, being above higher than the present recommendations (ANON. 1986). According to MACKAY et al. (1966), if one nutrient is in excess, the surplus effect should be alleviated

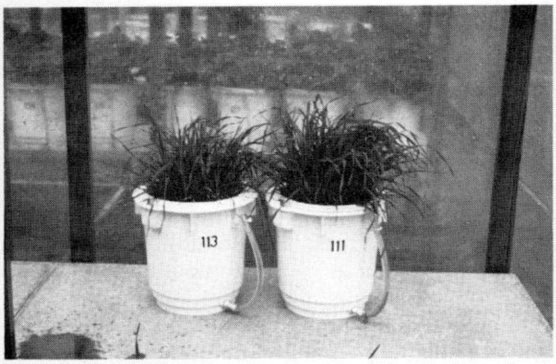
 

Fig. 5. Effect of liming on timothy growing in peat poor in molybdenum. Pots 113 and 112 were unlimed and pots 111 and 110 limed, in 1984 (left) and 1985 (right).

by application of the other, or if one nutrient is deficient as Mo here, applications of the other (here Cu) should aggravate the deficiency. In this study Cu fertilization of peat rich in copper and poor in molybdenum aggravated Mo deficiency in the Mo 0 treatment.

At the beginning of the study the calcium content of peat was only 600 mg / l and later less, which also could have restricted the solubility of molybdenum in this study. According to JAAKKOLA (1972) liming evidently improves the availability of both applied and native molybdenum in the soil. In addition to this study, we had two pots with similar fertilization as in the Mo 0 treatment but with liming (Fig. 5). In this case also, timothy growing on peat poor in molybdenum did not suffer due to Mo deficiency. After liming in the first summer the Mo content of timothy was 0,9 mg / kg, but in the following summer only 0,08 mg / kg DM. If the total reserves of Mo in soil are low, Mo supplement is necessary.

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SELOSTUS

Molybdeenin puutos turvemaalla

LEILA URVAS

Maatalouden tutkimuskeskus

Astiakokeella selviteltiin kahden molybdeenilannoitemäärän (2,9 ja 5,8 kg / ha Na_2MoO_4 $2H_2O$) vaikutusta timotein (*Phleum pratense* L.) ravinteiden ottoon turvemaalla (0,012 mg / l Mo) sekä timotein ja turpeen kivennäisainepitoisuuteen.

Molybdeenilannoitus kaksinkertaisti timotein kokonaissadot. Molybdeenilannoituksen saaneen timotein molybdeenipitoisuus oli nelin- tai kahdeksankertainen verrattuna lannoittamattomaan timoteihin riippuen lannoitemäärästä. Koko sadon ottamat molybdeenimäärät olivat jopa 10- tai 19-kertaiset lannoitetuilla koejäsenillä verrattuna lannoittamattomaan, koska molybdeeni nosti sekä timoteisatoa että sen molybdeenipitoisuutta.

Molybdeeniköyhällä turvemaalla (0,012 mg / l Mo) molybdeenilannoituksen saaneiden astioiden sadon K-, Zn- ja Cu-pitoisuudet olivat alempia kuin lannoittamattomien astioiden sadossa, myös K-pitoisuus ja Cu / Mo-suhde olivat parempia rehuksi sopivuuden kannalta.

Kokeen jälkeen otetuissa maanäytteissä Mo 0 -koejäsenellä molybdeenipitoisuus oli pysynyt samana, mutta muiden ravinteiden määrät olivat nousseet huomattavasti eli jääneet maahan heikon kasvuston vuoksi. Molybdeenia saaneilla koejäsenillä molybdeenipitoisuus oli noussut huomattavasti.

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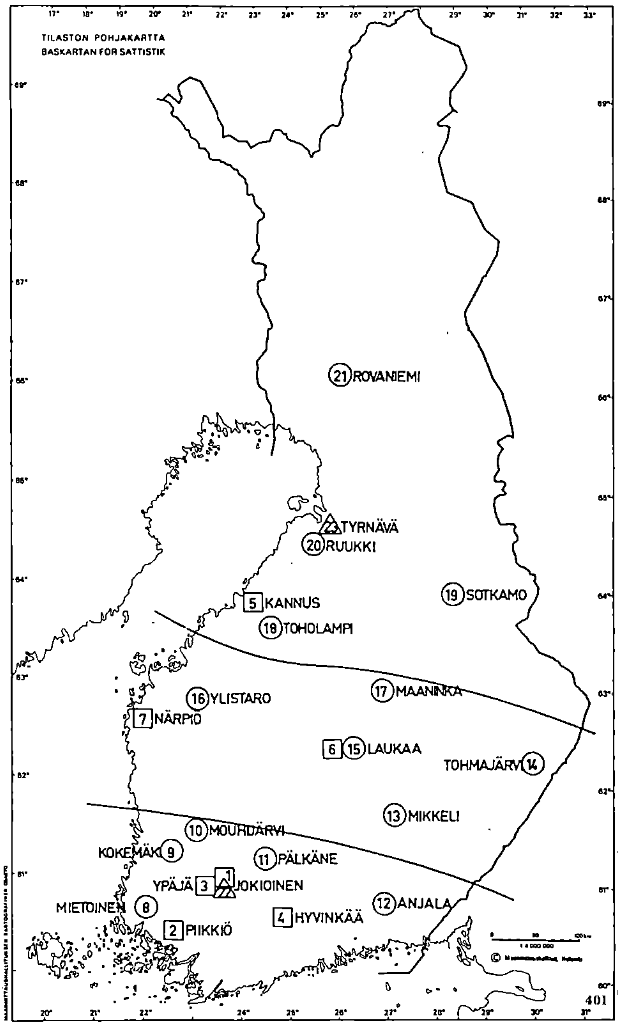

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