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ANNALES AGRICULTURAE FENNIAE, VOL. 26: 167—170 (1987)
Seria ANIMALIA NOCENTIA N. 125 — Sarja TUHOELÄIMET n:o 125

Research note

PESTS OF CULTIVATED PLANTS IN FINLAND DURING 1986

MARTTI MARKKULA

MARKKULA, M. 1987. **Pests of cultivated plants in Finland during 1986.** Ann. Agric. Fenn. 26: 167—170. (Agric. Res. Centre, Dept. Pest. Inv., SF-31600 Jokioinen, Finland.)

Damage caused by nearly fifty insect and other animal pests to cereals, forage plants, root crops, vegetables, rape, sugar beet, apple, berries and other cultivated plants in Finland during 1986 is reported based on the results of questionnaire surveys.

The beginning of the growing period was warmer than usual and extremely dry. Midsummer was approximately normal but the end of the growing period was colder and rainier than usual. The average abundance of all pests, in terms of a five-point scale, was 2,4., i.e. nearly the same as the average of 2,5 during the period from 1965 to 1984.

Sitodiplosis mosellana continued to cause damage to the cereal fields of southern Finland and use of insecticides was necessary on many farms. The area of damage expanded westwards. Populations of *Rhopalosiphum padi* were very small.

Of the pests to root crops and vegetables, *Trioza apicalis* and *Psila rosae* were more abundant than usual, but *Plutella xylostella* was extremely scarce.

Argyresthia conjugella and *Cydia pomonella* did not cause significant damage to apple orchards. *Microtus agrestis* reached a peak in its population growth.

Index words: plant pests, severity of damage, *Sitodiplosis mosellana, Rhopalosiphum padi, Trioza apicalis, Psila rosae, Plutella xylostella, Argyresthia conjugella, Cydia pomonella, Microtus agrestis.*

INTRODUCTION

The survey is based on replies to inquiries sent to the advisers of Agricultural Advisory Centres. The network of 200 advisers covers all 461 municipalities of the country. During previous years, four inquiries were sent to advisers during the growing period. This year, however, the inquiry forms were simplified and only three inquiries were sent. The replies were as follows:

	Replies	%	Municipalities	%
Spring inquiry	118	50	160	35
Summer inquiry	93	43	130	28
Autumn inquiry	95	45	129	28

For simplification purposes, an appraisal of the general frequency of damage was omitted. Thus each inquiry requested only an estimate of the severity of the 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 a scale of 1—5 was employed: very sparse (1), sparse (2), normal (3), abundant (4), very abundant (5). The same inquiry requested an estimate of the percentage of apples damaged by *Argyresthia conjugella* and *Cydia pomonella* and pea pods damaged by *Cydia nigricana.* The advisers reported the pest situation in a total of 207 municipalities.

The beginning of May was exceptionally warm in southern and central Finland and plant growth started well. June was very warm, about three degrees warmer than usual, and rainfall was slight. Midsummer was quite favourable for plant growth, but from the middle of August onward the weather was colder and rainier than usual, too.

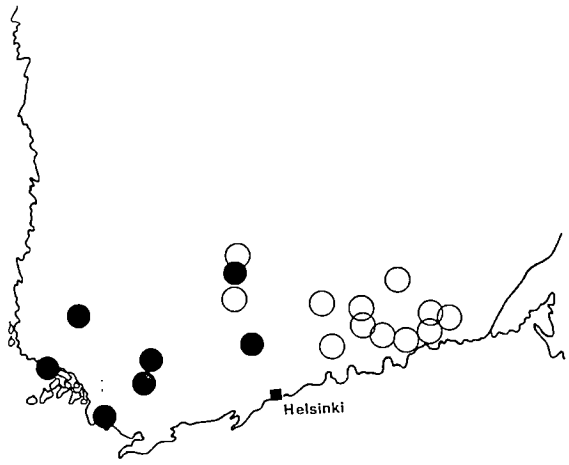

Fig. 1. The localities of the most severe infestations of the orange wheat blossom midge *Sitodiplosis mosellana* in 1985 (open circles) and in 1986 (filled circles). Each circle denotes a locality, in which the abundance of the midge was greater than the economic treshold for control (1 larva/wheat ear). (The map prepared by researcher SIRPA KURPPA).

Results of the inquiries

For the entire growing period, the average abundance of pests, in terms of the 1—5 scale, was 2,4, i.e. nearly the same as the average of 2,5 during the period from 1965 to 1984.

As in previous years, a forecast was presented in the spring on the summer abundance of *Rhopalosiphum padi.* It indicated that no damage was to be expected, and by the beginning of July it was clear that the forecast had been accurate. The bird cherry aphid was very scarce and required control only in fields on the southern coast, which was affected by aphids brought by winds from the southern side of the Gulf of Finland.

The orange wheat blossom midge (*Sitodiplosis mosellana* Geh.) continued to occur in large numbers in the wheat fields of southern Finland. The damage from 1983 to 1985 was concentrated in the eastern part of Uusimaa province (KURPPA 1986), but in 1986 the most abundant populations were found in south-western Finland (Fig. 1). The occurrence of this species has not essentially diminished in the areas noted above, but chemical control has reduced populations to below the economic threshold (1 larva/wheat ear).

The rape blossom beetle (*Meligethes aeneus*) was markedly less abundant than in the previous year and generally during the last few years. However, chemical control was usually necessary in rape fields. There were no alarming reports of damage to cauliflower (cf. HOKKANEN et al. 1986).

For sugarbeet the amount of pests was normal. Nowadays, there are no great differences in the yearly abundance of these pests, as three regular dimethoate sprayings keep the insect populations under control.

The pest most detrimental to pea, the pea moth (*Cydia nigricana*), seems to have lost some of its economic importance during the last few years. A reduction in the area of pea cultivated, the use of early pea varieties and the cultivation of peas for the fresh vegetable market have all reduced moth populations. When the pea crop is harvested early, the majority of larvae do not reach the adult stage, thus diminishing the population. The accurate and efficient spraying procedures currently employed, made possible by the use of pheromone trap forecasts, have also helped to reduce pea moth populations.

For vegetable crops, the pest situation was normal. The most destructive pests of carrot, the carrot psylla (*Trioza apicalis*) and the carrot rust fly (*Psila rosae*), were slightly more numerous than the 20-year average. The cabbage moth (*Plutella xylostella*) was extremely scarce.

Insects caused only minor damage to apple orchards. The apple fruit minor (*Argyresthia conjugella*) and the apple moth (*Cydia pomonella*) were equally abundant as in the previous year, being markedly less common than the 20-year average. The damage estimates of advisers indicate the following:

	percentage of apples damaged			replies
	1986	1985	1965—84	1986
Argyresthia conjugella	14	12	28	18
Cydia pomonella	14	13	19	17

The orchard mite caused more damage in apple orchards than that in many years (researcher Tuomo Tuovinen, oral communication), although this is not evident from the results.

The field vole (*Microtus agrestis*) reached a peak in its abundance. The severity of damage for the previous year averaged 0,7 compared to 3,6 for 1986. However, damage to apple orchards was not great, since almost all professional farmers nowadays place protective collars around the tree trunks. Many home gardeners, too, quite commonly protect their apple trees in this way. In reforested areas damage was again fairly extensive.

Pest damage to berry plants was slightly less than normal.

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 1986	Severity of damage 1986	1965—84
CEREALS			
Rhopalosiphum padi (L.)	102	0,6	1,1
Oscinella frit (L.)	201	0,4	0,8
Phyllotreta vittula (Redtb.)	83	0,4	0,7
FORAGE PLANTS			
Nanna spp.	69	0,5	1,3
RAPE AND TURNIP RAPE			
Meligethes aeneus (F.)	80	1,4	1,6
Phyllotreta spp.	47	0,4	
SUGAR BEET			
Aclypea opaca (L.)	44	1,0	1,2
Lygus rugulipennis Popp.	48	1,5	1,6
Pegomya betae (Curt.)	118	1,3	1,6
Chaetocnema concinna (March.)	56	1,0	1,4
PEA			
Cydia nigricana (F.)	65	1,1	1,7
ROOT CROPS AND VEGETABLES			
Trioza apicalis (Först.)	69	1,4	1,3
Delia radicum (L.) and *D. floralis* (Fall.)	81	1,3	1,8
Phyllotreta spp. on crucifers	66	1,1	1,6
Psila rosae (F.)	89	1,1	0,8
Delia antiqua (Mg.)	83	1,0	1,5
Phaedon cochlearie (F.)	52	0,6	0,9
Plutella xylostella (L.)	68	0,5	1,7
APPLES			
Microtus agrestis (L.)	114	3,6	1,2
Lepus europaeus Pallas and *L. timidus* L.	119	1,6	1,8
Cydia pomonella (L.)	64	1,0	2,0
Arvicola terrestris (L.) root damages	90	1,0	0,7
Argyresthia conjugella Zell.	66	0,8	2,7
Psylla mali (Schmidbg.)	77	0,7	0,8
Aphis pomi (Deg.)	43	0,6	1,2
Panonychus ulmi (Koch.)	75	0,4	1,1
Yponomeuta padellus malinellus Zell.	49	0,3	1,2

BERRIES			
Byturus tomentosus (Deg.)	75	1,5	1,5
Anthonomus rubi (Abst.)	70	1,5	1,4
Tarsonemus pallidus Bks.	78	1,3	1,9
Cecidophyopsis ribis (Westw.)	133	1,2	2,0
Pachynematus pumilio Knw.	80	1,2	1,2
Nematus ribesii (Scop.) and *Pristiphora pallipes* Lep.	67	1,1	1,5
Aphididae on Ribes spp.	73	1,1	1,6
Lampronia capitella Cl.	116	0,8	1,7
Zophodia convolutella (Hbn.)	56	0,7	0,8
PESTS ON SEVERAL PLANTS			
Hydraecia micacea (Esp.)	71	1,5	1,1
Deroceras agreste (L.) etc.	69	1,2	1,3

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SELOSTUS

Viljelykasvien tuhoeläimet 1986

MARTTI MARKKULA

Maatalouden tutkimuskeskus

Kasvukauden aikana ei ilmennyt erityisiä tuholaisongelmia. Piiriagrologien antamien tietojen mukaan tuholaisten määrä oli hieman tavanomaista vähäisempi. Tähkäsääski esiintyi nyt tuhoisana myös Lounais-Suomessa. Tuomikirvan kanta jäi vähäiseksi, kuten ennusteissa arvioitiin. Porkkanakemppi ja porkkanakärpänen esiintyivät hieman tavanomaista runsaampina, kun taas omenakääriäisen, pihlajanmarjakoin ja kaalikoin esiintyminen oli niukkaa. Peltomyyrällä oli huippuvuosi runsaudenvaihtelussaan.

Suomenkielinen katsaus on julkaistu Koetoiminta ja Käytäntö -lehdessä 19.2.1987.

ANNALES AGRICULTURAE FENNIAE, VOL. 26: 171—179 (1987)
Seria ANIMALIA NOCENTIA N. 126 — Sarja TUHOELÄIMET n:o 126

LIFE CYCLE OF THE POTATO CYST NEMATODE IN FINLAND

KARI TIILIKKALA

TIILIKKALA, K. 1987. **Life cycle of the potato cyst nematode in Finland.** Ann. Agric. Fenn. 26: 171—179. (Agric. Res. Centre, Dept. Pest. Inv., SF-31600 Jokioinen, Finland.)

Development of the potato cyst nematode (*Globodera rostochiensis*) (PCN) populations in the field was studied during 1981—1984. The first migrating larvae were found 2—3 weeks before planting. At that time soil temperature at a depth of 10 cm was 4—5 °C. Peak emergence occurred from 1 to 3 weeks after planting. Free-living larvae were found from the beginning of May until September. Invasion of roots started at a soil temperature of 10 °C 1—3 weeks after planting and peaked at 15 °C. The first males and females on the roots were encountered 33 days after planting potatoes and the first new eggs and larvae 40 and 63 days after planting respectively. The whole life cycle required 765 ± 34 day degrees of which 104 ± 11 day degrees accumulated before planting. The number of encysted larvae was at the minimum when the heat sum of the growth season was 640 ± 89 day degrees.

It was concluded that PCN is well adapted to the low soil temperature in Finland and able to develop throughout the entire potato growing region up to the polar circle. Calculation of heat accumulation is a useful method for timing the control of PCN with early harvesting. For quantitative and long-term forecasting simulation models are needed to optimize control tactics.

Index words: potato cyst nematode, *Globodera rostochiensis*, soil temperature, rain, population dynamics, life cycle, hatching.

INTRODUCTION

In Finland potatoes are grown commercially on about 41 000 hectares. The cultivated area extends from the southern coast (60° 00′ N) to Lappland (69° 00′ N). In southern Finland the planting of potatoes begins mid-May and potatoes are harvested in late August or September. In the north the growing season is more than one month shorter.

The potato cyst nematode (PCN) was first found in Finland in Hyvinkää (60° 40′ N, 24° 50′ E) in 1946 (VAPPULA 1954). At the beginning of the 1980s PCN was common in southern Finland. Some infestations were encountered in central Finland but northern Finland was almost non-infested (TIILIKKALA and AAPRO 1980). The northernmost discovery was made near the town of Rovaniemi in Lappland, located a few kilometers north of

Polar Circle (SARAKOSKI 1976). In Finland PCN has been considered the most harmful pest to potatoes since the beginning of the 1970s. It has been variously controlled by crop rotation, resistant cultivars and early harvesting.

The development of PCN has been published in several papers (EVANS 1969, INAGAKI 1977, PHILIS 1980, STOREY 1982). It is known that the rate of development depends mostly on the soil temperature during the growing season (JONES and PARROT 1969, JONES 1975a). Heat accumulation into the soil as day degrees has been used as a basis to predict the rate of development. The base temperature for calculations varies from 3,9 to 10 °C in different localities (JONES and PARROT 1969, MUGNIERY 1978, PHILIS 1980). SIGGEIRSSON and QUIGLEY (1983) have reported that one generation requires about 690 day degrees above 5 °C. The most advanced predictions of PCN development have been made from models (WARD et al. 1985). This research has chiefly been done in warmer climates with higher soil temperatures than those normal for Finland.

Many results indicate that PCN populations may be able to adapt to cold soil temperatures (HOMINICK 1982, SIGGEIRSSON and QUIGLEY 1983). The rate of development and readiness to hatch has been observed to vary between populations from different localities (MCKENNA and WINSLOW 1972).

The aim of this study was to monitor different stages of PCN in field conditions and correlate the development with an accumulated day-degree sum above 4,4 °C. The possible use of heat sum calculations for timing the life-cycle of PCN and for planning control tactics is discussed.

MATERIAL AND METHODS

Two experimental field blocks, one composed of sandy clay, the other fine sand, were established at Jokioinen (60° 50′ N, 23° 30′ E). Potatoes had been frequently cultivated for over ten years on both fields which were heavily infested by PCN (*Globodera rostochiensis*). The nematode populations developed poorly on andigena-resistant potato varieties. The experiments lasted for four years (1981—1984) on the clay field and for only one year (1984) on the sandy field. The block area was 20 m × 12 m for both fields.

The blocks were hand planted with tubers (variety Bintje) 12 cm deep and 25 cm apart on May 27th in 1981, 25th in 1982, 24th in 1983 and 25th in 1984. Potatoes were harvested during the last week of September every year.

The density of encysted PCN population was monitored each year. At 7-day intervals from May 1st to the end of Sebtember, 50 soil sample cores (25 cm × 2,5 cm) were taken from the blocks. After the planting samples were taken from the ridges at a distance of 5 cm from the plant. All samples were throughly mixed and half of each sample was left in an open box to dry for a further 4 months before cyst extraction. The other half was used for analysis of free living larvae. Cysts were extracted by a Fenwick can from a 200 g dry soil/sample, and were picked by hand under a microscope then squashed by an electrically stirred perspexrod in glass tubes. The number of eggs and larvae were counted under a microscope.

The number of migrating larvae were counted during the day of sampling from 100 ml soil samples for the years 1982—1984. The soil was washed through a screen with 46 holes to collect cysts. The material which passed through was sieved and decanted by COBB's

(1918) method. The larvae were finally separated from the water suspension by centrifugal flotation (GOORIS and D'HERDE 1972).

During the growing seasons four potato plants/week chosen at random from the blocks were dug up. The roots were washed and weighed in the laboratory. The number and colour of females on the roots were counted under a microscope for the years 1981 and 1982. The number of invaded larvae (L2), third and fourth stage larvae (L3 + L4), males, females, new eggs and embryonated larvae were counted for the years 1983 and 1984. For this the washed roots were cut into 1 cm long pieces and the nematodes were extracted by centrifugal flotation (COOLEN and D'HERDE 1972).

Soil temperatures were obtained from the routine measurements made by the Finnish Meteorological Institute at Jokioinen (4 km from the experimental field) and at Sodankylä, Lappland (67° 25′ N, 26° 40′ E). The mean soil temperature/day was calculated from the minimum and maximum temperatures at the depth of 10 cm (Fig. 1A). The amount of rainfall/week was counted from the measurements made at Jokioinen (Fig. 1C). Heat accumulation was counted in day degrees above an assumed basal development temperature of 4,4 °C after the first of May to the end of September (Fig. 1B). The basal development temperature was chosen to be 4,4 °C to simplify the comparison of results with the calculations of JONES (1975a) and JONES and PARROT (1969) who also used 4,4 °C. The soil temperature exceeded 4,4 °C on the 3rd of May every year except 1981, when it was on the 11th of May. The total heat sums after the first of May to the end of September at Jokioinen and at Sodankylä were as follows:

year	JOKIOINEN after May 1st	before planting	SODANKYLÄ after May 1st
1981	1241	92	741
1982	1214	58	757
1983	1345	93	903
1984	1381	114	863

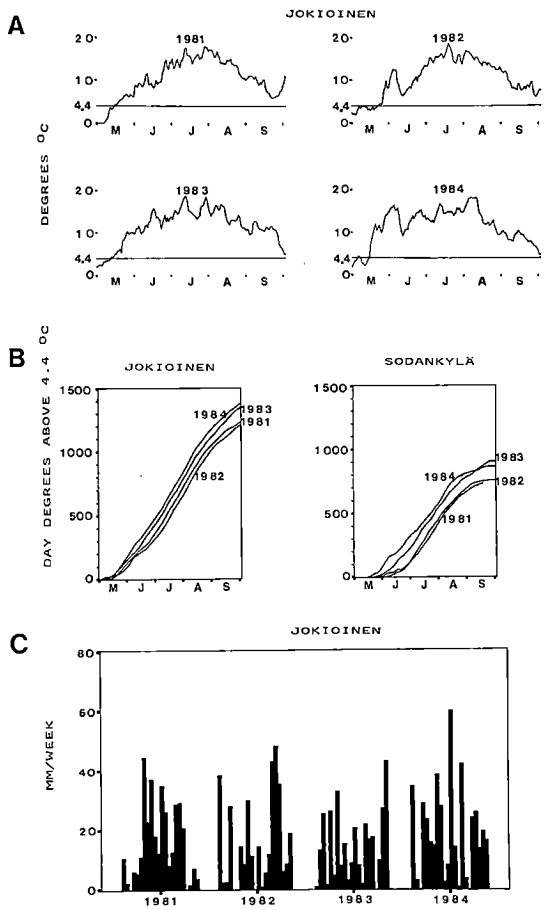

Fig. 1. Soil temperature (A) and rainfall (C) at Jokioinen: the cumulative heat sum over +4,4 °C at Jokioinen and at Sodankylä (B) +4,4 °C was assumed as the base temperature for PCN development.

Migrating larvae

The first migrating larvae were found during the first days of May. (Fig. 2). The number of migrating larvae was low until the soil temperature exceeded +10 °C after which migration accelerated rapidly. The peak of migration was on June 8th in 1982 and the 6th in 1984. Migration was prolonged in 1983 when the soil warmed up slowly and peaked on June 22nd. Free-living larvae were found throughout the seasons and low secondary peaks occurred in August 1983 and 1984.

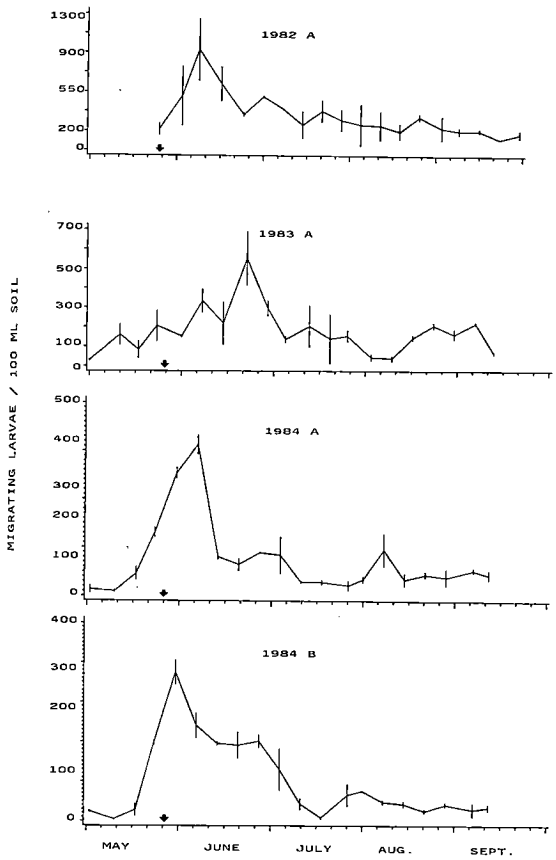

Fig. 2. Numbers of migrating larvae in soil samples taken from the fields in 1982, 1983 and 1984, A) clay soil, B) sandy soil. Vertical bars represent the minimum and maximum values and arrows indicate the date planted.

Nematodes in roots

The first L2-larvae in the roots were observed 14 days and 5 days after planting in 1983 and 1984, respectively. The total heat sums were 203 and 176 day degrees. The number of L2 larvae was at the maximum on June 22nd 1983 (Fig. 3). A difference between the soil types was encountered in 1984. On sandy soil the peak was on 6th of June but in the clay soil two peaks were found, on the 6th and 27th of June. The soil temperature was very low between these two dates and the second peak of invasion was found at the time when the soil had warmed again. The last L2-larvae in the roots were found on the 7th of September in 1983 and on the 29th August in 1984. In the clay soil fewer larvae invaded the roots than in the sandy soil. The peak numbers of migrating larvae were equally high, 314 and 375/100 ml soil in clay and sandy soil, but the peak numbers of invaded larvae were 41 and 321/g in the roots, respectively.

The first L3 + L4 stage larvae in the roots were found at the beginning of June and their number was at the maximum from the 20th to the 27th of June. The last developing larvae were found in August (8th to 24th). The first males and females were found at the end of June and the last males one month later. The number of females was highest at the end of July. Thereafter plant sampling did not give accurate estimates because the matured cysts dropped off the roots during sample handling thus decreasing the catch. Females on the roots were most easily found during the last week of July when the number of females in the yellow stage was highest.

New generation

The first new eggs were found on June 29th in 1983 and on July 4th in 1984 in clay soil, and

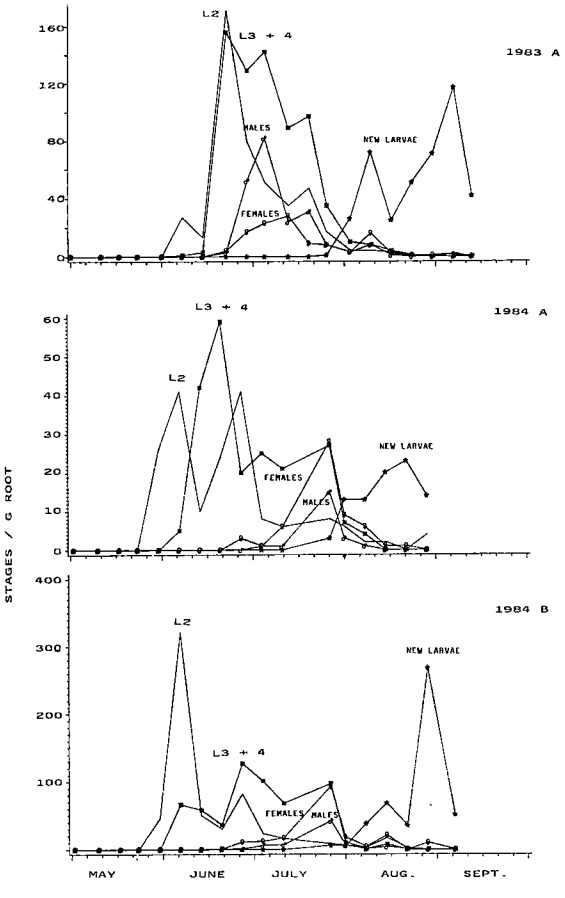

Fig. 3. Changes in the number of different stages of PCN in potato roots during the growing seasons 1983 and 1984, A) clay soil, B) sandy soil. L2 = invaded second stage larvae, L3 + 4 = sum of third and fourth stage larvae, males = males inside the roots, females = females inside and on the roots, new larvae = new embryonated larvae inside new cysts.

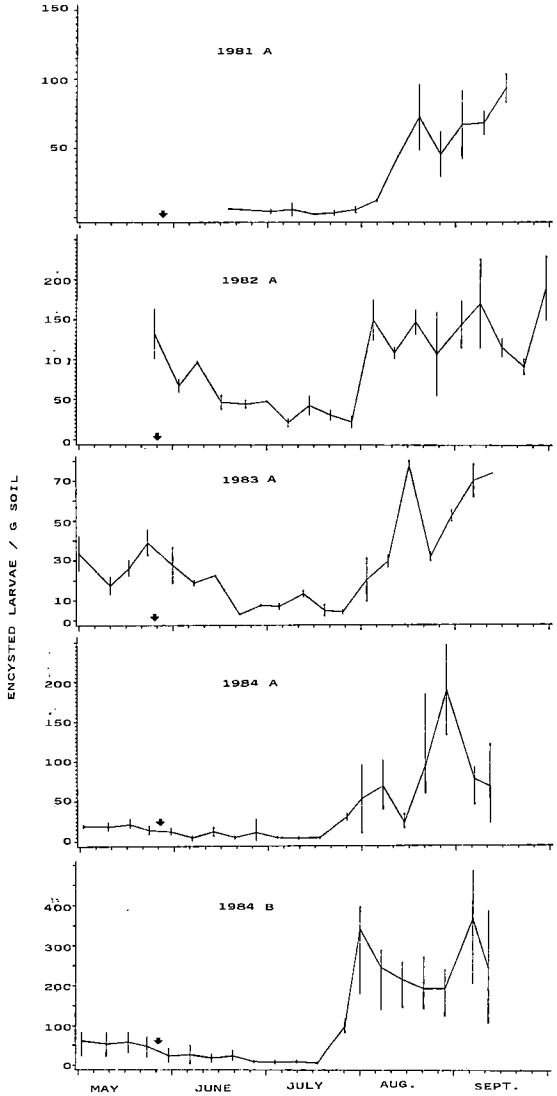

Fig. 4. Numbers of encysted larvae in soil in summer 1981, 1982, 1983 and 1984, A) clay soil, B) sandy soil. Vertical bars represent the minimum and maximum values and arrows indicate the date planted.

on July 11th in 1984 in sandy soil (Fig. 3). The first new larvae (coiled embryos) were found on July 26th in 1983 and on July 27th in 1984 on both of the experimental fields. The sum of day degrees when the first larvae were found was 729 degrees in 1983 and 798 in 1984 of which 93 and 114 day-degrees accumulated before planting, respectively.

Encysted population in soil

In the clay soil the hatching rate as a percent of the initial population was 65 %, 83 %, 88 % and 90 % in the successive experimental years (Fig. 4). The number of encysted larvae was at

the minimum in July and the total heat sum at that time varied between 603 to 729 day degrees. The dates and heat sums were as follows:

year	clay soil date	heat sum	sandy soil date	heat sum
1981	July 23rd	631	—	—
1982	July 29th	645	—	—
1983	July 26th	729	—	—
1984	July 11th	603	July 18th	690

The increase of encysted larvae was rapid at the beginning of August while some decrease occurred in the middle of August.

DISCUSSION

The first larvae emerged during the first days of May when the soil temperature was at 4—5 °C. FELDMESSER and FASSULIOTIS (1950) have reported similar results, but FRANCO (1979) did not notice any hatching at 5 °C. FOOT (1978) found larvae to emerge at 7 °C degrees and INAGAKI (1977) reported that PCN in Japan hatch when the soil temperature is 10 °C. It seems that in Finland PCN can emerge at lower temperatures than populations in warmer climates. Adaptation to low temperatures has been shown earlier (HOMINICK 1979) but there are few results on adaptation to soil temperatures below +5 °C (SIGGEIRSSON and QUIGLEY 1983).

The rate of hatching (80—90 %) was about the same as that used in the models (WARD et al. 1985). One reason for the low hatching (65 %) in 1981 was the later start of sampling. Migration in the sandy soil progressed quicker than in the clay soil in 1984. In sand the larvae invaded the roots before the cold period, but in the clay soil one half invaded after the soil warmed up again. Sandy soil is known to favour the movement of *Heterodera* larvae (JONES 1975b). The effect of soil type and biological activity on the increase and decrease of PCN populations ought to be studied before long term predictions can be calculated.

The peak of emergence was at 15 ± 2 °C just as WILLIAMS et al. (1977) reported for *Heterodera avenae* and INAGAKI (1977) for *Globodera rostochiensis.* There were free living larvae in the soil throughout the growing season and the results indicate that part of the new larvae hatch from yellow cysts as ELLENBY & SMITH (1967) and STOREY (1982) have also reported. The hatching process must be studied more precisely before its effect on population build-up is known.

Invasion of the roots began 5 days after planting, when 52 day degrees had accumulated in 1984. MUGNIERY (1978) found the first larvae to invade the roots 3 days, but STOREY (1982) two weeks after planting. According to JONES and PARROT (1968) the invasion starts when 167 day degrees have accumulated following planting. There are differences among populations from different localities, and it seems that in Finland PCN invade the roots as soon as root growth begins. The main invasion occurred over a brief period as INAGAKI (1977) reported, at the time when the first females were found and at the soil temperature of about 15 °C.

When soil temperature dropped suddenly during the invasion, from 15 °C to 10 °C in 1983, the invasion rate decreased and a new peak followed when the temperature rose again. It seems that 10 °C is too low for a mass invasion. There was no invasion in August although migrating larvae were found at that

time. STOREY (1982) did not find any larvae invading roots late in the season either but EVANS (1969) did.

The third and fourth stage larvae developed soon after the invasion and males were found about 21 days after planting. The development rate was about the same as MUGNIERY (1976) reported. Yellow females normally peaked during the last week of July. In Finland this is the best time to take plant samples, if field examination is used to locate new PCN infestations.

The first new larvae were found about 63 days after planting, but the real start of PCN increase was possibly missed by sampling only four plants per week. A better estimate for the beginning of the new generation was calculated by the date for the minimum of encysted larvae in the soil, as the soil samples were taken from 50 different sites on the field. The heat sum for the minimum of encysted larvae was approximately 765 day-degrees during the four study years. That sum suffices for PCN development in Iceland (SIGGEIRSSON and QUIGLEY 1983). The time required for PCN development was about two weeks shorter than that presented by EVANS (1969) and STOREY (1982), and is one sign of good adaptation to a cold climate. The number of new larvae increased in August as rapidly as STOREY (1982) reported from England.

In Finland early potato varieties are harvested before the end of July. Therefore PCN can not develop new larvae during so short a season, except in such warm years as 1984. For other *G. rostochiensis* populations it has been calculated that harvesting beyond 89 days after planting can control the increase (WEBLEY and JONES 1981). It appears that PCN populations in Finland are able to develop so rapidly that harvesting must occur 70—75 days after planting if the population increase is to be controlled. A better prediction for harvesting time can be calculated by soil temperature. Potatoes must be harvested before the total heat sum is 700 day degrees in order to avoid PCN increase.

If it is calculated that the whole life cycle of PCN requires 700 day degrees, then it follows that PCN can develop throughout entire area of potato cultivation in Finland. At Sodankylä the heat sum was at the same level as that in Iceland, where SIGGEIRSSON and QUIGLEY (1983) found that one generation of PCN is possible when 690 day degrees above 5 °C have accumulated. In Lappland possibly only a minor part of the nematodes produce new larvae. In the main seed potato growing area in the province of Oulu, the rate of increase may also be lowered because of the shortness of the growing season. In southern Finland all invaded larvae can produce new eggs if potatoes are harvested in September.

Globodera pallida has not yet been encountered in Finland, but the low soil temperatures increase the risk that *G. pallida* would be favoured and selected, which may be even a more serious threat to potato cultivation than *G. rostochiensis*. *G. pallida* needs fewer day degrees to hatch, develop and produce eggs than does *G. rostochiensis* (MUGNIERY 1978, FRANCO 1979 and FOOT 1978). Therefore early harvesting could favour *G. pallida* and if done routinely, might also lead to the increase of this species and the replacement of *G. rostochiensis* (WEBLEY and JONES 1981). In addition long daylength has some selecting effect on different species and populations (FRANCO and EVANS 1979) but selection pressure by light and temperature must be studied more precisely before any conclusions can be made.

Calculation of heat accumulation is a useful method for timing the development of PCN during one season. For quantitative and long term forecasting, however, simulation models are needed to optimize control tactics.

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SELOSTUS

Peruna-ankeroisen kehitysnopeus Suomen oloissa

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Maatalouden tutkimuskeskus

Peruna-ankeroinen, *Globodera rostochiensis,* löydettiin Suomesta ensimmäisen kerran vuonna 1946 Hyvinkäältä. Neljässäkymmenessä vuodessa laji on levinnyt lähes kaikkiin Etelä-Suomen kuntiin. Ankeroismäärät ovat nousseet monilla perunaviljelyksillä haitallisen korkeiksi ja satotappiot ovat olleet huomattavia. Vioituksen ankaruuteen vaikuttaa eniten ankeroismäärä, mutta olennainen merkitys on myös perunalajikkeen sietokyvyllä, maalajilla ja kasvukauden säällä. Ankeroisten runsaus riippuu siitä kuinka usein altista kasvia viljellään samalla paikalla ja kuinka paljon ankeroinen lisääntyy yhden kasvukauden aikana ennen sadonkorjuuta.

Maan lämpötila on tärkein peruna-ankeroisen kehitysnopeuteen vaikuttava tekijä kasvukauden aikana altista perunaa viljeltäessä. Tällä tutkimuksella hankittiin tietoa peruna-ankeroisen kehitysnopeudesta ja eri kehitysvaiheiden lämpötilavaatimuksista. Kenttäkokeet tehtiin vuosina 1981—1984 Jokioisilla. Koealueella viljeltiin Bintje-perunaa normaalien viljelymenetelmien mukaisesti. Maassa ja perunoiden juurissa olleet ankeroismäärät laskettiin viikoittain otetuista näytteistä. Säätiedot saatiin Ilmatieteen laitoksen Jokioisten observatorion mittauksista ja tehoisa lämpösumma laskettiin peruslämpötilan 4,4 °C ylittäneistä maalämpötiloista.

Ensimmäiset peruna-ankeroistoukat lähtivät liikkeelle toukokuun alussa, kun maan lämpötila ylitti +4 °C, mutta pääosa toukista liikkui vasta kun lämpötila ylitti +10 °C. Ensimmäiset toukat tunkeutuivat juuriin heti juurien kehityksen alettua ja pääosa juhannuksen aikoihin.

Naaraat alkoivat näkyä juurien pinnalla heinäkuun alussa. Juurinäytteistä laskettujen kystojen määrä oli suurimmillaan heinäkuun viimeisellä viikolla joten perunan juuritarkastukset tulisi tehdä heinäkuun lopussa, jolloin vähäisetkin ankeroismäärät tulevat helposti näkyviin.

Ensimmäiset uudet toukat kypsyivät heinäkuun lopulla tai viimeistään elokuun alussa. Maasta, kystojen sisältä laskettujen toukkien määrä oli alhaisimmillaan tehoisan lämpösumman ollessa n. 700 astetta.

Maassa olevaa ankeroismäärää voidaan vähentää altistakin perunaa viljeltäessä, jos perunat nostetaan lämpösumman ollessa vielä alle 700 °C. Normaalikesänä nosto tulisi tehdä viimeistään heinäkuun viimeisellä viikolla. Pari viikkoa myöhemmin ankeroismäärä on jo kevään ankeroismäärän tasolla ja lisääntyminen jatkuu nopeasti elokuun puolessa välissä.

Lämpötilamittausten perusteella voidaan arvioida, että peruna-ankeroinen voi elää koko perunanviljelyalueella Suomessa. Pohjoisin tähän mennessä löydetty peruna-ankeroisesiintymä on Rovaniemellä. Sodankylä on lisääntymiskyvyn äärirajalla, jossa vain pieni osa naaraista ehtisi tuottaa uusia toukkia. Etelä-Suomessa lähes kaikki juurissa kehittyneet naaraat ehtivät tuottaa uusia toukkia, jos peruna nostetaan vasta syyskuun lopussa. Mitä vähäisempää lisääntyminen on yhden kasvukauden aikana sitä useammin voidaan altista perunaa viljellä samalla paikalla. Kasvinvuorotuksen tarve Pohjois-Suomessa on siten vähäisempi kuin Etelä-Suomessa.

Ankeroisenkestävilläkin lajikkeilla lisääntyvän *Globodera pallida* -lajin lämpötilavaatimus on alhaisempi kuin meillä yleisesti esiintyvän *G. rostochiensis* -lajin. Suomen ilmasto suosii siten *G. pallida* -lajin levintää perunaviljelyksillemme ja siksi sen levinnän estämiseen ja torjuntaan tulisi kiinnittää erityinen huomio.

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PROPERTIES OF FINNISH ISOLATES OF CUCUMBER MOSAIC VIRUS AND EVIDENCE FOR VIRAL DOUBLE-STRANDED RNA TO INDICATE VIRULENCE

AARNE KURPPA

KURPPA, A. 1987. **Properties of Finnish isolates of Cucumber mosaic virus and evidence for viral double-stranded RNA to indicate virulence.** Ann. Agric. Fenn. 26: 181—193. (Agric. Res. Centre, Dept. Plant Path., SF-31600 Jokioinen, Finland.)

Eight Finnish CMV isolates from cucumber, tomato and ornamental plants were characterized for their host range and symptomatology, genomic properties and antigenic and serological properties.

Symptom diversity in the main natural host species, cucumber and tomato, was wide. Two of the isolates were particularly virulent in cucumber.

In electrophoretic fractionation of viral double-stranded RNA in agarose gels, extra minor components between RNA-3 and RNA-4, were present in the nucleic acids of the two virulent isolates mentioned above. Otherwise the fractionated nucleic acid patterns were typical of CMV and the isolate. Different nucleic acid components approximated their standard molecular weights but their relative proportions depended considerably on the virus isolate.

Antigenically all CMV isolates were rather closely related. Tests by the Ouchterlony double-diffusion method indicated even distinct differences but these were partially due to virus particle disruption during testing and presence of antibodies in the antisera to particle dissociation products. The ELISA was found very reliable for detection of cucumber mosaic virus in different crude or partially purified plant samples and was far superior to immunodiffusion tests in agar or agarose.

Index words: cucumber mosaic virus, CMV, Cucumo-viruses, double-stranded RNA, immunodiffusion tests, ELISA test.

INTRODUCTION

Cucumber mosaic virus (CMV) has world-wide distribution and is a common cause of diseases in a great variety of plant species (FRANCKI et al. 1979). Severe disease outbreaks occur regularly and have been reported particularly in such cultivated crops as cucumber, squash, melon, tomato, tobacco, celery, spinach and a number of ornamental plants (van SLOGTEREN 1966, HÄNI 1971, FRANCKI et al. 1979, NAMETH et al. 1986).

In addition, CMV infects hundreds of plant species including weeds, trees and shrubs (PRICE 1940, DOUINE et al. 1979). An extremely wide host range together with a

rapid non-persistent manner of transmission by a number of aphid species makes the virus difficult to control. Transmission is supported by a relative high rate of seed transmission in common weed species including *Stellaria media, Lamium purpureum, Gerastium holosteoides, Spergula arvensis* (TOMLINSON and CARTER 1970), *Senecio vulgaris, Urtica urens* and *Capsella bursa-pastoris* (TOMLINSON et al. 1970).

Cucumber mosaic virus has been studied intensively over the years and much is known about disease outbreaks, host range and symptoms, biological and physicochemical properties, particle properties and serology (van REGENMORTEL 1967, HABILI and FRANCKI 1974a, 1975, LINNASALMI and TOIVIAINEN 1974, FRANCKI et al. 1979). Moreover its genomic properties are well characterized (PEDEN and SYMONS 1973, HABILI and FRANCKI 1974b). In addition to four single-stranded RNA species, some virus isolates may also contain small encapsidated single-stranded RNA molecules of about 1×10^5 daltons (KAPER et al. 1976, MOSSOP and FRANCKI 1977, TAKANAMI 1981). The most well-known of these, CARNA-5, has been found to be related with high virulence in plants (KAPER and TOUSIGNANT 1977). Furthermore an opposite nature of satellite molecules has also been reported (MOSSOP and FRANCKI 1979).

Although much is known about the virus and its behavior in the host species, still more information is needed on the properties of diverse strains, types and minor variants, as well as about virulence factors and reliable detection and identification of the virus.

The aim of this study was to characterize some new CMV isolates in Finland and compare their properties to isolates previously characterized by LINNASALMI (1966) and LINNASALMI and TOIVIAINEN (1974) with a particular interest in their genomic properties in relation to virulence in the main host species. Antigenic and serological properties of the isolates as well as their reliable identification were also of great interest.

MATERIAL AND METHODS

Host range and symptomatology

Virus material included four newly isolated field or greenhouse isolates and four Finnish isolates previously characterized by LINNASALMI (1966) and LINNASALMI and TOIVIAINEN (1974) as follows:

Isolate	Origin
2/82	cucumber, field cultivation, Helsinki 1982
3/84	greenhouse cucumber, Merikarvia 1984
25/85	greenhouse cucumber, Salo 1985
18/86	*Phlox subulata*, Lappeenranta 1986

K7/64, K31/63, TK106/64, TK144/63 (LINNASALMI 1966)

The new uncharacterized virus isolates were isolated from their original hosts in 0,06 M phosphate buffer pH 7 with mechanical inoculation into *Chenopodium quinoa* Willd., *Cucumis sativus* L. cv. Muromin and *Nicotiana glutinosa* L., and further from single lesions in *C. quinoa* leaves to *C. sativus* cv. Muromin and *N. glutinosa*, where they were maintained. The old isolates had been stored in phosphate buffered cucumber sap and *N. glutinosa* from 10 to 13 years at −20 °C. They were inoculated into *C. quinoa* and further into *C. sativus* and *N. glutinosa* for maintenance. Before and after inoculation the test plants were kept in darkness overnight at c. 15 °C. Otherwise greenhouse temperature was 21—23 °C and illumination was natural, supplemented by

mercury vapour lamps 4—12 h/day during the wintertime.

Herbaceous test plants and other indicator species used for host range and symptomatology studies are listed in Tables 1 and 2. For the experiments with cucumber cultivars four replications were performed, otherwise two plants of each species were used. Inoculum for these experiments as well as for all other tests and studies described later were taken from systemically infected leaves of *N. glutinosa.* Symptoms in the plants were observed from three to eight weeks depending on the host. Symptomless indicator plants and those expressing very mild or questionable symptoms were tested for the presence of the virus with the ELISA test (enzyme-linked immunosorbent assay) (CLARK and ADAMS 1977) by using two immunoglobulins and their enzyme conjugates from different sources.

Extraction of double-stranded RNA and its fractionation

Viral double-stranded RNA (dsRNA) was extracted and purified from plant tissue essentially by the two column method of KURPPA and MARTIN (1986). The difference was, however, that also the second cellulose column was composed of CF-11 (Whatman) cellulose rather than Cellex N-1 (Biorad) cellulose. The hosts used for extraction material included *C. sativus* cvs Favör II, Levo, Muromin and Septa F_1, *Lycopersicon esculentum* Mill cv. Virosa TM C5 FEZ, *Nicotiana clevelandii* Gray, *N. glutinosa, N. tabacum* cv. Samsun, *Phlox paniculata* L. cv. Kesselring and *Spinacea oleracea* L. cv. Verina Hg. For comparative analysis of virus isolates, dsRNA was extracted from *N. glutinosa* tissue.

Horizontal electrophoresis of purified dsRNA samples was done in agarose (1,0 or 1,2 % NA agarose, Pharmasia Fine Chemicals) gels in a GNA-100 gel apparatus (Pharmasia Fine Chemicals). DsRNA bands were visualised with UV light of 302 nm with a Macrovue Transluminator (LKB Wallac) and photographed using a standard black and white pancromatic film, e.g. Kodak Plus-X Pan with a Kodak Wratten A 23 filter.

The dsRNAs of tobacco mosaic virus and brome mosaic virus, as well as ssRNAs of healthy *N. clevelandii* served as molecular weight standards.

Serology

For the serological studies antisera were produced in rabbits for two of the new isolates. Antigens were purified by a method of LOT et al. (1972). In addition another method described by MOSSOP et al. (1976) was tried for viral purification. The rabbits were immunized with three subcutaneous injections at one-week intervals followed by a booster injection three weeks after the third injection. 200—500 μg of purified antigens (not treated with formaline) in 0,5 ml 0,001 M borate buffer pH 9 emulsified with an equal volume of Freund's incomplete adjuvant were administered each time. Antisera for the comparative tests were taken two weeks after the booster. For serological comparisons CMV antisera from the Agriculture Canada Research Station, Vancouver B.C. and the National Institute of Plant Pathology, Lyngby, Denmark, kindly supplied by Dr. R. Stace-Smith and Dr. M. Heide, respectively, were used. An antiserum to tomato aspermy virus from the Danish source was also made available.

Agars for the double diffusion tests (OUCHTERLONY 1962) were prepared in 0,005 M borate buffer pH 9 and in phosphate buffered saline (PBS) pH 7,4 by melting 1 g bactoagar (Difco) in 100 ml buffer. Suitability of the agar media for the virus isolates was not optimized. For titer determination in double-diffusion tests also formaline (1 %) treated

purified antigens were used. Otherwise all tests were performed with non-treated purified antigens, or with antigens in crude plant extracts. The results were recorded after 18, 42 and 66 hrs of incubation at 4 °C.

The ELISA test immunoglobulins for coating the plates (Microstrip^R, Eflab, Helsinki) and for preparation of phosphatase conjugates were purified by the Sepharose-protein-A-method from crude antisera to the isolate 25/85 and to a Canadian isolate. Immunoglobulins were used at 1 μg/ml and the test was performed essentially as described by CLARK and ADAMS (1977). Tap water was, however, used instead of PBS-Tween for washing the plates. This was because of our long experience of using tap water in experiments and in routine tests without any unwanted effects. Test samples were incubated on the plates overnight at 4 °C and readings were taken after 1 h substrate incubation at 20 °C with a Titertek Multiscan MCC reader.

RESULTS

Host range and symptomatology

The host range of the new CMV isolates was relatively uniform, severity of disease in the host species ranged from no obvious symptoms to severe mosaic, stunting or necrosis in some host species. Variation in disease severity was particularly true with tomato, spinach and *N. glutinosa* (Table 1). *C. quinoa* and all *Nicotiana* species always reacted with clearly visible symptoms to the virus. Only a minor proportion of the plants of the species *Phlox paniculata, Potentilla fruticosa* D. Don and *Apium graveolens* L. became infected.

Table 1. Symptoms of the uncharacterized CMV isolates in selected host species.

Host species	Isolate and symptom description			
	2/82	3/84	25/85	18/86
Apium graveolens cv. Balder Bali	—	—	S ivch 12d	—
Chenopodium quinoa	Lchl, Lnl 3—4d	Lchl 4d	Lchl, Lnl 3d	Lchl, Lnl 3—4d
Lycopersicon esculentum cv. Virosa TM C5 FEZ	Sfl (s) 12d	Smo, Sfl (m) 12d	Sfl (m) 12d	Sfl (s) 10—12d
Nicotiana clevelandii	Smo, Svy, Slp Smaf 10—12d	Lchr 6d, Smos, Sstunt 10d	Svy, Smos (m) 10d	Smo, Smos 10d
N. debneyi	Svcl (m) 6—8d	Schl, Svcl, Smo 8—10d	Svcl, Sch (m) 6—8d	Schl, Svcl (m) 8d
N. glutinosa	Lchr 4d, Smos, Slp, Sstunt 8—10d	Lnr 5d, Symos (s) Sstunt 10d	Svcl, Smo, Sg/ymos 8—10d	Lchl 4d, Schl, S mos (s) 8—10d
N. tabacum cv. Samsun	Schr, Smos 6—8d	Lchl 4d, Schl, Smos 8d	Lchl 4d, Schr, Svcl 8d	Lchl 4d, Schl, Smos 6—8d
Phlox paniculata cv. Kesselring	Schl, Sch 12d	—	—	—
Potentilla fruticosa cv. Katherine Dykes	—	—	Lnl 4d, Sstunt (m) 10d	—
Spinacia oleracea cv. Verina Hg	Sch 8—10d	Sch, Sstunt (s) 12d	Sch (m) 10d	Sch, Sstunt 10d

L = localized symptoms; S = systemic symptoms; ch = chlorosis, chlorotic; n = necrosis, necrotic; l = lesions; r = rings; rs = ringspots; mo = mottle; mos = mosaic; vcl = vein clearing; vy = vein yellowing; g/y = green/yellow; iv = interveinal; lp = line patterns; fl = fern leaf; stunt = stunting; — = not infected; d = days from inoculation; (m) = mild; (s) = severe

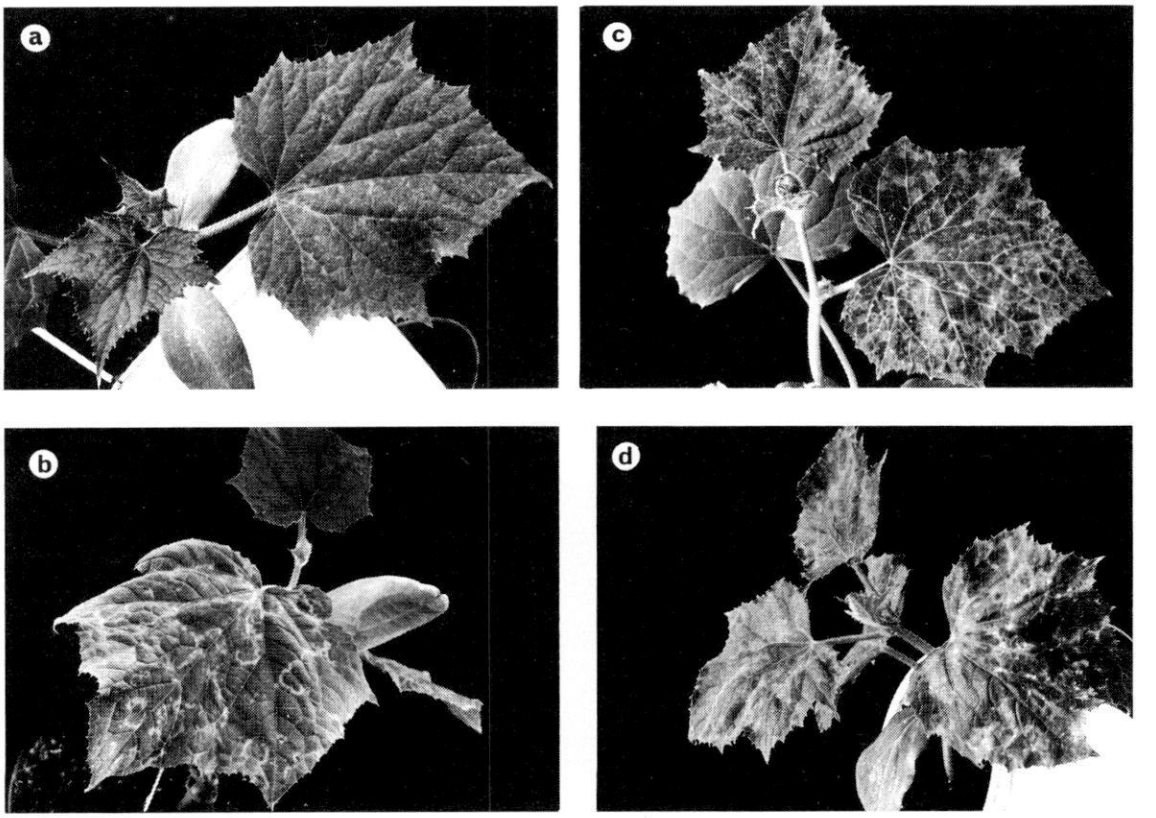

Fig. 1. Symptoms induced by four cucumber mosaic virus isolates in cucumber cv. Septa F_1 as seen two weeks after mechanical inoculation to the cotyledons. The isolates are as follows: a = 2/82, b = 3/84, c = K31/63 and d = TK 106/64.

There were great difficulties in regenerating the old isolates of Dr. Linnasalmi after the 10 to 13-year preservation period in buffered plant sap at −20 °C. Following several attempts to inoculate cucumber and *C. quinoa* seedlings, a few diffusive chlorotic local lesions developed in the leaves of *C. quinoa.* From these single lesions the virus isolates could be easily transferred to their maintenance hosts, cucumber and *N. glutinosa.*

All isolates produced pale local lesions and systemic mottling in the leaves of most cucumber cultivars. Symptoms in the cultivar Levo were mild or very mild in each case and local lesions were seldom present. In the rest of the cultivars severity of the symptoms (mosaic, yellowing, stunting and deformation) was highly variable. The symptoms in cucumber were typically more related to the virus isolates than to the cultivars with the exception of cv. Levo. The isolates K7/64 and TK106/64 were found to be clearly more virulent than the other isolates in cucumber (Table 2, Fig. 1.). Symptoms remained severe during later growth of the cucumber, too. Large yellow chlorotic systemic rings were typical of the isolate 3/84 in all cultivars excluding Levo (Fig. 1.). The isolate 18/86 induced more yellowing, yellow mosaic and stunting than the other isolates. Isolate 2/82 was particularly virulent in squash.

Table 2. Symptoms induced by eight CMV isolates in selected Cucurbits.

Virus isolate	The hosts and symptom descriptions					
	Cucumis sativus cvs					*Cucumis melo* cv.
	Favor II	Levo	Muromin	Septa F_1	Landora F_1WW SF	Caserta
2/82	Lchl 3—4d, Symo 8—10d	Svy (m) 8d	Lchl 3d, Smo, Smos. 8d	Sivch 8—10d	Lnl 4d, Schr, Svy 10d	Lchl 4d, Smos, Symo (s) 8—10d
3/84	Svcl (m) 8d	Sg/ymos 8d	Svy (m) 8d	Svy (m)	Lnl 4d, Svy (m) 8d	Lnl 4d, Smos (m) 8—10d
25/85	Lchl 4d, Syr 8d	Sivchr 8—10d	Schl, Schr 8d	Schl, Schr 8d	Lchl, Lnl 4d Svy 8—10d	Svcl, Smos 8—10d
18/86	Lchl 4d, Sstunt, Sg/ymos (s) 8d	Svy (m) 8—10d	Lchl 3d, Sstunt, Sg/ymos (s) 8d	Lchl 4, Sg/ymos (s), Sstunt 8d	Lchl, Lnl 4d, Svy, Smos 10d	Sg/ymos 8d
K7/64	Lchl 3d, Sg/ymos (s) 6—8d	Svy 8d	Lchl 3d, Sg/ymos (vs) 6—8d	Lchl 3d, Sg/ymos (vs) 6—8d	Lchl, Lnl 4d, Sg/ymos 10d	Sg/ymos 8d
K31/63	Svcl (m) 6—8d	Svy (m) 8—10d	Svy (m) 8d	Smos (m) 8d	Lchl 4d, Smos (m) 8—10d	Lchl 4d, Sg/ymos (m) 6—8d
TK106/64	Lchl, Lnl 3d, Sg/ymos (s) 8d	Lchl 4d, Schl, Smos (m) 8d	Lchl, Lnl 3d Sg/ymos (vs)	Lchl, Lnl 3d Sg/ymos (vs) 8d	Lnl 4d, Smos (s) Smos (s)	Lchl 4d, Sg/ymos, Sstunt (s) 8—10d
TK144/63	Lchl 4d, Svy (m) 8—10d	Svy (m) 8—10d	Smos (m)	Smo, Smos (m) 8d	Svy (m) 8—10d	Smos (m) 8d

L = localized symptoms
S = systemic symptoms
ch = chlorosis, chlorotic
n = necrosis, necrotic
l = lesions
r = rings
mo = mottle
mos = mosaic
vcl = vein clearing
vy = vein yellowing
y = yellow
g/y = green/yellow
iv = interveinal
stunt = stunting
(m) = mild
(s) = severe
(vs) = very severe
d = days from inoculation

Viral double-stranded RNA

The method used for nucleic acid extraction and purification gave relatively high yields of clean dsRNA preparations from all host species which became systemically infected with the virus. Yields from different extractions from the same species were not directly compared, but two grams of infected tissue was each time sufficient to produce enough dsRNA for a clearly visible genomic pattern in agarose gel when fractionated with electrophoresis. Yields of dsRNA extracted were highest from *N. glutinosa*, *N. clevelandii* and *S. oleracea* on average. In addition cucumber and *N. tabacum* cv. Samsun yielded high dsRNA in most cases.

No dramatic differences in the molecular weights of the genome components originating from different hosts or from different extractions were found. The dsRNA pattern after gel electrophoresis was always typical of CMV as well as typical of the isolate. Although the molecular weights of dsRNAs of different virus isolates were relatively unique, the relative proportion of different RNA species of the total RNA was variable (Fig. 2). This did not depend much on the source of extraction material. In addition to four RNA species, the isolates K7/64 and TK106/64 contained an extra minor band between RNA-3 and RNA-4 with a molecular weight of c. 1,0 million (dsRNA). This was present in all preparations from different plant species. No satellite RNA as CARNA-5 was detected.

Serological properties

Yields of purified preparations of up to 400 mg virus/kg *N. glutinosa* tissue were obtained from the isolates 2/82 and 25/85 with the method of LOT et al. (1972). The other method was not

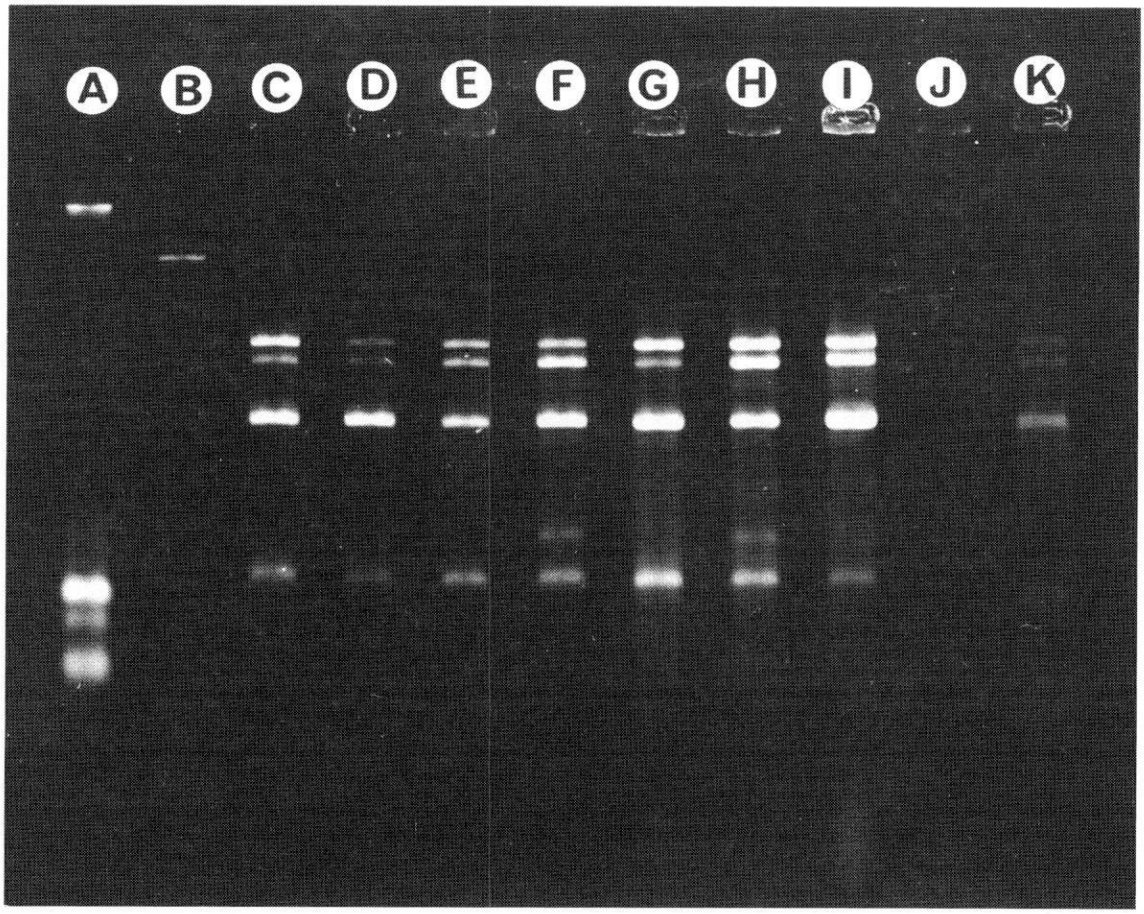

Fig. 2. An agarose gel showing different dsRNA patterns of CMV detected in *Nicotiana glutinosa* tissue (lines C—J) after electrophoretic fractionation. The lines in order as follows:
A = Marker DNA (MW c. 8×10^6) and ssRNAs (MW c. 0,7 and $0,5 \times 10^6$)
B = dsRNA of tobacco mosaic virus (MW 4,0)
C = dsRNA 2/82, D = 3/84, E = 25/85, F = K7/64, G = K31/63,
H = TK106/64, I = TK144/63
J = dsRNA from healthy *N. glutinosa*
K = dsRNAs from brome mosaic virus (MW 2,18, 1,98, 1,50 and $0,56 \times 10^6$)

successful at all.

Homologous titers of the antisera taken two weeks after booster injections were 1/512 and 1/1024 (isolates 2/82 and 25/85, respectively) when tested against formaline treated purified preparations with the Ouchterlony double-diffusion method in 0,005 M borate agar pH 9. Heterologous titers were one or two two-fold steps lower. No double precipitin lines were present between antibody and antigen wells in agar. Similarly no spur formations developed when these two isolates were tested in peripheral neighbour wells in agar. The use of non-treated antigens resulted at least in some double precipitin line appearence. The straight line close to the antibody well was rather faint with the use of 25/85 antiserum and disappeared when diluted 1/8 or more. In

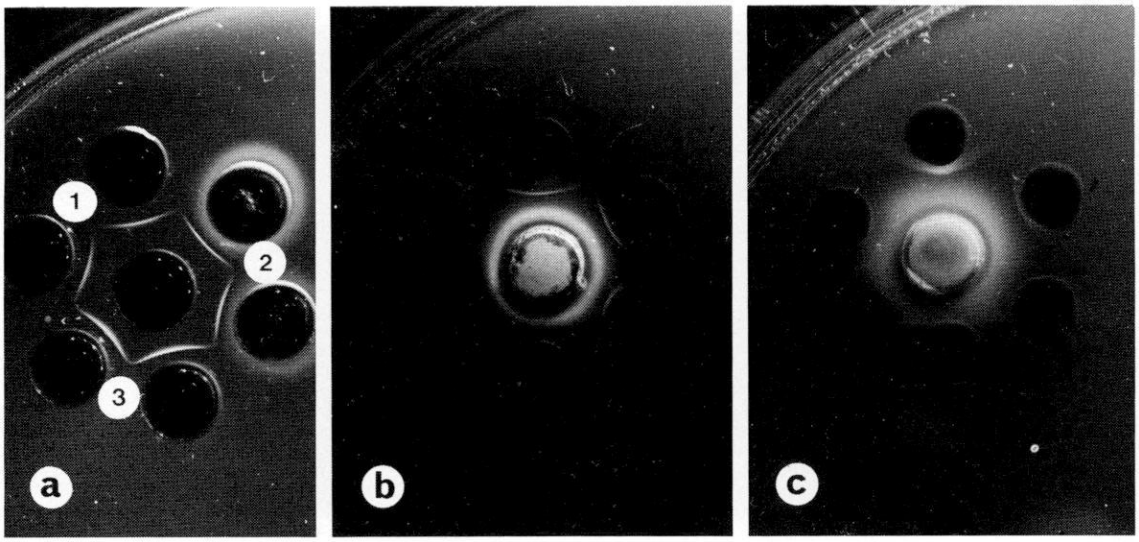

Fig. 3. Reactions of virus antigens to CMV 2/82 antiserum in Ouchterlony double-diffusion tests.
a. Partially purified preparations in the peripheral wells; 1 = 25/85, 2 = K7/64, 3 = 2/82
b. Isolate K31/63 in crude plant extract in the center well, antiserum dilutions starting from 1/8 at two-fold steps
c. Isolate TK144/63 in the center well, antiserum dilutions from 1/8 at two-fold steps

homologous reactions of the isolate 2/82, the straight precipitin line was present up to a dilution of 1/64, and in reactions to the 25/85 antigens to a dilution of 1/16.

Tests with crude plant extracts in borate agar without NaCl resulted in relative high titers and sharp single precipitin lines (Table 3). A clearly visible double precipitin line (titer 1/16) was only found in the homologous reaction of the isolate 2/82. In PBS agar the titers were low in most cases. Only the virus isolates 25/85 and K31/63 reacted with sharp precipitin lines to the antibodies with titers of 1/64 and 1/32, respectively (Fig. 3). In the other cases the titers were lower, the precipitin lines more or less diffuse, or double precipitin lines were present (Table 3).

Serological relationships between the CMV isolates studied were relatively close according to the results of double-diffusion tests. The lowest heterologous titer recorded was 1/32 (TK144/63 against both antisera). In addition

Table 3. Reaction of the virus isolates to selected Cucumo-virus antisera in Ouchterlony double-diffusion test in agar made in 0,005 M borate buffer, pH 9,0 and in phosphate buffered saline, pH 7,4 (in brackets).

	Titers							
Antisera	2/82[1)]	3/84	25/85	18/86	K7/64	K31/63	TK106/64	TK144/63
CMV 2/82	256 (32)	256 (32)	128 (64)	64 (16)	64 (16)	128 (64)	64 (16)	32 (4)
25/85	128 (32)	128 (16)	512(128)	64 (16)	64 (8)	128 (64)	64 (8)	32 (16)
Danish	32 (8)	64 (8)	16 (16)	16 (16)	32 (0)[2]	32 (16)	16 (0)	8 (0)
Canadian	4 (8)	16 (8)	0 (0)	0 (0)	0 (0)	4 (4)	0 (0)	0 (0)
Tomato aspermy virus, Danish	2 (2)	0 (0)	2 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

1) Virus isolates in sap of systemically infected *Nicotiana glutinosa*
2) 0 indicates no reaction

Table 4. Detection of the CMV isolates with ELISA in diluted sap of *Nicotiana glutinosa* and in partially purified preparations. Antibodies to the isolate 25/85 were used in the tests.

Virus isolate	Absorbances at 405 nm							
	1/10*	$1/10^2$	$1/10^3$	$1/10^4$	$1/10^5$	$1/10^6$	$1/10^7$	$1/10^8$
2/82	>2	1,501	0,626	0,162	0,064	0,028	0,011	0,008
3/84	>2	1,312	0,327	0,112	0,048	0,021	0,009	0,008
25/85	>2	1,977	0,890	0,218	0,063	0,024	0,009	0,007
18/86	>2	1,606	0,373	0,125	0,031	0,014	0,009	0,008
K7/64	1,877	0,570	0,116	0,062	0,026	0,011	0,006	0,007
K31/63	1,919	1,202	0,185	0,062	0,028	0,014	0,007	0,006
TK106/64	1,709	1,168	0,260	0,091	0,033	0,017	0,010	0,008
TK144/63	1,398	0,790	0,167	0,075	0,019	0,011	0,008	0,007
2/82P[1)]	>2	>2	>2	0,829	0,143	0,009	0,006	0,004
25/85P[1)]	>2	>2	>2	1,414	1,056	0,488	0,082	0,016
Healthy *N. glutinosa*	0,033	0,019	0,011	0,008	0,008	0,006	0,005	0,005

P[1)] = purified preparation, 1/10 dilution corresponds 100 µg/ml
* = sample dilution at ten-fold steps

the isolates K7/64, TK106/64 and 18/86 differed serologically more from the isolates 2/82 and 25/85 than the rest of the isolates. Spurious reactions were found between the isolates 2/82 and K7/64 as well as between 25/85 and K7/64 (Fig. 3).

Heterologous titers of the Danish CMV antiserum with the virus isolates varied from 1/8 (TK144/63) to 1/64 (3/84). The Canadian antiserum reacted poorly to all of the isolates with the highest titer of 1/16 (3/84). Only two of the isolates reacted to tomato aspermy virus antiserum; the reaction was always very weak and diffuse.

All of the CMV isolates were readily detected in crude extract of systemically infected *N. glutinosa* with the ELISA test. Absorbance readings were rather low when antibodies to the Canadian virus isolate were used, and only three of the isolates (2/82, K31/63 and TK144/63) were detected at a dilution of $1/10^3$. With the antibodies to the isolate 25/85 all virus isolates were detected at a dilution of $1/10^4$ (Table 4). Serological relationships between the isolates were even closer than indicated by the Ouchterlony double-diffusion test.

Essentially higher readings than in *N. glutinosa* extracts were obtained in some samples of *S. oleraceum.* These samples included the isolates 2/82, 3/84 and 25/85, but otherwise the readings were noticeably lower. Samples of cucumbers gave comparable maximum absorbance readings to those of *N. glutinosa* but much variation was present depending on the virus isolate and cucumber cultivar. Virus concentrations in the cultivar Levo were always relatively low compared to the cultivars Muromin and Septa F_1.

Cucumber mosaic virus was detected with the ELISA in a purified preparation of the isolate 25/85 at a concentration of 0,1 ng/ml. The level of detection of the heterologous isolate 2/82 was between 1 and 10 ng/ml.

DISCUSSION

Diversity of symptoms in the studied host species was wide as reported by a number of scientists over the years. Although some of the virus isolates were radically or clearly more

severe in cucumbers and tomatoes, no characterization could be made on the basis of the symptoms. Symptomatology has, however, been commonly used as the main criterium for strain classification, e.g. (PRICE 1934, MOSSOP et al. 1976). Since the late 1960s physicochemical (van REGENMORTEL 1967) and antigenic properties (DEVERGNE and CARDIN 1973) have been used for characterization. Symptomatological observations may often be misleading. According to KAPER and WATERWORTH (1981) apparent differences among isolates derive from many nonviral causes such as laboratory practices, growing conditions, the specific cultivar tested and interpretations of symptoms observed. Furthermore the source of inoculum may be related to changed symptom expression as MARCHOUX et al. (1971) have reported.

High virulence, or on the contrary, lack of virulence in a given host species may also result from two replicative entities; a virus and a satellite RNA in the plant as reported by KAPER and WATERWORTH (1977), MOSSOP and FRANCKI (1979) and TAKANAMI (1981). For isolate comparison and classification, knowledge of genomic properties is therefore necessary.

In the present study the genomic properties of the isolates were illustrated via extraction of viral double-stranded RNA directly in plant tissue and fractionation of it in horizontal agarose gel dyed with UV light-sensitive ethidium bromide. This method offers a powerful tool for isolate comparison, if some precautions are taken. For according to KAPER et al. (1976) and KAPER and TOUSIGNANT (1977) the relative proportion of the encapsidated RNA components may vary, in addition to the virus strain, also with the host plant and several other conditions. In our study similar variation was found, but it had only a minor role compared to the relatively stable genomic properties related to the virus isolates. There are some reports (e.g. KAPER and WATERWORTH 1981) on an extra fragment of nucleic acid of c. 0,5 million daltons (1 million d. as dsRNA) associated with virulent CMV isolates. The origin of this fragment is not exactly known, but it is possibly associated with a large accumulation of CARNA-5 satellite RNA. This might be one explanation for the abnormally high virulence in cucumber associated with the isolates K31/63 and TK 106/64. In addition to an extra fragment between RNA-3 and RNA-4, no such low molecular RNA as CARNA-5 was found in the fractionated dsRNA of these virus isolates.

Yields of 400 mg purified virus from one kilogram of infected *N. glutinosa* tissue are among the highest values ever reported. Unsuccessful attempts to purify the virus with the method of MOSSOP et al. (1976) indicate that low molar phosphate buffer in virus extraction is unsuitable and a source of particle disruption.

Subcutaneous immunization of rabbits using relatively low amounts of antigens seems to be a convenient means for producing high titered antisera. Some amount of antibodies in the antisera to soluble antigens was expected due to the use of a non-treated immunogen. According to FRANCKI and HABILI (1972) and RICHTER et al. (1975) CMV particles are readily dissociated into fragments without formaline treatment and the relative proportion of antibodies in antisera to soluble antigens may reach a high level. Avoidance of this was not desired, because it allowed for better comparison of some properties of the virus isolates and the test methods. In the present study the isolate 25/85 was found to be very stable and it introduced an antiserum with a small relative proportion of antibodies to soluble antigens. The isolate 2/82 was less stable and it contained a moderate amount of antibodies to the dissociation products.

Double-diffusion tests in agar or agarose are commonly used for the detection and identification of spherical viruses. The technique has

been found especially suitable for CMV, and as little as 8 to 10 μg of antigen can be detected according to DEVERGNE and CARDIN (1970), if the conditions are optimal for the virus. No optimization of the test conditions was attempted in the present study, nevertheless, it was clearly found that in the presence of NaCl, particles of many virus isolates disrupted into fragments which reacted separately with their specific antibodies and formed a straight precipitin line between the antibody well and the curved precipitin line of intact virus particles and their antibodies. Essentially decreased particle disruption in borate agar without NaCl, as also reported by FRANCKI et al. (1966), may indicate possibilities to create optimal test conditions for any CMV isolate.

A very weak serological reaction found with two CMV isolates to a Danish antiserum to tomato aspermy virus agrees with the reports of GOVIER (1957) and DEVERGNE et al. (1981).

Although the Ouchterlony double-diffusion test is reliable for detecting cucumber mosaic virus in purified preparations and in plant extracts, a critical approach is needed for comparison of the results obtained by different laboratories.

Superior detection of CMV with the ELISA compared to gel diffusion tests may result from several factors. The limit of detection of viral antigens with the ELISA is low and less than 1 ng of antigen/ml is detectable according to CLARK and ADAMS (1977) and KURPPA (1983). The lowest records with the double-diffusion test are around 10 μg/ml (DEVERGNE and CARDIN 1970, SHEPARD 1972), which indicates a 1000-fold difference in sensitivity. In the case of CMV, loss of sensitivity in gel diffusion tests also arises from virus disruption in the samples and antibody heterogenity in the antiserum. An ideal CMV antiserum for general detection purposes with the ELISA might contain a minor relative proportion of antibodies to soluble viral proteins without an essential loss of sensitivity. It may cause some loss of strain specificity but this is often a desired property which has been sought through indirect modifications of the ELISA test. Small serological differences between the virus isolates may have been a result of partial particle dissociation in crude plant samples and minor heterogenity in the test antibodies. The level of detection, however, was close to the dilution end point, 10^4, reported by GIBBS and HARRISON (1970), which indicates the very high sensitivity of the test.

Serological methods are reliable and convenient for the detection of CMV for practical purposes. If more information about the strains, types or minor variants is needed, investigation of the genomic properties is necessary. When correctly handled nucleic acids are very stable and genomic properties thus remain unchanged during sample processing for characterization by fractionation or testing with hybridization techniques. The study of viral dsRNA offers an easily available means for describing certain genomic structures. Fractionation of dsRNA also detects the presence of satellite molecules, as well as any other extra nucleic acid components which may increase the severity of disease in certain infected plant species.

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SELOSTUS

Kurkun mosaiikkiviruksen suomalaisten rotujen ominaisuuksia sekä taudinaiheuttamiskyvyn mahdollinen liittyminen perimän ribonukleiinihapon ylimääräisiin osasiin

AARNE KURPPA

Maatalouden tutkimuskeskus

Kurkun mosaiikkivirus (CMV) on yleisimpiä maassamme esiintyviä kasviviruksia. Se on harvoin aiheuttanut epidemioita, mutta merkittävää paikallista vahinkoa se aiheuttaa vuosittain kasvihuonekurkulla, avomaakurkulla ja tomaatilla. Tämän lisäksi CMV on verraten yleinen monissa koristekasveissa ja sitä tavataan myös joskus marjakasveista.

CMV on erittäin helposti muuntuva virus ja sen taudinaiheuttamiskyky on vaihteleva. Pahimmillaan se voi tappaa tomaattikasvustoja tai pilata kurkkuja käyttökelvottomiksi.

Tämän tutkimuksen tarkoituksena oli selvittää äskettäin eristettyjen CMV-rotujen ominaisuuksia ja verrata niitä prof. Linnasalmen 1960-luvulla eristämien rotujen eräisiin ominaisuuksiin sekä tutkia perusteellisesti koko aineiston taudinaiheuttamiskykyä ja siihen vaikuttavia tekijöitä. Myös viruksen nopea luotettava määrittäminen sisältyi tutkimuksen perustavoitteisiin.

Kaikki virusisolaatit aiheuttivat taudinoireita kasvihuone- ja avomaan kurkuissa, kaksi jopa poikkeuksellisen voimakkaita. Myös tomaatissa osa isolaateista aiheutti voimakasta kapealehtisyyttä ja kitukasvuisuutta. Virus tartutti myös joitakin koristekasveja, kuten pensashanhikkia ja syysleimua.

Virus voitiin osoittaa ja määrittää valmistettujen vasta-aineseerumien avulla luotettavasti mistä tahansa tartunnan saaneesta kasvista. Perinteinen geelidiffuusiomenetelmä ei kuitenkaan ollut ongelmaton, koska näytteen viruspartikkelit hajoavat herkästi rakenneosiin testin aikana. Myös vasta-aineiden tunnistamiskyvystä jää tässä menetelmässä suuri osa hyödyntämättä. ELISA-menetelmä (enzyme-linked immunosorbent assay) todettiin viruksen määrittämisessä erittäin luotettavaksi. Testin herkkyys oli yhtä hyvä kuin testikasvien avulla saavutettu. ELISA-menetelmää käytettäessä virusisolaattien erot jäivät oletettua vähäisemmiksi, mikä edelleen lisää tunnistamisluotettavuutta. Vasta-ainetesteissä havaittiin vähäistä sukulaisuutta CMV:n ja tomaatin aspermiaviruksen välillä.

Kaksisäikeis-RNA-menetelmän (dsRNA) avulla eristetty viruksen perimäaines todettiin CMV:lle tyypilliseksi, mutta isolaattien väliset erot olivat selkeitä ja toistettavasti yhdenmukaisia. Viruksen perimä on jakautuneena neljään osaan, joista kolme molekyylipainoltaan suurinta on toiminnallista. Molekyylipainoiltaan kaikkien isolaattien perimän jako-osat olivat lähes yhtäläisiä, mutta osien suhteelliset osuudet vaihtelivat selvästi. Kurkussa erittäin voimakkaita oireita aiheuttaneiden isolaattien perimästä tavattiin RNA-3:n ja RNA-4:n väliltä lisäkomponentti, molekyylipainoltaan noin $0{,}5 \times 10^6$ daltonia, mikä on mahdollisesti yhteydessä voimakkaaseen taudinaiheuttamiskykyyn. Tämä perimän lisäosanen todettiin kaikissa analysoiduissa viruksen tartuttamissa isäntäkasveissa. Pienikokoisia "satelliittimolekyylejä" ei perimäaineksissa tavattu.

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OIL CONTENT AND FATTY ACID COMPOSITION OF OATS

MARKETTA SAASTAMOINEN

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Oil content, fatty acid composition as well as some other agronomic and chemical traits were studied in four oat (*Avena sativa* L.) variety trials of commercial varieties and breeding lines.

Oil content had a slightly positive correlation with grain yield ($r = 0{,}234^{*}$). No significant association was found between oil and protein content. Oil content correlated positively with stearic acid and oleic acid content and negatively with palmitic acid, linoleic acid and linolenic acid concentrations in all trials.

Oleic acid content had a positive association with the stearic acid content ($r = 0{,}245$ — $r = 0{,}611^{**}$). Linoleic acid concentration correlated positively with the linolenic acid concentration ($r = 0{,}271$ — $r = 0{,}647^{***}$) in all trials. High negative correlations were observed between the oleic acid and linoleic acid contents ($r = -0{,}641^{**}$ — $r = -0{,}940^{***}$). The negative correlations can be explained by successive desaturation of linoleic and linolenic acids produced by oleic acid. Protein content correlated positively with linoleic acid content ($r = 0{,}500^{***}$) and negatively with oleic acid content ($r = -0{,}418^{***}$). It is obviously rather easy to breed oat varieties high in protein, and linoleic acid, but it appears to be more difficult to find genotypes with the combination of high protein, high oil and high linoleic acid content.

Index words: oats, *Avena sativa*, oil content, fatty acid composition, protein content.

INTRODUCTION

Oat (*Avena sativa* L.) caryopses contain considerable amounts of oil which increase their nutritional value. Oat oil contains saturated fatty acids, myristic, palmitic and stearic acids, as well as unsaturated fatty acids, oleic, linoleic and linolenic acids. Linoleic acid is essential to mammalian nutrition.

Palmitic acid increases oil stability, while linolenic acid causes oil instability (HAMMOND et al. 1972, THRO et al. 1983). The natural oxidation of linolenic acid forms chemical intermediates that cause poor oil flavor (MOUNTS et al. 1978).

Oat oil contains more oleic, palmitic and linoleic acids than other fatty acids. The fatty acid composition of oats is similar to that of soybean (*Glycine max* (L.) Merr.) in having a high concentration of linoleic acid and a low

concentration of linolenic acid. However, oat oil is more resistant to oxidation than soybean oil is, as the linolenic acid content of oats is lower than that of soybean (KALBASI-ASHTARI and HAMMOND 1977).

In the present study oil content and fatty acid composition were studied in oat breeding material. The dependence of fatty acid composition on oil content and associations between different fatty acid contents were studied. The correlations of oil content and fatty acid composition to other traits were examined, as the effort to improve one trait by plant breeding may impair other characteristics.

MATERIAL AND METHODS

Oil content and its fatty acid composition were studied in four oat variety trials established in 1981 at Jokioinen. All trials employed the rectangular lattice design (COCHRAN and COX 1957).

Fertilization and sowing dates of the trials were the following:

Area of Jokioinen	Trial No	Soil type	Fertilization N kg/ha	P kg/ha	K kg/ha	Sowing date
Kuuma	I	mull (mouldered peat)	131	21	39	19.05.1981
Nummela	II	sandy clay	163	35	65	15.05.1981
Nummela	III	sandy clay	163	35	65	16.05.1981
Ketola	IV	very fine sand	96	42	78	13.05.1981

The trials included commercial oat varieties and breeding lines (Jo lines). The oat material was different for each trial.

Oil content and its fatty acid composition were analysed by the Central Laboratory of the Agricultural Research Centre. Oil contents were analysed by the Soxhlets method. Ether served as an extraction solvent. The fatty acid methyl esters were prepared according to METCALFE and SCHMITZ (1961) and analysed using a Perkin-Elmer Sigma 115 gas chromatograph. A 2 m × 2 mm stainless steel column was packed with 3 % Silar 10C 100/120 Gaschrom Q. Both injector and detector ports were set at 260 °C. Oven temperature was 140 °C 2 min at the beginning then raised to 190 °C at a rate of 5 °C/min. N flow was 20 ml/min. Injected sample size was 1 µl. Nu Chek Prep GLC-63 standard was used in the standardization.

Protein contents were analysed using a NIR (near infrared reflectance) NEOTEC GQA Model 21 analyser. Hull contents were analysed by dehulling 5 g of oat grains and calculating the weight percentage of the hulls from the whole sample.

RESULTS AND DISCUSSION

Small differences in oil content and fatty acid composition were found between the four trials (Table 1). A higher protein content was found in trials II and III, which received the highest nitrogen fertilization. The average oil content of trial IV was slightly lower than that of the

Table 1. Quality characteristics of different oat trials.

Trial	Number of trial members	Protein content %		Oil content %		Myristic acid content %		Palmitic acid content %		Stearic acid content %		Oleic acid content %		Linoleic acid content %		Linolenic acid content %	
	n	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
I	41	12,7	0,83	5,49	0,46	0,11	0,03	18,28	0,73	0,91	0,12	39,14	1,35	38,04	1,38	3,56	0,34
II	42	13,6	0,87	5,37	0,46	0,11	0,02	17,38	0,53	0,83	0,13	36,11	1,06	41,93	0,97	3,63	0,28
III	20	13,3	0,77	5,43	0,45	0,12	0,04	17,70	0,58	0,85	0,14	36,31	1,41	41,42	1,10	3,63	0,28
IV	18	12,7	0,63	5,12	0,48	0,17	0,05	19,42	0,68	1,04	0,11	37,21	0,75	39,31	0,69	2,93	0,16
F-test between trials (F-value)		10,70***		3,02*		15,15***		47,37***		13,06***		51,20***		96,95***		27,73***	

Significance: * $p < 0,05$; *** $p < 0,001$

Table 2. Means ($\bar{x}$) and standard deviations (s) of yield, growing time and grain characteristics of oats in different trials.

Experimental trial	Grain yield kg/ha		Growing time days		1000 grain weight, g		Hull content %	
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
I (n = 41)	3140	258	97	3,17	26,5	1,95	28,9	2,13
II (n = 42)	3900	353	99	2,69	31,6	2,09	25,6	1,15
III (n = 20)	4150	387	98	3,63	31,8	2,05	25,9	1,37
IV (n = 20)	4950	289	96	3,44	36,1	2,32	24,8	1,10
F-test between trials (F-value)	152,64***		8,21***		104,61***		44,11***	

Significance: *** $p < 0,001$

other trials, even though average yield was higher in trial IV than in other trials (Table 2). Oil content correlated, however, somewhat positively with grain yield ($r = 0,234^*$; $p < 0,05$; $n = 121$). FORSBERG et al. (1974), however, have found both positive and negative correlations between oil content and grain yield. No significant correlation between the protein content and oil content was found, which is consistent with the results of FORSBERG et al. (1974).

The correlations between the oil content and different fatty acid contents were toward the same direction throughout the different trials (Table 3). A high oil content is associated with high oleic acid and stearic acid contents and with low palmitic, linoleic and linolenic acid contents. In previous studies it has been found that oil content is positively correlated with oleic acid content, positively or not correlated with stearic acid content, negatively correlated with linoleic acid, and negatively or not correlated with linolenic acid content (FORSBERG et al. 1974, FREY and HAMMOND 1975,

Table 3. Correlation coefficients (r) between oil content and different fatty acid contents in different oat trials.

r	Myristic acid (14:0)	Palmitic acid (16:0)	Stearic acid (18:0)	Oleic acid (18:1)	Linoleic acid (18:2)	Linolenic acid (18:3)
Oil content						
trial I (n = 41)	−0,043	−0,086	+0,026	+0,251	−0,138	−0,272
trial II (n = 42)	−0,052	−0,331*	+0,237	+0,489**	−0,253	−0,435**
trial III (n = 20)	+0,020	<0,453*	+0,486*	+0,769***	−0,744***	−0,277
trial IV (n = 18)	−0,283	−0,469*	+0,473*	+0,293	−0,021	−0,078
Whole oat material (n = 121)	−0,148	−0,236*	+0,154	+0,359***	−0,195*	−0,135

Significance: * $p < 0,05$; ** $p < 0,01$; *** $p < 0,001$

Table 4. Correlation coefficients (r) between different fatty acid concentrations in different oat trials.

r	Palmitic acid (16:0)	Stearic acid (18:0)	Oleic acid (18:1)	Linoleic acid (18:2)	Linolenic acid (18:3)
Palmitic acid					
trial I		−0,965***	0,073	−0,618***	−0,223
trial II		−0,270	−0,334*	−0,150	−0,095
trial III		−0,483*	−0,647**	0,409	−0,131
trial IV		−0,327	−0,462	−0,323	−0,065
Stearic acid					
trial I			0,245	−0,379*	−0,168
trial II			0,376*	−0,332*	−0,107
trial III			0,611**	−0,553*	−0,322
trial IV			0,352	−0,288	0,022
Oleic acid					
trial I				−0,820***	−0,762***
trial II				−0,840***	−0,445**
trial III				−0,940***	−0,337
trial IV				−0,641**	−0,478*
Linoleic acid					
trial I					0,647***
trial II					0,175
trial III					0,271
trial IV					0,368
Linolenic acid					
trial I					
trial II					
trial III					
trial IV					

Significance: * $p < 0,05$; ** $p < 0,01$; *** $p < 0,001$

WELCH 1975, YOUNGS and PÜSKÜLCÜ 1976, de la ROCHE et al. 1977, SAHASRABUDHE 1979, KAROW and FORSBERG 1984). A higher oil content caused by genotype or environment is associated with a higher oleic acid content and a lower linoleic acid content. Breeding for higher oil content increases oleic acid content and decreases linoleic acid content. An increase in energy content is usually associated with impaired fatty acid composition, as linoleic acid is the essential fatty acid for mammals.

The correlation coefficients between the different fatty acid contents were quite similar in all of the trials, even if the genotypes in these trials were essentially different (Table 4). The oleic and stearic acid contents and the linoleic and linolenic acid contents correlated positively. The oleic acid content correlated negatively with the linoleic and linolenic acid contents. The correlations found are mainly consistent with the results of FORSBERG et al. (1974).

The negative correlation between oil content and linoleic acid content may make it difficult to breed high oil, high linoleic acid oat cultivars. Oil content is positively correlated with the oleic acid content, while oleic acid and linoleic acid contents are negatively correlated. There is conclusive evidence that linoleic and linolenic acids are produced from oleic acid by successive desaturation (CHERIF et al. 1975) which may explain the correlations between these fatty acids (KAROW and FORSBERG 1984). Similar evidence has been obtained by breeding soybean for a high oleic acid content. Selection for high oleic acid content has thus caused a simultaneous decrease in linoleic and linolenic acid concentrations (WILSON et al. 1981, BURTON et al. 1983).

Protein content had no significant correla-

tion with oil content. However, protein content correlated significantly with the different fatty acid contents. The following significant correlations were found between the protein content and different fatty acid contents:

palmitic acid content: $r = -0{,}331^{***}$
stearic acid content: $r = -0{,}369^{***}$
oleic acid content: $r = -0{,}418^{***}$
linoleic acid content: $r = +0{,}500^{***}$
(*** $p < 0{,}001$).

Protein content correlated positively with linoleic acid content and negatively with palmitic, stearic and oleic acid contents. The negative correlation between protein and oleic acid content and the positive correlation between the protein and linoleic acid content gives the impression that the association between the oil and protein content is negative even if no significant correlation was found. BROWN et al. (1966) have found significant negative correlations between the oil and protein content in spring and winter oats.

The possible positive association between protein content and linoleic acid content can make the breeding of oat varieties with high nutritive value easier. The negative correlation between the oil content and the linoleic acid content may, however, make it more difficult to breed high protein, high oil, high linoleic acid oat cultivars.

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SELOSTUS

Kauran öljypitoisuus ja sen rasvahappokoostumus

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Maatalouden tutkimuskeskus

Kauran öljypitoisuutta ja öljyn rasvahappokoostumusta tutkittiin neljässä lajikekokeessa olleissa kauralajikkeissa ja linjoissa. Kauran rasvapitoisuus oli keskimäärin 5 % kuiva-aineesta. Kauran rasvassa on paljon palmitiinihappoa, öljyhappoa ja linolihappoa, lisäksi siinä on pieniä määriä myristiinihappoa, steariinihappoa ja linoleenihappoa. Linolihappo on välttämätön rasvahappo nisäkkäille. Palmitiinihappo lisää öljyn säilyvyyttä, pysyvyyttä ja linoleenihappo taas aiheuttaa sen epästabiilisuuden, alttiuden hapettumiselle.

Eri koepaikoissa kasvaneiden kokeiden välillä oli pieniä eroja öljypitoisuudessa, rasvahappokoostumuksessa ja muissa viljelyksellisissä ja laatuominaisuuksissa.

Satoisissa kauralajikkeissa oli hiukan korkeampi öljypitoisuus kuin vähemmän satoa tuottavissa. Öljypitoisuudella ei ollut muuten merkittävää suhdetta muihin viljelyominaisuuksiin. Öljyn rasvahappokoostumus sen sijaan oli riippuvainen öljyn määrästä. Kauralajikkeissa, joissa oli korkea öljypitoisuus, oli keskimäärin enemmän steariinihappoa ja öljyhappoa ja keskimäärin vähemmän palmitiinihappoa, linolihappoa ja linoleenihappoa. Myös korkea öljyhappopitoisuus oli yhdistyneenä korkeaan steariinihappopitoisuuteen ja korkea linolihappopitoisuus oli yhdistyneenä korkeaan linoleenihappopitoisuuteen. Erityisesti öljyhappo- ja linolihappopitoisuuden välillä vallitsee negatiivinen vuorovaikutussuhde: korkeaan öljyhappopitoisuuteen oli yhdistynyt matala linolihappopitoisuus ja päin vastoin. Tämä selittynee sillä, että linoli- ja linoleenihappo syntetisoidaan (= tuotetaan) öljyhaposta.

Niissä kauralajikkeissa, joissa oli keskimäärin enemmän valkuaista, oli samalla hiukan vähemmän öljyhappoa, useimmiten niissä oli myös keskimäärin vähemmän palmitiinihappoa ja steariinihappoa. Korkea valkuaispitoisuus oli melko usein yhdistynyt korkeaan linolihappopitoisuuteen.

Rasvahappokoostumuksen riippuminen öljypitoisuudesta saattaa vaikeuttaa jalostustyötä. Korkean linolihappo- ja öljypitoisuuden yhdistäminen samaan lajikkeeseen näyttää vaikealta. Korkean valkuaispitoisuuden ja linolihappopitoisuuden välinen positiivinen vuorovaikutussuhde saattaa kuitenkin helpottaa ravintoarvoltaan korkeatasoisten kauralajikkeiden jalostusta.

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CHANGES IN THE WEED POPULATION OF SPRING CEREALS IN FINLAND

LEILA-RIITTA ERVIÖ and JUKKA SALONEN

ERVIÖ, L-R. & SALONEN, J. 1987. **Changes in the weed population of spring cereals in Finland.** Ann. Agric. Fenn. 26: 201—226. (Agric. Res. Centre, Dept. Crop Sci., SF-31600 Jokioinen, Finland.)

The number and weight of weeds in spring cereal fields have decreased to about one-third of the values detected in the early 1960s. In 1982—84 spring cereal fields had an average of 173 weeds/m^2 with a dry weight of 320 kg per hectare. The most common and most abundant species were the annuals *Chenopodium album, Stellaria media, Viola arvensis, Galeopsis* spp. and the perennial *Elymus repens.* The frequency of some annual species resistant to MCPA has increased. Of the grass weeds, *Elymus repens* has become more widespread, and more attention should be paid to its control. The annual *Spergula arvensis* and several perennial weeds have become less frequent.

A few species account for most of the problems caused by weeds in spring cereals. Six weed species amount to 62 % of the total weed number, and three species account for 51 % of the air-dry weight of weeds in fields. Single factors proved to affect the occurrence of weeds only in few cases in this study.

Index words: weeds, weed species, weed population, occurrence of weeds, frequency, number, abundance, weight, weed flora changes, reasons for changes, spring cereals, Finland.

INTRODUCTION

In the 1960s and 1970s, the Department of Crop Science of the Agricultural Research Centre carried out an extensive study on the occurrence of weeds in spring cereals, leys and winter cereals (MUKULA et al. 1969, RAATIKAINEN and RAATIKAINEN 1975, RAATIKAINEN et al. 1978). Farming methods have changed and management techniques developed since the study on spring cereals carried out in 1962—64 (RAATIKAINEN 1986). To large extend, farms growing cereal no longer have livestock, and manure has been replaced by artificial fertilizers. Placement of fertilizers under the seed bed, combine harvesters and herbicides are now in common use. These changes, as well as any changes in cultivation techniques, have obviously affected the weed populations. A new survey on weeds in spring cereals was therefore considered necessary.

The new study was carried out in 1982—84 to determine not only the occurrence of weeds but also the economic significance of the use of herbicides in spring cereals. The study was financed by the Ministry of Agriculture and

Forestry and the following institutes participated in the work: the Agricultural Research Centre's Department of Crop Science and Department of Soil Science, the University of Helsinki's Department of Horticulture and the National Agricultural Advisory Organizations (MKL and SLF).

The results of the study presented in this paper deal with the frequency, abundance and weight of weeds in areas that were not treated with herbicides in the year of the study, and the changes in weed population in comparison with the situation in the 1960s.

MATERIAL AND METHODS

Localities, fields and farms

In the main, the study was carried out using the same methods that were applied in 1962—64. The methods as well as the data on the cultivation of cereals in Finland were presented in detail in a report issued in 1969 (MUKULA et al. 1969).

As a result of available resources, the new study covered a smaller area than the previous one. In order to follow up the possible changes in weed flora, ten localities were chosen amongst the 32 localities studied in 1962—64 (Fig. 1).

The purpose was to select 35 fields from each area that had been surveyed previously.

Year		Localities	Fields 1982–84	1962–64
1982	1	Lieto/Paimio	36	8
	2	Forssa/Tammela	33	20
		Total	69	28
1983	3	Laihia	26	8
	4	Laitila	25	25
	5	Nurmijärvi	25	23
	6	Mikkelin mlk	23	18
		Total	99	74
1984	7	Kitee	25	19
	8	Laukaa/Toivakka	25	15
	9	Nauvo/Korppoo	26	15
	10	Nivala	23	4
		Total	99	53
1982–84		Total	267	155

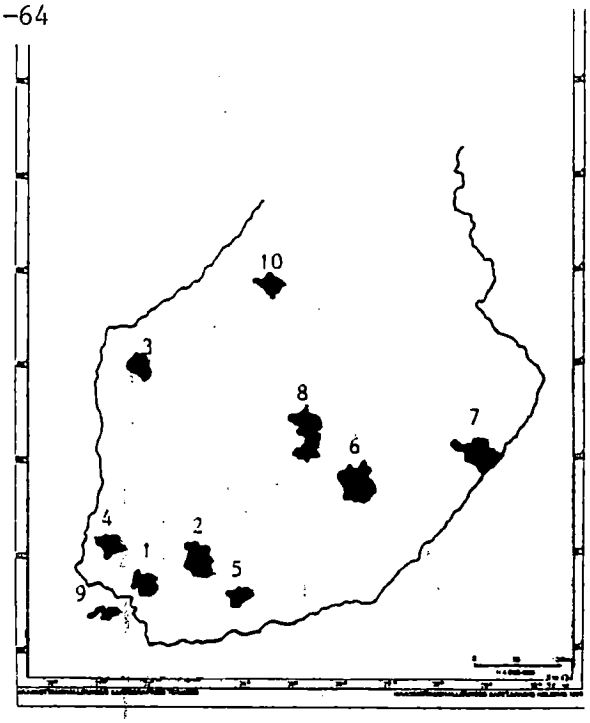

Fig. 1. Localities and number of fields.

Because of the agricultural changes since the 1960s, not all the farms surveyed previously could be included. Such farms were replaced with the assistence of municipal agricultural secretaries. However, the number of fields was less than the set number, with the exception of localities 1 and 2, where the survey was carried out in 1982. Four localities with 23—26 fields per each were studied in the following two years. A total of 267 fields were assessed, of which 155 fields had also been studied in 1962—64. These fields were distributed among the study localities very unevenly (Fig. 1).

In all, the study comprised 161 cereal-growing farms. Their size according to arable land can be classified as follows:

under 5 hectares	1 farm	=	0,6 %
5—10 hectares	14 farms	=	8,7 %
10—25 hectares	74 farms	=	46,0 %
25—50 hectares	46 farms	=	28,6 %
over 50 hectares	26 farms	=	16,1 %

Sampling

Farms were visited first time immediately after sowing in order to position the sample plots in the fields. Arable land with the same soil type, preceding crop and the same spring cereal was considered a study field. Data on the cultivation history and farming methods used for fields were obtained from farmers.

The sample plots of each field were determined by random selection. Weed assessments were done from four marked plots per field, 180 by 240 cm in size during the summer. The farmers themselves treated their fields. Before herbicide application the farmers used a plastic film, to cover plots not to be sprayed.

Weed samples were taken during the latter half of July. A circle frame of 0,25 m^2 in size was used for weed sampling in each marked plot. Further, soil samples were taken from the fields, to be determined for soil type and pH.

Assessments

The present study was restricted to the most important weed species occurring in spring cereal fields. For this reason the species and taxa were determined only for 35 weeds set in advance (Table 3). Other species were recorded in the group labelled 'others'.

The weeds were cut at the soil surface and taken to the laboratory, where they were sorted and counted. After air drying the weeds were weighed by species.

In connection with sampling, observations were made of the cover of crop and weeds in each sampling area.

Factors explaining occurrence

To find some factors possibly explaining the changes in the occurrence of weeds the variables given in Table 1 were subjected to variance analysis and selective regression analysis.

Field characteristics

To explain the characteristics of the field, attention was paid to distance from the farmstead by road, drainage, moisture and soil type.

Most of the studied fields were situated in the immediate vicinity of the farmstead or at a distance of not more than 1 000 metres. A little less than a quarter of the fields surveyed were located more distantly.

Subsurface-drainage was common in the fields studied. There were more fields without ditches than with open ditches. The moisture of the fields could usually be regarded as normal. Some 16 % of fields suffered from drought, and 5 % were too wet.

Mineral soil was prevalent in the fields of this study, which were distributed almost evenly between coarse mineral soils and clays.

Table 1. Variables studied as factors regulating the occurrence of weeds and its changes, and distribution of the material of the classified variables.

Classified factors		
DISTANCE OF FIELD FROM THE FARMSTEAD		
less than 100 m	97 fields	= 36 %
less than 1000 m	107 »	= 40 %
more than 1000 m	63 »	= 24 %
DRAINAGE OF THE FIELD		
open ditches	39 fields	= 15 %
subsurface-drainage	175 »	= 65 %
no ditches	53 »	= 20 %
MOISTURE CONDITIONS OF THE FIELD		
dry	42 fields	= 16 %
normal	212 »	= 79 %
wet	13 »	= 5 %
SOIL TYPE		
coarse mineral soils	116 fields	= 43 %
clay soils	120 »	= 45 %
organic soils	31 »	= 12 %
LIMING DURING PREVIOUS 10 YEARS		
no liming	84 fields	= 32 %
limed	182 »	= 68 %
MANURING		
not used	188 fields	= 70 %
used	79 »	= 30 %
FERTILIZING METHOD		
placement of fertilizers	218 fields	= 82 %
surface fertilizing	46 »	= 17 %
ARTIFICIAL N-FERTILIZING		
with manuring:		
N less than 60 kg/ha	49 fields	= 62 %
N 60—90 kg/ha	26 »	= 33 %
N more than 90 kg/ha	4 »	= 5 %
total	79 »	= 100 %
without manuring:		
N less than 60 kg/ha	32 fields	= 17 %
N 60—90 kg/ha	106 »	= 56 %
N more than 90 kg/ha	50 »	= 27 %
total	188 »	= 100 %
SPECIES OF CEREAL		
spring wheat	55 fields	= 21 %, 131 ha = 27 %
barley	111 »	= 41 %, 200 ha = 41 %
oats	101 »	= 38 %, 157 ha = 32 %
total	267 »	488 ha
INSOWN LEY		
no insown	224 fields	= 84 %
ley sown	43 »	= 16 %
CEREAL DOMINATION		
cereals succeedingly		
at least 3 years	150 fields	= 56 %
less than 3 years	117 »	= 44 %
PRECEDING CROPS		
fallow	2 fields	= 1 %
ley	41 »	= 15 %
winter cereals	16 »	= 6 %
spring cereals	182 »	= 68 %
potato	3 »	= 1 %
sugar beet	3 »	= 1 %
turnip rape/rape	17 »	= 7 %
peas	3 »	= 1 %
CLASSIFIED PRECEDING CROP		
cereal	198 fields	= 74 %
ley	41 »	= 15 %
others	28 »	= 11 %
HERBICIDE TREATMENT DURING 9 PREVIOUS YEARS		
no herbicides	9 fields	= 3 %
1—3 years	49 »	= 19 %
4—6 years	72 »	= 27 %
7—9 years	137 »	= 51 %
TREATMENT OF PRECEDING CROP		
untreated	51 fields	= 19 %
MCPA	58 »	= 22 %
MCPA mixtures	68 »	= 25 %
other herbicide	21 »	= 8 %
COMBINE HARVESTING DURING PREVIOUS 9 YEARS		
no combiner harvesting	3 fields	= 1 %
1—3 years	54 »	= 20 %
4—6 years	83 »	= 31 %
7—9 years	127 »	= 48 %
Other factors		
cereal cover in field:	minimum	13 %
	maximum	100 %
effective temperature sum between sowing and sampling	minimum	281,8 dd
	maximum	856,7 dd
pH of soil:	minimum	4,85
	maximum	7,65
P-fertilization		
K-fertilization		

Twelve per cent of the fields were situated on organic soils.

Liming and fertilizing

A majority of the fields had been limed in the course of ten years preceding the study, but 32 % of the fields were unlimed. Manure had been used only on 30 % of the fields. When manure was spread, the use of artificial fertilizers was usually smaller than 60 kg nitrogen per hectare. One third of the fields fertilized with manure received additionally 60—90 kg of nitrogen per hectare. When only

artificial fertilizers were used, more than one half of the fields had received 60—90 kg of nitrogen per hectare.

The principal method of fertilizing was placement under the seed bed.

Crops

Cereal species were distributed unevenly between the localities (Table 2). This concerned especially wheat fields. Barley was distributed relatively evenly to the study areas and also oats was cultivated in all the localities.

Most of our study was conducted in the localities where the proportion of ley cultivation was low. This was also reflected in the number of fields with insown ley. Only 16 % of the fields were sown with a spring cereal and ley in the years of the study.

Fields where cereals had been cultivated for at least three successive years out of four before the study, were classified as with cereal predominating fields. More than half of the fields surveyed were of this kind, for which reason cereals were the dominant preceding crops also in the year prior to the study. During the last four years preceding the study, spring cereals had been grown continually in most of the fields.

Herbicide treatment of fields

Herbicide treatment was common practice in the fields in this study. In more than 50 % of the fields, weeds had been controlled with herbicides for at least seven to nine years during the last nine years. The share of fields, where herbicides had not been used at all during the preceding nine years, was only 3 % of the total number of fields.

In the year prior to the study, in 51 fields the preceding crop had not been treated with herbicide. The majority of these untreated fields was cultivated leys, which are usually not treated with herbicides in Finland, with the exception of the sowing year.

Table 2. Distribution of spring cereal species between the localities in 1982—84.

Locality	Number of fields		
	Wheat	Barley	Oats
1	17	11	8
2	6	15	12
3	2	12	12
4	3	13	9
5	11	9	5
6	0	6	17
7	2	10	13
8	3	14	8
9	11	6	9
10	0	15	8
Total	55	111	101

In about every fifth field, the preceding crop had been treated with MCPA, and in every fourth field with a herbicide mixture containing MCPA. Other herbicides had been used in 8 % of the fields.

Combine harvesting

Information about the use of combine harvesting in the fields concerned nine successive years before the study. Combine harvesting was the most common method of harvesting spring cereals. In almost half of the fields, it had been used for at least seven to nine years and in one third of the fields for four to six years. In every fifth field, combine harvesting was a less common method. In these cases, other crops besides cereals had been cultivated in the fields. Only one per cent of the cereal fields were still harvested without a combine harvester.

Other factors

Amongst the other variables, attention was paid to the cover of the cereal, the effective temperature sum and precipitation in the interval between sowing and weed sampling, the pH value of the fields, and P- and K-fertilization.

The cover of the cereal was estimated to be

13 % in the thinnest crop and 100 % in the densest crop.

The weather data had been gathered in pentades at the official meteorological station nearest to each locality. The effective temperature sum for crop was determined according to the sowing date and the sampling date of each field.

The pH-value of soil varied a great deal in the fields studied. The lowest pH value detected in the top layer of 20 cm was 4,85 and the highest 7,65.

RESULTS

Frequency of weed species

Frequency is used to express the percentage proportion of fields in which certain species was observed. Of the 35 weed species included in the study, 34 were found among spring cereals, the only exception being *Solanum nigrum*, which is mainly a weed of vegetable cultivations. The most common annual species, were *Chenopodium album*, *Galeopsis* spp., *Viola arvensis* and *Stellaria media* which occurred in more than 80 % of fields. Of perennial species, *Elymus repens* was clearly the most common (Table 3).

The most common species were found in all localities surveyed, but their frequency and order varied according to each locality (Table 3). By contrast, some species were found more frequently only in a few localities. These included such annual species as *Lamium* spp., *Tripleurospermum inodorum* (including *M. recutita* L.), *Galium* spp., *Spergula arvensis* and *Erysimum cheiranthoides*, which were among the ten most common species only in some localities.

Abundance of weeds

Abundance is used to express the average number of weeds/m^2. In the 267 spring cereal fields of this survey it was 173 plants/m^2 (Table 4). The most abundant annual species/taxa were *Chenopodium album*, *Stellaria media*, *Viola arvensis*, *Galeopsis* spp. and *Lapsana communis*. Of the perennial species, *Elymus repens* was the most numerous.

The number of weeds varied according to cereal species, locality and year (Tables 4 and 5). The most dense weed stands were in areas 5 and 9. The lowest number of plants/m^2 grew in area 10. The five most abundant species in the various localities were mostly the same, although the number of plants/m^2 varied. *Chenopodium album*, *Galeopsis* spp., *Stellaria media* and *Viola arvensis* were usually among the most abundant annual weeds. Of the perennial weeds, *Elymus repens*, *Sonchus arvensis* and/or *Ranunculus repens* were the most abundant in all localities.

Percentages of species of the total number of weeds

The relative importance of the various weed species was compared by examining the percentage of each species of the average number of weeds in the fields. Altogether six species accounted for 61 % of the total number of weed plants or shoots (Fig. 2). Of the individual species, *Chenopodium album* and *Stellaria media* had the highest percentages.

Examination by localities showed that the three most important species accounted for 41 to 62 % of the total number of weeds (Table

Table 3. Frequencies of weed species (taxa) in spring cereal fields.

Species	Year/locality										
	1982		1983				1984				Average
	1	2	3	4	5	6	7	8	9	10	1982—84
1. *Achillea* spp. L.	0	3	0	0	8	13	28	12	0	0	6
2. *Avena fatua* L.	0	0	0	8	0	0	0	0	0	0	1
3. *Brassica* spp. L. cultivated	44	30	4	0	20	4	0	0	12	0	13
4. *Brassicaceae* others	6	6	19	8	20	39	16	0	0	9	12
5. *Capsella bursa-pastoris* L. Medicus	19	24	4	4	28	35	12	28	12	0	17
6. *Chenopodium album* L.[1]	97	91	85	84	84	83	92	84	100	74	88
7. *Cirsium arvense* (L.) Scop.	3	3	8	0	4	4	4	0	12	13	5
8. *Elymus repens* (L.) Gould	28	52	46	72	40	70	92	24	27	70	51
9. *Equisetum* spp. L.	31	9	8	8	12	12	0	8	27	9	13
10. *Erysimum cheiranthoides* L.	22	76	69	56	56	65	68	80	42	65	59
11. *Fallopia convolvulus* (L.) A. Löve	78	55	69	52	84	57	60	36	65	43	61
12. *Fumaria officinalis* L.	61	48	23	24	72	39	52	52	31	4	42
13. *Galeopsis* spp. L.	92	91	88	68	100	91	96	84	58	78	85
14. *Galium* spp. L.	36	30	46	44	64	9	20	8	73	13	35
15. *Gnaphalium uliginosum* L.	0	15	46	20	8	35	4	28	12	13	17
16. *Lamium* spp. L.	36	18	8	24	64	0	0	16	69	0	24
17. *Lapsana communis* L.	39	61	0	48	72	91	64	84	88	0	54
18. *Matricaria matricarioides* (Less.) Porter	3	12	27	20	16	35	12	20	12	39	18
19. *Myosotis* spp. L.	31	52	46	44	68	78	60	56	73	30	53
20. *Poa annua* L.	0	9	19	24	12	22	20	36	0	9	14
21. *Polygonum aviculare* L.[2]	36	61	65	76	36	74	52	32	54	48	53
22. *Polygonum lapathifolium* L.	25	36	31	36	20	48	32	16	46	22	31
23. *Ranunculus repens* L.	0	6	19	4	16	13	20	24	27	57	17
24. *Rumex* spp. L.	0	24	8	4	4	22	28	0	4	17	11
25. *Senecio vulgaris* L.	0	0	0	0	0	0	0	4	4	0	1
26. *Solanum nigrum* L.	0	0	0	0	0	0	0	0	0	0	0
27. *Sonchus arvensis* L.	33	39	4	8	24	4	24	36	54	35	27
28. *Sonchus* spp. others	0	0	0	0	0	13	4	20	4	0	4
29. *Spergula arvensis* L.	19	58	54	44	28	83	12	72	65	26	45
30. *Stachys palustris* L.	0	3	0	0	0	0	0	0	4	0	1
31. *Stellaria media* (L.) Vill.	89	91	65	92	96	78	68	80	92	52	81
32. *Thlaspi arvense* L.	22	24	8	8	20	9	20	8	27	4	16
33. *Tripleurospermum inodorum* Schulz Bip.[3]	39	42	23	12	44	26	12	24	73	9	31
34. *Urtica* spp. L.	0	3	4	8	0	0	12	0	0	0	3
35. *Viola arvensis* Murray[4]	75	76	92	92	92	87	96	80	96	61	84
Other monocotyledons	6	30	62	36	28	39	60	44	4	39	33
Other dicotyledons	25	52	58	60	60	61	96	44	65	43	55

1) Including *Atriplex patula* L.
2) Including *P. arenastrum* Boreau
3) Including *M. recutita* L.
4) Including *V. tricolor* L.

6), but these three species were not the same in all areas. Most often the group included *Chenopodium album, Galeopsis* spp. and *Viola arvensis.*

Number of weeds in infested fields

The number of weeds in infested fields gives the average number of plants/m^2 in those fields, where the species was found. In the case of species which were rare or grew only in some areas, this figure differed much from the abundance (Table 7). Thus the average number of *Stachys palustris, Matricaria matricarioides* and *Lamium* spp. in infested fields rose to the same level with the most abundant species. *Poa annua* and *Fumaria officinalis* were also numerous in fields where they were found. "Grassland weeds" were comparatively numerous in their

Table 4. Average number of weeds/m² in all the fields studied.
+ indicates < 1 plant/m².

Species	Year/locality										
	1982		1983				1984				Average
	1	2	3	4	5	6	7	8	9	10	1982—84
1. *Achillea* spp.	0	+	0	0	+	+	2	1	0	0	+
2. *Avena fatua*	0	0	0	+	0	0	0	0	0	0	+
3. *Brassica* spp. cultivated	3	2	+	0	3	+	0	0	1	0	1
4. *Brassicaceae* others	+	+	+	+	+	5	1	0	0	+	1
5. *Capsella bursa-pastoris*	+	1	+	+	+	2	+	1	+	0	+
6. *Chenopodium album*[1]	20	24	24	16	30	10	27	8	62	10	23
7. *Cirsium arvense*	+	+	+	0	+	+	+	0	+	+	+
8. *Elymus repens*	2	8	10	9	5	46	51	1	6	10	14
9. *Equisetum* spp.	1	+	+	+	+	+	0	1	1	+	1
10. *Erysimum cheiranthoides*	1	6	9	5	8	3	12	9	2	2	5
11. *Fallopia convolvulus*	6	5	5	2	12	2	3	1	4	2	4
12. *Fumaria officinalis*	5	7	1	2	19	1	3	5	2	+	5
13. *Galeopsis* spp.	17	11	26	25	37	7	16	10	5	7	16
14. *Galium* spp.	1	2	5	3	5	+	+	+	5	+	2
15. *Gnaphalium uliginosum*	0	2	8	1	1	2	+	2	+	+	2
16. *Lamium* spp.	7	2	1	9	17	0	0	1	29	0	7
17. *Lapsana communis*	1	5	0	28	9	37	28	24	12	0	13
18. *Matricaria matricarioides*	+	2	1	1	+	12	+	3	36	2	5
19. *Myosotis* spp.	1	4	4	5	5	15	4	5	4	2	5
20. *Poa annua*	0	5	5	2	+	2	3	2	0	1	2
21. *Polygonum aviculare*[2]	1	2	2	2	3	2	2	1	3	1	2
22. *Polygonum lapathifolium*	1	1	1	2	1	2	4	+	5	6	2
23. *Ranunculus repens*	0	+	1	+	+	1	1	1	2	3	1
24. *Rumex* spp.	0	3	+	+	+	2	3	0	+	+	1
25. *Senecio vulgaris*	0	0	0	0	0	0	0	+	+	0	+
26. *Solanum nigrum*	0	0	0	0	0	0	0	0	0	0	0
27. *Sonchus arvensis*	2	1	+	1	2	+	+	2	4	1	1
28. *Sonchus* spp. others	0	0	0	0	0	1	1	+	+	0	+
29. *Spergula arvensis*	1	15	3	7	1	18	4	8	6	4	7
30. *Stachys palustris*	0	+	0	0	0	0	0	0	2	0	+
31. *Stellaria media*	30	32	20	21	46	15	5	9	17	4	21
32. *Thlaspi arvense*	1	2	1	+	1	+	2	+	3	+	1
33. *Tripleurospermum inodorum*[3]	1	2	1	+	1	8	+	1	11	+	3
34. *Urtica* spp.	0	+	+	+	0	0	+	0	0	0	+
35. *Viola arvensis*[4]	3	20	26	18	33	16	27	20	24	6	19
Other monocotyledons	+	18	3	1	1	11	11	1	+	3	5
Other dicotyledons	1	4	3	2	8	3	9	1	11	2	4
Total	107	186	161	165	249	222	220	119	254	67	173

1) Including *Atriplex patula* L.
2) Including *P. arenastrum* Boreau
3) Including *M. recutita* L.
4) Including *V. tricolor* L.

habitats. The regional variation was similar to that in abundance figures, but appeared to be more marked.

Weight of weeds

The average air-dry weight of weeds gathered from untreated spring cereal fields was 320 kg/ha. The weight varied annually and regionally from 100 to 680 kg/ha.

The most abundant species also produced the highest weight (Table 8). The highest yield was produced by *Elymus repens* taking into account all fields studied. The next important species were four annuals. All in all 12 species produced an average of at least 10 kg/ha of air-dry weight per hectare.

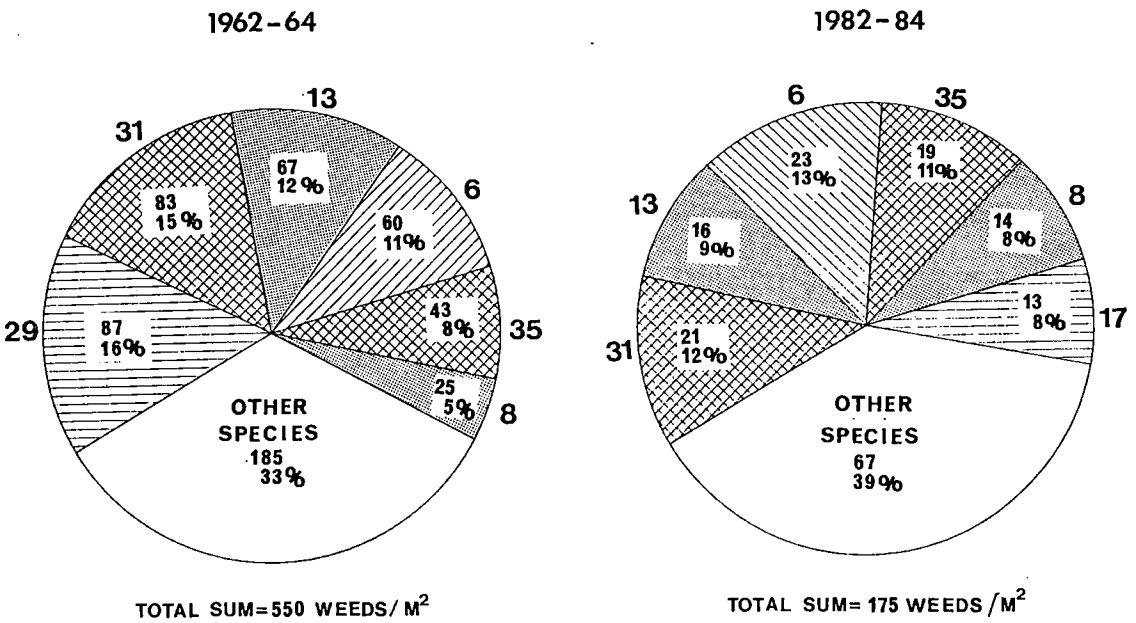

Fig. 2. Proportions of the most important species of the total number of weeds. Weeds: 6 = *Chenopodium album*, 8 = *Elymus repens*, 13 = *Galeopsis* spp., 17 = *Lapsana communis*, 29 = *Spergula arvensis*, 31 = *Stellaria media*, 35 = *Viola arvensis*.

Table 5. Number and weight of the most abundant weeds in spring cereals in 1982—1984. The table comprises only those weeds of which was found at least 5 plants/m² in each cereal species.

Weed	Plants/m²			Weight kg/ha		
	Wheat	Oats	Barley	Wheat	Oats	Barley
Chenopodium album	37	25	15	69	64	20
Stellaria media	38	16	16	33	22	16
Viola arvensis	22	17	19	10	9	7
Galeopsis spp.	29	14	12	80	47	40
Lapsana communis	12	18	10	21	28	15
Lamium spp.	22	3	2	15	3	1
Spergula arvensis	3	10	6	5	17	12
Erysimum cheiranthoides	5	5	6	7	8	10
Fumaria officinalis	9	3	4	8	4	6
Fallopia convolvulus	9	3	3	15	6	5
Myosotis spp.	5	5	4	3	3	2
11 annuals total	191	119	97	266	211	134
Elymus repens	6	24	9	29	106	44
Weeds total	220	193	132	348	410	219

The importance of the various weed species is reflected particularly by the weed weight in those fields where the species is found (Fig. 3). In this case *Elymus repens* was still in the first place, but also *Sonchus* spp. and *Avena fatua* produced more mass than average. *Stachys palustris, Cirsium arvense* and *Sonchus arvensis* proved to be more important than what could be induced from the whole material. Ranked according to the percentages of the total weed mass gathered, the most important species had the following order:

Elymus repens	20 %
Galeopsis spp.	16 %
Chenopodium album	15 %
Stellaria media	7 %
Lapsana communis	7 %
Spergula arvensis	4 %
Erysimum cheiranthoides	3 %
Viola arvensis	3 %
Fallopia convolvulus	2 %
Sonchus arvensis	2 %

The first three species form a group of their own. Their combined proportion of total weed

Table 6. The proportion of the three most important species of the total number and weight of weeds in each locality.

Locality number	Species/proportion of plant number	%	Species/proportion of weight	%
1	*Stellaria media*	28	*Elymus repens*	21
	Chenopodium album	18	*Galeopsis* spp.	20
	Galeopsis spp.	16	*Stellaria media*	14
	Together	62		55
2	*Stellaria media*	18	*Galeopsis* spp.	16
	Chenopodium album	13	*Stellaria media*	14
	Viola arvensis	11	*Spergula arvensis*	12
	Together	42		42
3	*Galeopsis* spp.	16	*Elymus repens*	33
	Viola arvensis	16	*Elymus* spp.	30
	Chenopodium album	15	*Chenopodium album*	9
	Together	47		73
4	*Lapsana communis*	17	*Galeopsis* spp.	31
	Galeopsis spp.	15	*Stellaria media*	13
	Stellaria media	13	*Lapsana communis*	11
	Together	45		55
5	*Stellaria media*	18	*Galeopsis* spp.	34
	Galeopsis spp.	15	*Stellaria media*	16
	Viola arvensis	13	*Fallopia convolvulus*	8
	Together	46		58
6	*Elymus repens*	21	*Elymus repens*	40
	Lapsana communis	17	*Lapsana communis*	11
	Spergula arvensis	8	*Stellaria media*	8
	Together	46		59
7	*Elymus repens*	23	*Chenopodium album*	24
	Lapsana communis	13	*Elymus repens*	24
	Viola arvensis	12	*Galeopsis* spp.	11
	Together	48		59
8	*Lapsana communis*	20	*Galeopsis* spp.	20
	Viola arvensis	17	*Lapsana communis*	16
	Galeopsis spp.	9	*Chenopodium album*	16
	Together	46		52
9	*Chenopodium album*	24	*Chenopodium album*	31
	Matricaria matricarioides	14	*Elymus repens*	11
	Lamium spp.	11	*Galeopsis* spp.	9
	Together	49		51
10	*Elymus repens*	15	*Elymus repens*	35
	Chenopodium album	15	*Chenopodium album*	21
	Galeopsis spp.	11	*Polygonum lapathifolium*	11
	Together	41		67

mass was 51 %. The three most important species also made up 42—73 % of the weed mass growing in the fields of each locality (Table 6). These species varied to some extent, but most often they included *E. repens* and *Galeopsis* spp.

Factors affecting the occurrence of weeds

This study indicated that the effects of the factors regulating the occurrence of weeds were interconnected. The significance of certain individual factors proved to be statistically reli-

Table 7. Average number of weeds/m² in the infested fields.

Species	Year/locality										
	1982		1983				1984				Average 1982—84
	1	2	3	4	5	6	7	8	9	10	
1. *Achillea* spp.	0	1	0	0	5	2	6	10	0	0	6
2. *Avena fatua*	0	0	0	5	0	0	0	0	0	0	5
3. *Brassica* spp. cultivated	6	8	1	0	16	1	0	0	4	0	8
4. *Brassicaceae* others	2	1	1	2	1	12	4	0	0	1	5
5. *Capsella bursa-pastoris*	2	2	1	2	1	5	2	3	1	0	3
6. *Chenopodium album*[1]	20	27	28	20	36	13	29	10	62	13	27
7. *Cirsium arvense*	4	1	2	0	1	1	1	0	3	3	2
8. *Elymus repens*	9	16	22	13	13	66	55	4	22	14	28
9. *Equisetum* spp.	4	4	1	2	3	3	0	15	5	3	4
10. *Erysimum cheiranthoides*	5	8	13	9	15	5	17	11	4	2	9
11. *Fallopia convolvulus*	8	9	8	3	14	3	6	2	6	4	7
12. *Fumaria officinalis*	8	14	5	7	26	2	7	10	7	6	11
13. *Galeopsis* spp.	18	12	30	37	37	8	17	12	8	9	19
14. *Galium* spp.	3	6	10	8	8	2	1	3	7	1	6
15. *Gnaphalium uliginosum*	0	10	17	3	16	4	3	7	1	3	9
16. *Lamium* spp.	19	11	9	40	26	0	0	5	41	1	27
17. *Lapsana communis*	3	8	0	59	13	41	43	28	13	0	25
18. *Matricaria matricarioides*	10	13	4	3	2	35	1	17	309	5	30
19. *Myosotis* spp.	3	7	9	11	7	20	6	10	5	5	9
20. *Poa annua*	0	50	25	9	2	9	13	4	0	7	13
21. *Polygonum aviculare*[2]	3	4	4	3	8	2	5	3	6	3	4
22. *Polygonum lapathifolium*	2	4	3	4	3	3	12	1	11	27	7
23. *Ranunculus repens*	0	6	4	1	1	6	3	3	6	5	4
24. *Rumex* spp.	0	11	2	1	2	7	10	0	3	3	7
25. *Senecio vulgaris*	0	0	0	0	0	0	0	1	1	0	1
26. *Solanum nigrum*	0	0	0	0	0	0	0	0	0	0	0
27. *Sonchus arvensis*	6	3	5	11	7	3	2	6	8	2	5
28. *Sonchus* spp. others	0	0	0	0	0	0	23	1	3	0	5
29. *Spergula arvensis*	3	26	5	15	4	22	36	11	10	17	15
30. *Stachys palustris*	0	1	0	0	0	0	0	0	59	0	30
31. *Stellaria media*	33	36	31	23	48	20	8	11	18	8	26
32. *Thlaspi arvense*	6	10	10	2	5	5	9	2	9	8	7
33. *Tripleurospermum inodorum*[3]	4	4	3	4	3	32	2	4	15	2	8
34. *Urtica* spp.	0	1	1	2	0	0	2	0	0	0	2
35. *Viola arvensis*[4]	4	26	28	20	35	18	28	25	25	11	22
Other monocotyledons	1	58	5	2	3	27	18	3	1	9	15
Other dicotyledons	3	8	6	3	14	5	10	2	16	4	8

1) Including *Atriplex patula* L. 2) Including *P. arenastrum* Boreau
3) Including *M. recutita* L. 4) Including *V. tricolor* L.

able only in the case of a few species (Table 9).

Climatic factors

The climatic conditions in the various study years differed considerably from each other at the turn of May—June when weeds usually emerge (Table 10). However, this fact did not seem to affect the occurrence of weeds as regional variation in the number of weeds was considerable in each year (Table 4). On the other hand, the regional differences in climatic conditions in the same year did not have a consistent effect on the number or weight of weeds (Tables 8 and 10).

Of the climatic factors, the effective temperature sum affected only the variation in the abundance of *Tripleurospermum inodorum.*

Field and soil factors

The drainage of field affected the occurrence of

Table 8. Average dry weight of weeds (kg/ha) in all the fields.
+ indicates the weight < 1 kg/ha.

Species	Year/locality										
	1982		1983				1984				Average
	1	2	3	4	5	6	7	8	9	10	1982—84
1. *Achillea* spp.	0	+	0	0	+	1	2	8	0	0	1
2. *Avena fatua*	0	0	0	7	0	0	0	0	0	0	1
3. *Brassica* spp. cultivated	6	23	0	0	13	2	0	0	2	0	5
4. *Brassicaceae* others	+	+	+	2	+	49	4	0	0	+	5
5. *Capsella bursa-pastoris*	+	1	0	+	+	2	+	1	+	0	+
6. *Chenopodium album*[1]	9	21	15	35	22	20	149	52	122	44	47
7. *Cirsium arvense*	+	+	4	0	0	+	0	0	8	+	1
8. *Elymus repens*	21	24	54	38	15	273	149	5	43	73	64
9. *Equisetum* spp.	5	+	1	+	3	3	0	2	12	+	3
10. *Erysimum cheiranthoides*	+	9	4	7	7	3	28	25	3	3	9
11. *Fallopia convolvulus*	3	5	6	5	23	3	16	2	10	4	7
12. *Fumaria officinalis*	2	6	1	4	12	2	7	20	5	+	6
13. *Galeopsis* spp.	19	31	49	108	99	31	70	66	34	16	51
14. *Galium* spp.	1	1	10	7	6	+	+	2	7	1	3
15. *Gnaphalium uliginosum*	0	+	1	0	+	+	+	+	+	+	+
16. *Lamium* spp.	2	+	+	11	11	0	0	1	22	0	5
17. *Lapsana communis*	+	3	0	39	9	73	41	54	10	0	21
18. *Matricaria matricarioides*	+	1	+	+	+	16	+	4	11	2	3
19. *Myosotis* spp.	+	1	1	3	2	11	2	5	+	2	2
20. *Poa annua*	0	1	+	+	0	2	1	1	0	2	1
21. *Polygonum aviculare*[2]	0	1	1	1	5	7	5	2	6	1	3
22. *Polygonum lapathifolium*	+	2	1	4	2	4	9	+	12	24	5
23. *Ranunculus repens*	0	+	0	0	0	+	+	1	+	2	+
24. *Rumex* spp.	0	1	+	0	0	2	5	0	0	1	1
25. *Senecio vulgaris*	0	0	0	0	0	0	0	0	0	0	0
26. *Solanum nigrum*	0	0	0	0	0	0	0	0	0	0	0
27. *Sonchus arvensis*	10	3	+	4	6	+	+	25	19	2	7
28. *Sonchus* spp. others	0	0	0	0	0	17	21	+	1	0	4
29. *Spergula arvensis*	1	25	1	8	1	46	10	22	9	9	13
30. *Stachys palustris*	0	0	0	0	0	0	0	0	2	0	+
31. *Stellaria media*	13	27	9	43	45	55	2	14	10	3	22
32. *Thlaspi arvense*	1	3	1	+	+	+	4	+	2	+	1
33. *Tripleurospermum inodorum*[3]	1	+	+	+	+	17	+	2	1	0	2
34. *Urtica* spp.	0	0	0	0	0	0	1	0	0	0	+
35. *Viola arvensis*[4]	+	2	4	13	7	10	23	16	6	5	8
Other monocotyledons	0	8	1	+	+	26	19	1	0	13	6
Other dicotyledons	2	1	1	3	1	2	61	3	34	5	11
Total	98	201	163	343	289	680	627	334	390	211	318

1) Including *Atriplex patula* L.
2) Including *P. arenastrum* Boreau
3) Including *M. recutita* L.
4) Including *V. tricolor* L.

four weed species. The moisture conditions of the field were important to the occurrence of *Galeopsis* spp. and *Myosotis* spp. *Galeopsis* spp. produced the highest weight in normally moist or dry fields and *Myosotis* spp. on dry fields.

Only the changes in the number and weight of *Galeopsis* spp. were dependent on soil type. *Galeopsis* spp. plants grew most in peat soils and least in coarse mineral soil. Its dry weight also changed correspondingly.

The effect of liming on the variations in the occurrence of *Chenopodium album* was in contradiction with the effect of the soil pH value. Liming in the course of ten years preceding the study caused a decrease in the growth of *C. album*, whereas a rise in the pH value enhanced its growth.

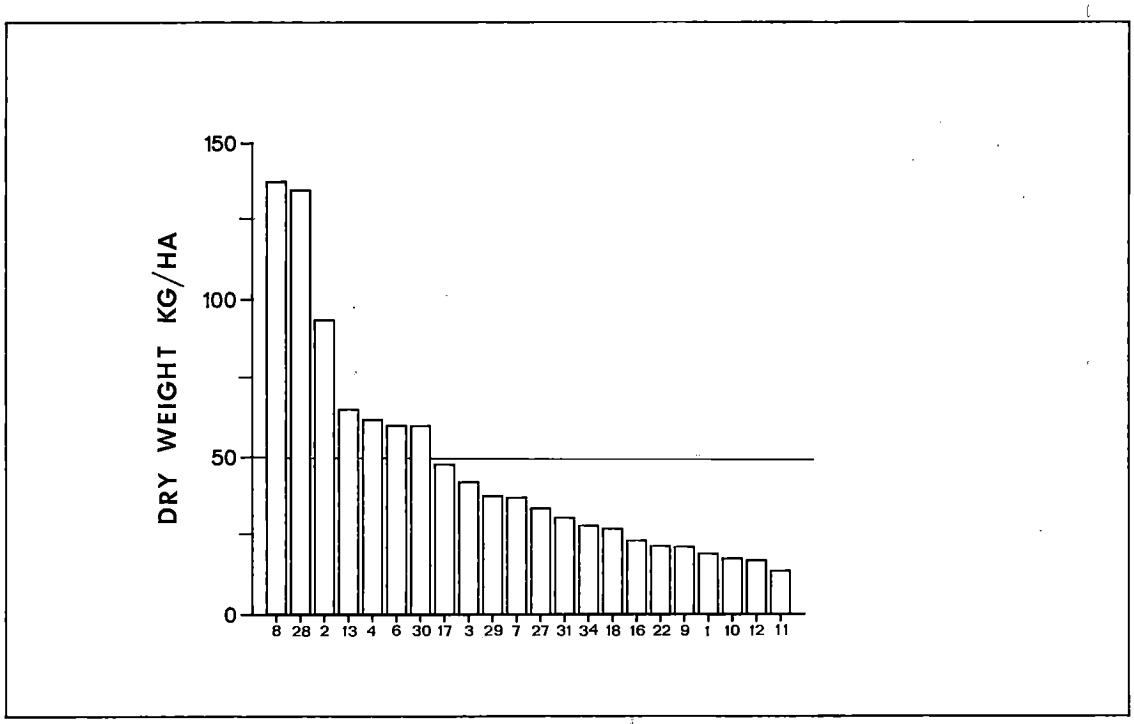

Fig. 3. Weight of weeds in infested fields. Weeds: 8 = *Elymus repens*, 28 = *Sonchus* spp. others, 6 = *Chenopodium album*, 30 = *Stachys palustris*, 17 = *Lapsana communis*, 3 = *Brassica* spp. cultivated, 29 = *Spergula arvensis*, 7 = *Cirsium arvense*, 27 = *Sonchus arvensis*, 31 = *Stellaria media*, 34 = *Urtica* spp., 18 = *Matricaria matricarioides*, 16 = *Lamium* spp., 22 = *Polygonum lapathifolium*, 9 = *Equisetum* spp., 1 = *Achillea* spp., 10 = *Erysimum cheiranthoides*, 12 = *Fumaria officinalis*, 11 = *Fallopia convolvulus*.

Fertilizing

Placement of fertilizers under the seed bed had been used on 82 % of the fields studied. Compared with surface fertilization, the lower abundance and/or mass production of some species was observed in fields with placement fertilizing.

The effect of K- and N-fertilization was seen on the occurrence of some weed species.

Crop

The crop cover proved to regulate the occurrence of seven weed species. As the cover increased, the number and/or weight of weeds growing in the field diminished.

Cereal species explained the occurrence of four weed species. Barley limited their number and weight the most, with the exception of *C. album*. Oats also reduced the number and weight of these weed species more efficiently than wheat.

Cereal-dominated cultivation, accounted only for the occurrence of *Myosotis* spp. by increasing the plant number.

Chemical control in the fields

The use of herbicides on the preceding crop regulated the number and/or mass production of three species. The use of a herbicide other

Table 9. Factors explaining the occurrence of weed plants. P = positive correlation, N = negative correlation.

Factor/species	Number of weeds plants/m²	F-value	Weight kg/ha	F-value
EFFECTIVE TEMPERATURE SUM				
Tripleurospermum inodorum	P	7,02**		N.S.
DRAINAGE OF THE FIELD				
Elymus repens		3,84*		3,71*
— open ditches	11		53	
— subsurface-drainage	7		33	
— no ditches	37		16	
Erysimum cheiranthoides		N.S.		3,99*
— open ditches			15	
— subsurface-drainage			5	
— no ditches			2	
Galium spp.		N.S.		5,10*
— open ditches			2	
— subsurface-drainage			3	
— no ditches			6	
Tripleurospermum inodorum		N.S.		4,18*
— open ditches			8	
— subsurface-drainage			1	
— no ditches			3	
PLOUGHING				
Erysimum cheiranthoides		12,88***		3,99**
— autumn ploughing	5		7	
— spring ploughing	17		34	
Polygonum aviculare		N.S.		4,35*
— autumn ploughing			2	
— spring ploughing			7	
MOISTURE CONDITIONS OF THE FIELD				
Galeopsis spp.		N.S.		6,01**
— dry			39	
— normal			46	
— wet			17	
Myosotis spp.		N.S.		3,49*
— dry			4	
— normal			2	
— wet			+[1]	
SOIL TYPE				
Galeopsis spp.		4,42*		6,59**
— coarse mineral soils	9		32	
— clay soils	19		47	
— organic soils	33		137	
SOIL pH				
Chenopodium album	P	7,37**		N.S.
LIMING				
Chenopodium album		N.S.		3,88*
— no liming			65	
— liming			31	
FERTILIZING METHOD				
Chenopodium album		4,83*		N.S.
— placement of fertilizers	20			
— surface fertilizing	36			
Elymus repens		N.S.		3,94*
— placement of fertilizers			54	
— surface fertilizing			103	
Erysimum cheiranthoides		4,85*		N.S.
— placement of fertilizers	4			
— surface fertilizing	11			

Galeopsis spp.		N.S.		7,94**
— placement of fertilizers			45	
— surface fertilizing			84	
Stellaria media		N.S.		8,13**
— placement of fertilizers			20	
— surface fertilizing			33	
K-FERTILIZING				
Fallopia convolvulus	N	4,51*		N.S.
Galium spp.	P	5,87*		N.S.
Polygonum aviculare	P	5,73*		
Sonchus arvensis	N	6,92**		10,92***
N-FERTILIZING				
Sonchus arvensis	N	5,52*	N	8,00**
CEREAL COVER				
Erysimum cheiranthoides	N	4,45*	N	4,63*
Fallopia convolvulus		N.S.	N	4,05*
Fumaria officinalis	N	7,10	N	8,01**
Polygonum aviculare		N.S.	N	4,08*
Spergula arvensis	N	6,92**	N	10,56**
Stellaria media	N	7,88**	N	8,03**
Viola arvensis	N	6,93**	N	21,34***
SPECIES OF CEREAL				
Chenopodium album		N.S.		3,16*
— wheat			69	
— barley			197	
— oats			516	
Fallopia convolvulus		3,94*		4,72*
— wheat	9		15	
— barley	3		5	
— oats	3		6	
Galeopsis spp.		7,42***		5,79**
— wheat	29		80	
— barley	12		40	
— oats	14		48	
Lamium spp.		3,98*		7,85***
— wheat	22		15	
— barley	2		1	
— oats	3		3	
CEREAL DOMINATION				
Myosotis spp.	P	4,76*		N.S.
CONTINUOUS HERBICIDE TREATMENT				
Sonchus arvensis	P	4,10*		N.S.
Stellaria media		N.S.	P	4,35*
HERBICIDE TREATMENT OF PRECEDING CROP				
Fallopia convolvulus		N.S.		
— untreated			7	4,35*
— MCPA			11	
— other herbicide			6	
Lapsana communis		4,63*		4,51*
— untreated	14		37	
— MCPA	31		44	
— other herbicide	7		8	
Myosotis spp.		3,56*		3,14*
— untreated	5		3	
— MCPA	2		1	
— other herbicide	5		3	
COMBINER HARVESTING				
Fumaria officinalis		N.S.	P	5,41*
Myosotis arvensis		N.S.	P	8,37**
Tripleurospermum inodorum		N.S.	P	6,37*

LOCALITIES		
Elymus repens	2,52**	3,61***
Erysimum cheiranthoides	2,76**	2,05*
Fallopia convolvulus	N.S.	2,52**
Fumaria officinalis	4,71***	4,28***
Galeopsis spp.	N.S.	2,61**
Galium spp.	2,90**	1,98*
Lamium spp.	N.S.	2,59**
Lapsana communis	N.S.	2,08*
Myosotis arvensis	3,31***	4,75***
Sonchus arvensis	2,13*	N.S.
Stellaria media	2,11*	8,47***
Tripleurospermum inodorum	2,14*	3,65**
Viola arvensis	2,42*	3,56***

[1] Weight < 1 kg/ha

Table 10. Meteorological data from the localities surveyed in 1982—84.

Year/ location		Month V	VI	VII	Month V	VI	VII
		Effective temperature sum DD in the end of month			Mean temperature °C		
1982	1	110,4	307,5	679,0	8,2	11,6	17,0
	2	115,8	303,3	657,1	6,0	11,3	16,4
1983	3	216,5	461,0	791,9	10,5	13,2	15,7
	4	226,6	460,8	842,6	10,8	13,5	16,7
	5	244,1	498,3	878,6	11,5	13,5	17,3
	6	243,9	500,5	882,6	11,3	13,6	17,4
1984	7	269,7	545,4	892,6	11,2	14,3	16,3
	8	274,4	529,1	845,5	12,9	13,5	15,2
	9	280,9	562,1	885,6	13,1	14,4	15,4
	10	245,0	478,7	784,2	11,9	13,6	17,4
		Precipitation mm			V Cumulative precipitation mm	VI	VII
1982	1	70,5	10,6	30,1	70,5	81,1	111,2
	2	70,9	12,9	84,1	70,9	83,8	167,9
1983	3	45,4	34,1	78,3	45,4	79,5	157,8
	4	36,1	64,0	68,5	36,1	100,1	168,6
	5	35,0	41,0	38,9	35,0	76,0	114,9
	6	81,7	75,9	36,2	81,7	157,6	193,8
1984	7	8,7	47,4	52,8	8,7	56,1	108,9
	8	28,5	64,3	137,1	28,5	92,8	229,9
	9	34,7	70,9	98,0	34,7	105,6	203,6
	10	34,6	73,2	121,1	34,6	107,8	228,9

than MCPA, on the preceding crop tended to reduce *Lapsana communis* the following year in the fields studied, whereas the use of MCPA on the preceding crop benefitted this species. The MCPA treatment of the preceding crop also increased the weight of *Fallopia convolvulus* the following year. MCPA treatment on the preceding crop seemed to suppress *Myosotis* spp.

Table 11. Distribution of the 24 main weed species according to their resistance to the herbicide MCPA.

	% of the total number of weeds	Number of species
Susceptible	29	8
Moderately susceptible	8	4
Moderately resistant	20	5
Resistant	29	7

Chemical control as such, continued for nine years before the study, proved to have importance only for *Stellaria media* and *Sonchus arvensis* which seemed to have benefitted from the treatment.

The effect of herbicide treatment on the weed population was studied also by classifying the most important species into four groups according to their resistance to MCPA (Table 11). These species totalled 24 of the 35 species studied. They were divided equally between sensitive and resistant species. The total number of broad-leaved weeds in the fields also included as high proportions of sensitive and resistant species.

Of the weight of weeds, the species sensitive to MCPA amounted to an overwhelming 48 %. Resistant species represented 19 % of the total weight of weeds.

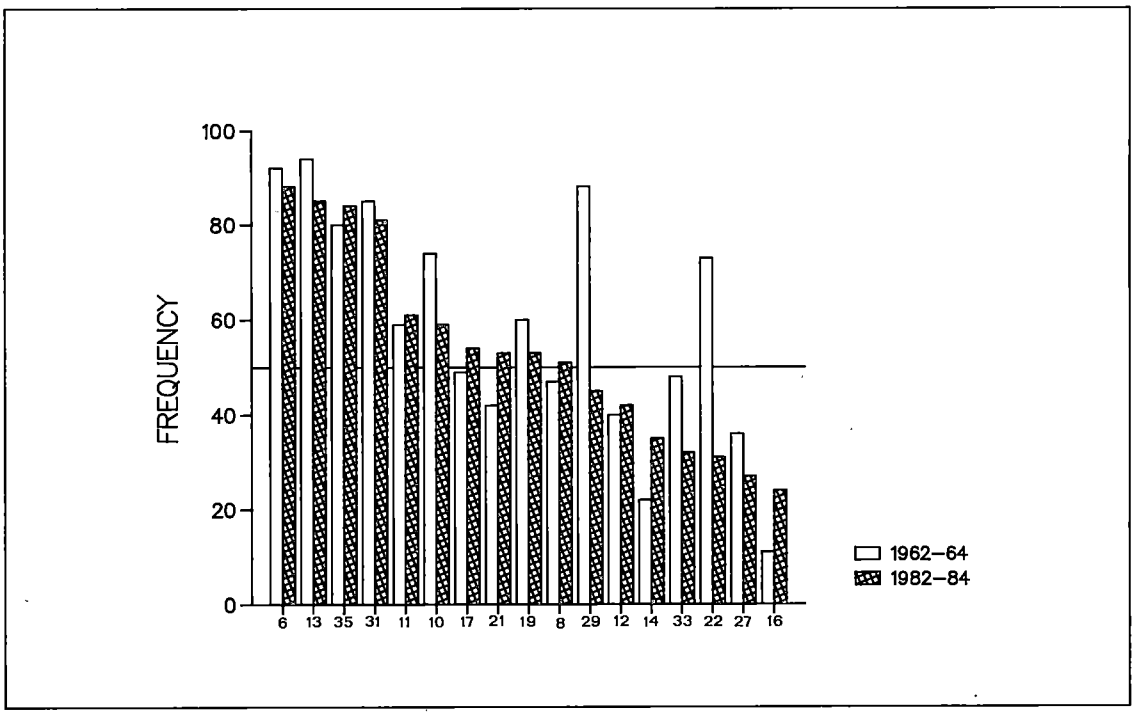

Fig. 4. Changes in the frequency of weeds in the last 20 years. Weeds: 6 = *Chenopodium album*, 13 = *Galeopsis* spp., 35 = *Viola arvensis*, 31 = *Stellaria media*, 11 = *Fallopia convolvulus*. 10 = *Erysimum cheiranthoides*, 17 = *Lapsana communis*, 21 = *Polygonum aviculare*, 19 = *Myosotis* spp., 8 = *Elymus repens*, 29 = *Spergula arvensis*, 12 = *Fumaria officinalis*, 14 = *Galium* spp., 33 = *Tripleurospermum inodorum*, 22 = *Polygonum lapathifolium*, 27 = *Sonchus arvensis*, 16 = *Lamium* spp.

Use of combine harvester

Repeated combine harvesting in the nine years preceding the study favoured three species.

Localities

Localities explained the occurrence of many weed species, when calculated either by abundance or by weight. A typical feature of areas 1 and 2 was that no weed species was found to be exceptionally abundant there (Table 4). Locality number 9, in the southwestern archipelago, had the most abundant stands of the species *Sonchus arvensis, Tripleurospermum inodorum* and *Lamium* spp. Of the localities situated in eastern Finland, number 6 was favourable to many weeds with high growing densities.

Changes compared with the 1960s

Frequency of weeds

Of the 35 species studied were 19 less frequent now than in the 1960s. These included *Chenopodium album, Galeopsis* spp., *Stellaria media, Erysimum cheiranthoides, Myosotis* spp., *Spergula arvensis* and *Tripleurospermum inodorum* (Fig. 4). Of the perennial weed species growing in annual crops *Sonchus arvensis* was somewhat less common and *Cirsium arvense*

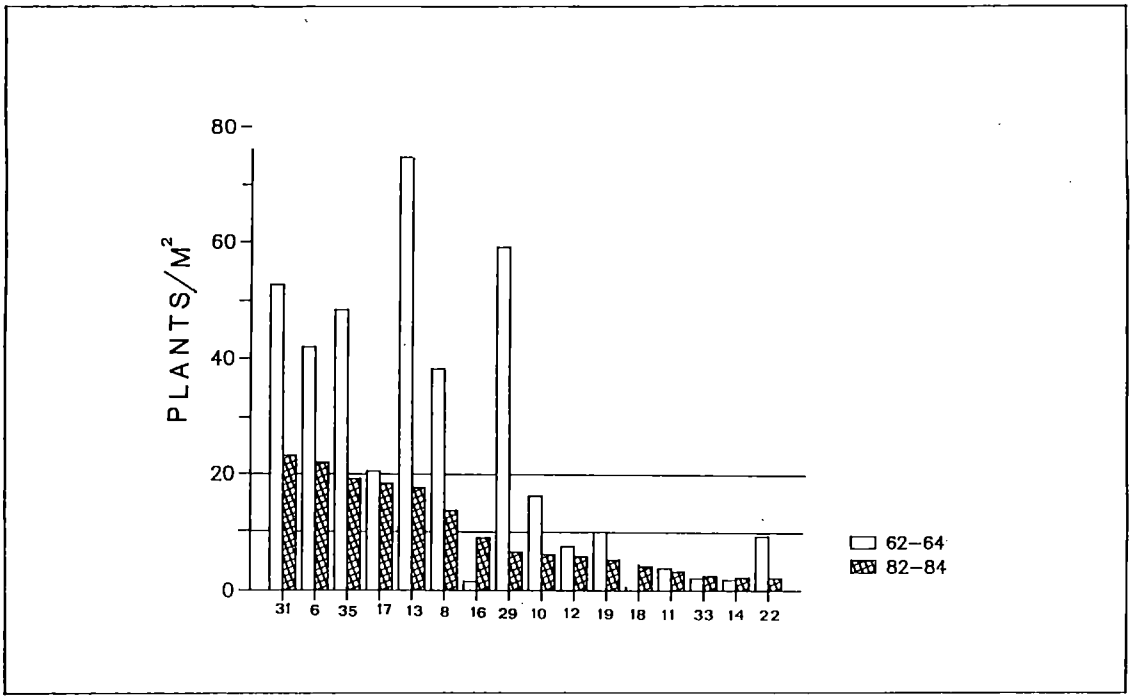

Fig. 5. Changes in the number of weeds in the last 20 years. Weeds: 31 = *Stellaria media*, 6 = *Chenopodium album*, 35 = *Viola arvensis*, 17 = *Lapsana communis*, 13 = *Galeopsis spp.*, 8 = *Elymus repens*, 16 = *Lamium* spp., 29 = *Spergula arvensis*, 10 = *Erysimum cheiranthoides*, 12 = *Fumaria officinalis*, 19 = *Myosotis* spp., 18 = *Matricaria matricarioides*, 11 = *Fallopia convolvulus*, 33 = *Tripleurospermum inodorum*, 14 = *Galium* spp., 22 = *Polygonum lapathifolium*. Note: In 1960s species 18 included in species 33.

considerably less common than in the 1960s.

Weed species that were found more frequently included *Viola arvensis, Fallopia convolvulus, Lapsana communis, Polygonum aviculare, Fumaria officinalis, Galium* spp., *Lamium* spp. and *Matricaria matricarioides*. Of the annual grass weeds *Poa annua* and, to a lesser extent, *Avena fatua* occurred more frequently. *Elymus repens* and *Sonchus* spp. were the only perennial species that were more common now than in the 1960s. All in all 14 species were more frequent now than previously.

Number of weeds

The number of plants/m^2 was now less than in the 1960s for nearly all species (Fig. 5, Table 12). The abundance of only nine species had increased; of these the number of *Lamium* spp. plants/m^2 had increased more than fivefold.

Proportionally, the number of *Cirsium arvense, Sonchus arvensis, Achillea* spp, *Ranunculus repens, Rumex* spp. (sorrels), *Spergula arvensis, Thlaspi arvense, Capsella bursa-pastoris, Brassica* spp. and *Gnaphalium uliginosum* had decreased the most.

The number of weeds were divided between species very similarly in 1982—84 as in 1960s. The most noticeable changes were the substitution of *Spergula arvensis* by *Lapsana communis* and the increase of the proportion of *Elymus repens* nearly twofold (Fig. 2).

Table 12. Statistical significance of the changes in number and weight of weeds. + = increased, − = decreased.

	Change in number F-value		Variation between localities 5) In number	In weight
Achillea spp.	23,51***	−	N.S.	N.S.
Brassicaceae others	4,81*	−	N.S.	N.S.
Capsella bursa-pastoris	13,50***	−	N.S.	N.S.
Chenopodium album[1]	7,25**	−	***	***
Cirsium arvense	13,83***	−	N.S.	6)
Elymus repens	14,46***	−	***	***
Equisetum spp.	16,83***	−	N.S.	N.S.
Erysimum cheiranthoides	19,84***	−	***	N.S.
Fallopia concolvulus	N.S.	−	*	6)
Fumaria officinalis	N.S.	−	***	N.S.
Galeopsis spp.	48,03***	−	***	*
Galium spp.	N.S.	+	N.S.	N.S.
Gnaphalium uliginosum	7,63**	−	**	6)
Lamium spp.	4,93*	+	***	N.S.
Lapsana communis	N.S.	−	***	N.S.
Matricaria matricarioides	N.S.	+	***	6)
Myosotis spp.	5,45*	−	***	6)
Poa annua	N.S.	+	N.S.	6)
Polygonum aviculare[2]	N.S.	+	N.S.	6)
Polygonum lapathifolium	9,30**	−	N.S.	6)
Ranunculus repens	5,94*	−	N.S.	6)
Rumex spp. (sorrels)	5,11*	−	N.S.	6)
Sonchus arvensis	13,83***	−	N.S.	N.S.
Spergula arvensis	18,84***	−	***	N.S.
Stachys palustris	N.S.	+	N.S.	N.S.
Stellaria media	11,18***	−	***	N.S.
Thlaspi arvense	4,48*	−	N.S.	N.S.
Tripleurospermum inodorum[3]	N.S.	+	***	N.S.
Viola arvensis[4]	42,25***	−	***	

1) Including *Atriplex patula* L.
2) Including *P. arenastrum* Boreau
3) Including *M. Recutita* L.
4) Including *V. tricolor* L.
5) Significance symbols of the χ^2-analyses
6) Not comparable due to small weights, < 0,5 kg/ha

Factors affecting the changes of weed flora

Very few of the studied factors alone were sufficient explanations for the observed changes in the abundance of weeds (Table 13). The properties of fields were significant factors the most often.

The distance between the field and the farmstead was significant in the reduction of *Stellaria media* and *Sonchus arvensis.* The longer was the distance between the field and the farmstead, the greater was decrease in their

Table 13. Significant factors to changes in the number of weeds, + = increase, − = decrease[1]), P = positive correlation, N = negative correlation.

Factor/species	Change Plants/m²	F-value
DISTANCE OF FIELD FROM THE FARMSTEAD		
Stellaria media	P	14,18***
Sonchus arvensis	P	5,07*
DRAINAGE OF THE FIELD		
Galium spp.		3,31*
— open ditches	− 5	3,31*
— subsurface-drainage	+ 1	
— no ditches	+	
Myosotis spp.		4,11*
— open ditches	− 3	
— subsurface-drainage	+	
— no ditches	−18	
Polygonum aviculare		3,06*
— open ditches	−	
— subsurface-drainage	+ 1	
— no ditches	− 2	
Sonchus arvensis		4,15*
— open ditches	− 3	
— subsurface-drainage	− 4	
— no ditches	−10	
MOISTURE CONDITIONS OF THE FIELD		
Stellaria media		3,57*
— dry	−33	
— normal	−33	
— wet	+17	
SOIL TYPE		
Spergula arvensis		4,00*
— coarse mineral soils	−79	
— clay soils	−14	
— organic soils	−91	6,58**
Sonchus arvensis		6,58**
— coarse mineral soils	− 2	
— clay soils	−11	
— organic soils	−	
LIMING		
Chenopodium album		6,06*
— no liming	+ 1	
— liming	−28	
PRECEDING CROP		
Elymus repens		3,47*
— cereal	−31	
— ley	+ 5	
— other crop	− 7	
Stellaria media		4,73**
— cereal	−18	
— ley	−105	
— other crop	−18	
CONTINUOUS HERBICIDE TREATMENT		
Galium spp.	N	4,12*

1) Symbols + or − solely indicates the change in average less than 1 plant/m².

number.

The type of drainage explained changes in the abundances of four weed species. Subsurface-drainage was favourable to the growth of these weeds except *Sonchus arvensis,* whereas the lack of ditches led to decreases particularly in the numbers of *Myosotis* spp. and *Sonchus arvensis.*

Moisture conditions on the fields explained the changes in the abundance of *Stellaria media.* Soil type was associated with changes in the abundance of *Spergula arvensis* and *Sonchus arvensis.*

Of the field treatment methods, liming brought about a reduction in the number of *Chenopodium album.*

The preceding crop before the year surveyed explained changes in the abundance of *Stellaria media* and *Elymus repens.*

Continual chemical weed control did not prove to have a significant effect on changes in weed population except *Galium* spp.

DISCUSSION

Material

In the 1960s, the occurrence of weeds in fields was studied in many countries (e.g. GRANSTRÖM 1962, BACHTHALER 1967, 1969, MUKULA et al. 1969). In some cases changes in weed flora have been studied by a new survey some decades later (e.g. MITTNACHT et al. 1979). This was the procedure followed in Finland in 1982—84, 20 years after the previous study on weed flora in spring cereals.

The total acreage of our study was 488 hectares which is 0,04 % of the total area of spring cereals in Finland. The distribution of the studied acreage between different spring cereals was roughly equivalent to the proportion of barley and oats of the total acreage of spring cereals in Finland. The area of wheat, however, was relatively higher than the proportion of wheat fields of Finnish spring cereals.

The weed population of fields now studied were fairly homogeneous. Thus the 35 weed species included in this survey well represented the most common weeds growing in spring cereals. Species rarely found in fields or found only in small numbers are not discussed in detail in this paper. Further, because of the small sample, local differences in the occurrence of weeds are inspected only for the most common species.

Factors explaining the occurrence

Individual factors explaining the occurrence of weeds and changes in the population could be determined only in some cases. Although some of the factors attained statistical significance (Tables 9 and 13), not all of them seemed to be meaningful. Such variables in our study were linked to certain properties of the fields and some aspects of the farming methods used. They obviously are the result of incomplete research material which do not cover the agricultural history of the fields for the entire 20-years period to the study. These factors should be regarded with caution, when explaining the occurrence of weeds in this kind of survey.

The observed effect of temperature sum on *Tripleurospermum inodorum* may be linked to the localities, as this species was the most abundant in areas 6 and 9 which also had a high effective temperature sum in early summer (Tables 4 and 10).

Of the factors associated with fields, mois-

ture conditions and drainage contributed to explain understandably the occurrence of some weed species. On the contrary the significancy of ploughing as an explaining factor might be questionable in this case (Table 9).

The favourable effect of lacking drainage on *Elymus repens* and on *Galium* spp. (Table 9), is probably connected to soil type and the cultivation of fields, at least as far as *E. repens* is concerned. Undrained fields are usually located in coarse mineral soils, in which *E. repens* is known to thrive (MUKULA et al. 1969) and open ditches usually indicate unintensive farming with good conditions for weed distribution.

In the case of conflicting effects of liming and soil pH on *Chenopodium album* (Table 9) the significance of the pH value should be considered as being more reliable. The data on liming collected for this study are incomplete and not give information on the total level and time of liming prior to the study; further, the literature supports the finding that a high pH value is favourable to *C. album.* This species is known to thrive in a wide range of pH value (SCHMALFUSS 1935), and additionally SCHMALFUSS and KLAUSS (1939) claim that it grows best in neutral or even slightly alkalic soils.

Placement fertilization, cereal species and crop cover affect the competitive ability of crop, thereby indirectly affecting weed population. In our study this became clear for certain weed species. Placement suppressed especially the most common weed species adapted to intensive cultivation. This is probably an indirect effect resulting from the improved competitiveness of cereals, though placing the fertilizer deeper than the emerging layer of weeds may also have a direct effect on weed growth. The preventive effect of crop cover was focused on low-growing weed species or on species growing along the ground during their early stages of development. Of this group, *Spergula arvensis,* in particular, suffers from shading and is unable to compete in dense cereal stands (FOGELFORS 1973).

Also the observed effect of K- and N-fertilization on some weed species in this study may be either direct or indirect influence. Intensified fertilization has increased the competitiveness of cereals, which in turn hinders the growth of weeds. On the other hand, *Galium* spp. and *Polygonum aviculare* which in our study benefitted from K-fertilization thrive on intensively cultivated fields.

The competitive effect of different cereals yielded modest results, as it proved to be a significant factor for the occurrence of only four weed species. Most effective against weeds was barley (Table 5). This result coincides with other studies concerning weeds in cereals (e.g. GRANSTRÖM 1962, ERVIÖ 1983, CHANCELLOR and FROUD-WILLIAMS 1984). The observed signification of cereals may also have a joint effect with the localities, as the cultivation of different cereals was unevenly distributed among the localities (Table 2).

Use of herbicides in fields before the study explained weed occurrence only in some cases. Thus treatment of preceding crop with mere MCPA understandably increased the occurrence of MCPA-resistant weed *Lapsana communis* in the survey year. On the other hand, the significance of continuous herbicide treatment only on *Stellaria media* and *Sonchus arvensis* must be considered with caution.

Combine harvesting may be important to the occurrence of small-seeded or low-growing weeds because such species may get back into the soil during harvesting (PETZOLD 1979, FOGELFORS 1981). We also found that combine harvesting promoted these kinds of weed species (Table 9).

The localities surveyed proved to have a more significant effect on occurrence than any other factor. The localities were significant either to the number or the weight of 13 weed species. As the survey was carried out in some localities during different years, the regional variation may also include the annual variation

characteristic to the occurrence of weeds (ERVIÖ 1981). There were, however, considerable differences between localities studied during the same year (Table 4).

The variation observed in the occurrence of weeds between the localities naturally is a result of regional climatic and soil conditions, crop rotation, and other factors, which as such were not statistically significant. Surveyed localities also differed from each other with respect to crops. Cereals were predominant in localities 1—5 and 9 (Table 2). Oilseed crops were also widely cultivated in these localities, with the exception of locality 3. Ley was predominant in localities 6—8 and 10.

Localities 1 and 10 had the least number of weeds. In the localities 2, 5, 6, 7 and 9 grow more than the average amount of weeds/m^2. Of these localities, number 6 had the most abundant stands of the winter annual *Tripleurospermum inodorum* and of the perennial *Elymus repens* (Table 7), a finding which illustrates the ley dominated cultivation in the eastern part of Finland. *T. inodorum* is a typical weed of young leys. Its seeds survive in the soil and later germinate also in spring cereals. *E. repens* is a perennial which thrives well in leys (RAATIKAINEN 1975).

Locality 9 is situated in the southwestern archipelago. In addition to cereal, proportionally more outdoor vegetable cultivation is practiced in this area than in the other localities surveyed (MONTHLY REVIEW OF AGRICULTURAL STATISTICS 1983). *Lamium* spp. and *Tripleurospermum inodorum* might be considered the characteristic weeds in this area; these species were less abundant in the other localities (Table 4).

Changes in weed flora and causes of the changes

Weed flora

This study revealed that changes had occurred in the frequency, number and weight of weeds growing in spring cereals. One of the greatest changes was the drop in total amount and weight of weeds, which on average had decreased to one-third of the values obtained 20 years ago (Tables 4 and 8, MUKULA et al. 1969, MUKULA 1974). Corresponding changes have been found in other countries, too (CHANCELLOR 1976, AAMISEPP and WALLGREN 1979, MITTNACHT et al. 1979, STREIBIG and HAAS 1979).

This study was restricted to the 35 most important weed species, and so it did not reveal whether less common species had disappeared, nor were changes in the number of species uncovered in a way comparable with the results of a study carried out in some municipalities of central Finland by the University of Jyväskylä (KALLIO-MANNILA et al. 1985).

Fallopia convolvulus, Fumaria officinalis, Lamium spp. and *Viola arvensis* are among the annual species observed to have increased in spring cereals (AAMISEPP and WALLGREN 1979). These species have become more common in Finland, too (Fig. 4), but the only significant increase in plant number was noted for *Lamium* spp. (Table 12, Fig. 5), which was abundant locally in some fields (Table 7). A corresponding increase was detected for *Matricaria matricarioides*, which was particularly abundant in some fields in locality 9. Within the entire material, however, the increase in this species was not statistically reliable. The spread of this species to spring cereals has also been observed in Denmark (STREIBIG and HAAS 1979).

The species becoming less frequent and reduced in number included *Spergula arvensis* and typical grassland weeds sensitive to tilling such as *Achillea* spp., *Ranunculus repens* and *Rumex* spp. (sorrels) (Tables 3, 4 and 12). The decrease of their occurrence in spring cereals is understandable because the total ley area in Finland has decreased and the proportion of ley in crop rotation has become smaller (THE

OFFICIAL STATISTICS OF FINLAND 1964, MONTHLY REVIEW OF AGRICULTURAL STATISTICS 1983).

Stachys palustris, which is considered to be more and more harmful in Finnish sugarbeet and potato fields, had not increased significantly in spring cereals, not even regionally (Table 12). This species is relatively easily controlled by using MCPA, which may prevent its spread in spring cereal fields.

The sampling method applied in this study does not provide a fully accurate information of perennial species growing only in patches, e.g. *Cirsium arvense* and *Sonchus arvensis.* Because of the patchy occurrence, they may be absent from sample plots even though they are found elsewhere in the same field. Thus their frequency may have been underestimated.

Because of the increased cultivation of cruciferous oil plants, turnip rape (*Brassica rapa* L. var. *oleifera* subvar. *annua*) has appeared as a new weed in spring cereals. Its seeds survive in the soil for a long time and emerge as weeds in the subsequent crops. In this study the maximum frequency of turnip rape was 44 %, the abundance 3 plants/m^2 in all fields and 16 plants/m^2 in infested fields (Tables 3, 4 and 7).

Of the grass weeds, this study considered the species of *Elymus repens* and the annuals *Poa annua* and *Avena fatua,* because changes in their occurrence have been observed in many countries (e.g. CHANCELLOR 1976, MITTNACHT et al. 1979, ROLA 1979).

The present study showed that the frequency of *Elymus repens* has increased, but its number of shoots in Finnish spring cereals has decreased over the last 20 years (Figs. 4 and 5). *Poa annua,* which in the literature is mentioned as an increasing species (CHANCELLOR 1976, BYLTERUD 1983), was also found more frequently (Table 3, MUKULA et al. 1969), but no statistically significant change in the plant number could be detected (Table 12).

No clear increase in the occurrence of *Avena fatua* could be determined in this study, though *A. fatua* is known to be infesting an ever increasing field area in Finland (SOMERLA 1986). The reason for this result may be that the species is concentrated in certain municipal regions not included in this study.

Reasons for changes

In studies concerning weed flora in fields, attention has also been paid to the reasons of certain changes in the flora. Actual results of studies on the effects of various farming and harvesting methods have been presented, e.g., in Sweden and Germany (AAMISEPP and WALLGREN 1979, PETZOLD 1979, GUMMESSON 1986).

In some cases the continuous application and selective effect of herbicides has been considered the main reasons for the changes in weed population, especially as concerns the increased number of grass weeds (ROLA 1979, STRYCKERS 1979). On the other hand, it has often been obvious that the effects of various factors are difficult to distinguish from each other. For example, the more general application of herbicides has been accompanied by the increased cereal monoculture and the intensified nitrogen fertilization (e.g. AAMISEPP and WALLGREN 1979, STREIBIG and HAAS 1979, PESSI 1983). This has significantly improved the competitive ability of cereals and has eventually decreased the number of weeds in dense cereal stands (ERVIÖ 1972, MAHN 1984). MAHN (1984) has even concluded that the contribution of nitrogen fertilization to the changes in weed flora has been underestimated, as compared with herbicide treatment.

In Germany it has been shown that the reason for the decline of some weed species is intensified tillage and denser cereal stands (MITTNACHT et al. 1979). In Sweden, the improvement of fields has weakened the growth conditions of weeds and improved those of crops (AAMISEPP and WALLGREN 1979). The cultivation of more high-yielding varieties than

before and the increased yield level have probably also contributed to the observed changes in weed flora.

Our study was consistent with the literary in showing that the changes in weed population were caused by many simultaneous and interacted factors, for only few of the studied variables as such proved to be statistically significant reasons (Table 13).

Most often significant were factors concerning the moisture and drainage of fields, which in turn related to soil type or to intensified farming with field improvements. Still the effects of these factors were detected only in the case of a few weeds (Table 13). The importance of the distance of the field for the changes in the number of *Stellaria media* and *Sonchus arvensis* might be explained by the field improvement and by intensified cultivation which usually concerns the distant fields later than other fields of a farm. As a consequence the number of weeds has dropped mostly in these fields improved during the last 20 years. Liming, which has decreased the number of *Chenopodium album*, is also part of intensified farming. Liming, as such, hardly had any effect on changes in *C. album*, but these kinds of results might have been caused by the incomplete data concerning liming (cf. p. 221).

According to literature, monoculture of cereals favours grass weeds (e.g. AAMISEPP and WALLGREN 1979). Our study did not support this concept, for the number of *Elymus repens* shoots decreased the most when cereal was the preceding crop, whereas ley as a preceding crop increased the number of shoots.

Contrary to expectations, the continuous application of MCPA or other herbicides did not prove a significant reason for changes in weed population (Tables 12 and 13). The limited importance of herbicide treatment is also supported by the fact that *Chenopodium album* and *Galeopsis* spp., which are both sensitive to MCPA, are still the most frequent and abundant species in Finnish spring cereals.

Most of the weed species that have disappeared from fields require light and can grow with very little nitrogen (MITTNACHT et al. 1979). *Spergula arvensis*, for example, which has clearly withdrawn from spring cereals needs light and suffers from the shading of crop. FRYER and CHANCELLOR (1970) also regard liming as one of the possible reasons for the decline of this species. However, according to our study it alone did not affect *S. arvensis*.

There are few weed species which are to be regarded as the most important ones in Finnish spring cereals. Attention has to be paid on their control and additionally on all those weeds that have become more frequent during the last 20 years. The new situation in the fields involves a careful evaluation of the need of chemical control and the choise of a herbicide adapted to the weed population.

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SELOSTUS

Kevätviljojen rikkakasvillisuuden muutokset

LEILA-RIITTA ERVIÖ ja JUKKA SALONEN

Maatalouden tutkimuskeskus

Maatalouden tutkimuskeskuksen kasvinviljelyosasto tutki vuosina 1962—64 rikkakasvien esiintymistä maamme kevätviljapelloilla. Tutkimus uusittiin vuosina 1982—84 kymmenellä aiempaan tutkimukseen sisältyneellä paikkakunnalla. Nyt tutkittiin kaikkiaan 267 peltolohkoa, joista 155 oli samoja kuin 20 vuotta sitten.

Rikkakasvien lukumäärä ja paino olivat vähentyneet noin kolmannekseen 20 vuoden aikana. Kevätviljapelloilla kasvoi nyt keskimäärin 173 rikkakasvia/m^2 ja niiden kuivapaino oli 320 kg/ha. Yleisimmät ja runsaimmat lajit olivat yksivuotiset jauhosavikka, pihatähtimö, pelto-orvokki ja pillikkeet sekä monivuotinen juolavehnä. Eräät yksivuotiset MCPA:ta kestävät lajit olivat yleistyneet, mutta tärkeysjärjestyksessä ensimmäisillä sijoilla olivat edelleen MCPA:lle arat jauhosavikka ja pillikkeet. Rikkaheinistä oli yleistynyt juolavehnä.

Kevätviljapeltojen rikkakasvihaitat aiheutuivat muutamasta vallitsevasta lajista. Jauhosavikan, pihatähtimön, pelto-orvokin, pillikkeiden, linnunkaalin ja juolavehnän yhteinen osuus oli 62 % rikkakasvien kokonaislukumäärästä. Pelloilla kasvaneesta ilmakuivasta rikkakasvimassasta 51 % koostui juolavehnästä, pillikkeistä ja jauhosavikasta.

Rikkakasvien esiintymistä ja siinä tapahtuneita muutoksia säätelevien tekijöiden yksittäinen vaikutus ilmeni vain joissakin tapauksissa.

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COPPER CONTENT OF COARSE MINERAL AND PEAT SOILS AND THE GROWTH OF OATS IN A POT EXPERIMENT

RAILI JOKINEN and HILKKA TÄHTINEN

JOKINEN, R. & TÄHTINEN, H. 1987. **Copper content of coarse mineral and peat soils and the growth of oats in a pot experiment.** Ann. Agric. Fenn. 26: 227—237. (Agric. Res. Centre, Dept. Agric. Chem. Phys. SF-31600 Jokioinen, Finland.)

The correlation between EDTA-Cu contents (2,2 ± 2,6 mg/litre of soil) and HCl-Cu contents (4,4 ± 3,4 mg/litre of soil) was closer in peat soils ($r = 0{,}92^{**}$) than in coarse mineral soils ($r = 0{,}67^{**}$). Irrespective of soil type, the EDTA-Cu content was lowest (less than 30 %) in comparison with the HCl-Cu when the EDTA-Cu contents were below 1 mg/l.

The critical limit of the EDTA-Cu content seemed to be 1,5 to 2,0 mg/litre of soil, if no adjustment has been made for organic carbon content or pH (H_2O).

The dependence of the oat grain yield, grain copper content, grain copper uptake and the whole yield copper uptake on the soil EDTA-Cu content was slightly closer than the dependence on HCl-Cu content. Changes in the EDTA-Cu contents of soils explained 25—45 % of the variation in the above parameters of the crop.

Index words: coarse mineral soil, peat soil, EDTA-Cu, HCl-Cu, critical limit, oats, yield, copper content, copper uptake.

INTRODUCTION

A scarcity of copper was detected on some cultivated land in Finland in the 1930s and the first copper fertilization experiments were set up in 1939 (TAINIO 1963). A considerable number of new experiments have been carried out on arable land since 1945. TAINIO (1955, 1960) published some results in Finnish. The final review of the results of these experiments was performed by TÄHTINEN (1971). She concluded that only the copper content of the soil had a significant negative effect on the increase in grain yield resulting from copper fertilization (12 kg/hectare Cu), explaining some 10 % of the variations in yield increase.

Data on low copper contents in coarse mineral soil and in peat soil have been received from various parts of the world (e.g. BERROW and REAVES 1985, KRUGER et al. 1985). Studies on copper fertilization have therefore often been made using these two soil types.

According to LUNDBLAD et al. (1949), the total amount of copper in the soil is not a reliable indicator of the copper available to plants. In Finland, the copper content of the

hydrochloric acid extract (2 M HCl) from ashed soils formed the basis of fertilization advice for a long time (KURKI 1972). In organic soils, the copper thus obtained is almost equal to the total copper.

Several extracting liquids have been used to extract soil copper available to plants from the soil, for example, ethylenediaminetetraacetic acid, EDTA (VIRO 1955), diethylenetriaminepentaacetic acid, DTPA (LINDSAY and NORVELL 1978), and a mixture of acidic (pH 4,65) 0,5 M ammonium acetate and 0,02 M EDTA (LAKANEN and ERVIÖ 1971). In many studies, the various methods are also compared (e.g. LAKANEN and ERVIÖ 1971, HAYNES and SWIFT 1983, MAKARIM and COX 1983, NORVEL 1984, BEST et al. 1985, SIPPOLA and ERVIÖ 1986). The amount of copper available to plants in soil has been estimated in both extraction experiments and pot and field experiments.

In this study we compared two soil extraction methods to indicate the need for copper fertilization. In a pot experiment the dependences between soil copper content and the yield parameters of oats were studied.

MATERIAL AND METHODS

The soil sample material of the study comprised 32 peat soils and 45 coarse mineral soils; they were all taken from the plough layer of arable land. Some of the soils were selected for this study because their low copper content had previously restricted the plant growth there.

Altogether four series of annual pot tests were carried out in 1975—1978 with oats (*Avena sativa*), using about 20 soils as the culture medium annually. Moist soils were sieved through a 10-millimetre sieve and weighed into 6-litre pots. The amount of moist soil weighed into a pot corresponded to 450—1 640 grams of air-dry peat and 2 500—4 600 grams of coarse mineral soil. The pots were fertilized with 1 000 mg of N (NH_4NO_3), 400 mg of P ($Ca(H_2PO_4)$), 1 000—1 500 mg of K (K_2SO_4), 200 mg of Mg ($MgSO_4 = 7H_2O$), and with sufficient amounts of B, Mn, Mo and Fe. Within each soil sample the treatments were replicated three times. Twenty-five oat seeds were sown in each pot and the plant stands were not thinned later in the growing season. The plants were grown outdoors in a net hall. The crops were harvested when ripened, and the grain and straw yields were dried and weighed separately.

Five grams of plant matter was dried for 2 hours at 105 °C and burned to ashes (450 °C) in quartz bowls; the ashes were dissolved in 10 ml of 4 M HCl, evaporated on a water bath, dissolved again in 2,5 ml of 2 M HCl and filtered. The filter paper with ash residue was burned again (600 °C), dissolved in 2,5 ml of HF, evaporated on a sand bath and dissolved in 1 ml of 2 M HCl. The solution was filtered into the same bottle as the earlier filtrate and up to 50 ml of water was added to the bottle. The copper content was determined using an atomic absorption spectrophotometer.

Samples of the original soils were taken for analysis and air-dried. The soil samples taken at the end of the experiments were dried in the same way. The calcium extractable in acid ammonium acetate (v:v = 1:10) and the pH in water suspension (v:v = 1:2,5) were determined from the soil samples (VUORINEN and MÄKITIE 1955).

The copper in the soil was extracted with the acid (pH 4,65) mixture of 0,5 M ammonium acetate and 0,02 M EDTA proposed by LAKANEN and ERVIÖ (1971); extraction ratio 1:10 (v:v) and extraction time 1 h. The copper content in the extract was determined

using an atomic absorption spectrophotometer. The copper in the original soils was also determined using the method proposed by KURKI (1963). The soil was burned to ashes (520 °C), the ashes were extracted in 2 M HCl and the copper content of the filtered extract was determined as above. This paper refers to the first-mentioned copper content as EDTA-Cu and to the latter as HCl-Cu. The results are given as milligrams per litre of air-dry soil.

The correlation and regression analyses indicating the dependences between soil and yield properties were calculated according to a linear model and logarithmic or square root transformation models (EZEKIEL and FOX 1961).

RESULTS

Copper contents of soils

In Finland, soils containing less than 4 mg/l of HCl-Cu are classified as needing copper fertilization. Of the samples in this study, 30 coarse mineral soils and 14 peat soils were in this group (Table 1). The copper contents of six peat soils were over 8 mg/l and copper fertilization was not necessary on the basis of the HCl-Cu content. Almost all of the peat soil material and about one third of the mineral soil samples were clearly in need of liming (pH (H_2O) below 5,50).

The mean EDTA-Cu content (2,2 ± 2,6 mg/l) was about half the mean HCl-Cu content (4,4 ± 3,4 mg/l). The linear correlation between the methods was r = 0,83** in the whole material; however, in peat soils the correlation (r = 0,92**) was closer than in coarse mineral soils (r = 0,66**, Fig. 1). Because of the partial selection of sampling places, the variation range in the copper contents of the coarse mineral soils was much narrower than in the peat soils (Table 2).

In both soil types EDTA-Cu, on average, constituted almost the same percentage of HCl-Cu; in the coarse mineral soils 42 ± 18 % and peat soils 45 ± 22 %. When the EDTA-Cu was below 1 mg/l, it was about 30 % of HCl-Cu; between 1 and 2 mg/l it was about 35 %,

Table 1. Number of soil samples in different pH (H_2O) and HCl-Cu classes.

pH (H_2O)	Number of samples								
	HCl-Cu, mg/l of soil								
	<4		4—8		>8		Total		
	min.	peat	min.	peat	min.	peat	min.	peat	all
—4,50		5		3		1		9	9
4,51—5,50	14	8	3	7		5	17	20	37
5,51—6,50	14	1	10	2			24	3	27
6,51—	2		2				4		4
Total	30	14	15	12		6	45	32	77

min. = coarse mineral soils
peat = peat soils

Table 2. Some characteristics of the original soils (mean, standard deviation, range).

	Coarse mineral soils (n = 45)		Peat soils (n = 32)	
	$\bar{x} \pm s$	range	$\bar{x} \pm s$	range
pH (H_2O)	5,6±0,5	4,6—6,8	4,9±0,5	3,9—6,0
Ca mg/l	924±538	25—2550	1456±854	300—3400
EDTA-Cu mg/l	1,54±1,01	0,30—5,0	3,11±3,71	0,28—13,6
HCl-Cu mg/l	3,6±1,5	2,0—8,2	5,6±4,7	0,9—18,8

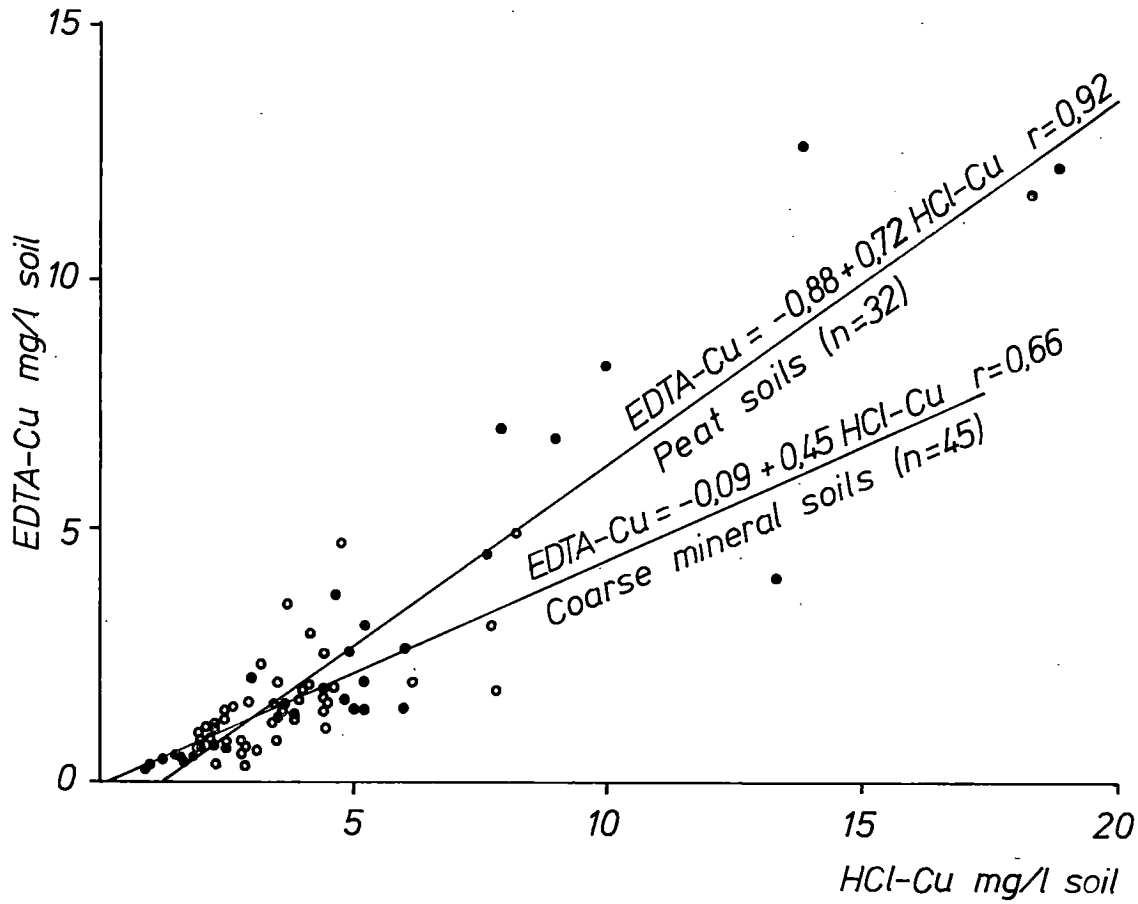

Fig. 1. Correlation between the methods for determining soil copper content in coarse mineral soils (○) and peat soils (●).

and when EDTA-Cu content was over 2 mg/l it was about 65 % of HCl-Cu. In some peat soil samples a high EDTA-Cu content and its high percentage of HCl-Cu were observed in the same sample. If the need for copper fertilization is estimated by comparing the EDTA-Cu and HCl-Cu figures, and the extraction capacity of the acid ammonium acetate-EDTA is taken into account, copper fertilization seems to be necessary for soils containing less than 1,5 mg/l of EDTA-Cu.

In Finland, the recommendations on copper fertilization issued to farmers since the 1950s have been based on HCl-Cu. EDTA-Cu has been used successfully in scientific research, and since 1986 the advisory services have been based on it. Replacement of the extraction method may make it necessary to convert the old HCl-Cu figures into new EDTA-Cu figures, until farmers have had analyses made according to the new method. Our fairly limited material gave the following conversion factors:

coarse mineral soils	EDTA-Cu = 0,63 * HCl-Cu
peat soils	EDTA-Cu = 0,44 * HCl-Cu
all material	EDTA-Cu = 0,61 * HCl-Cu

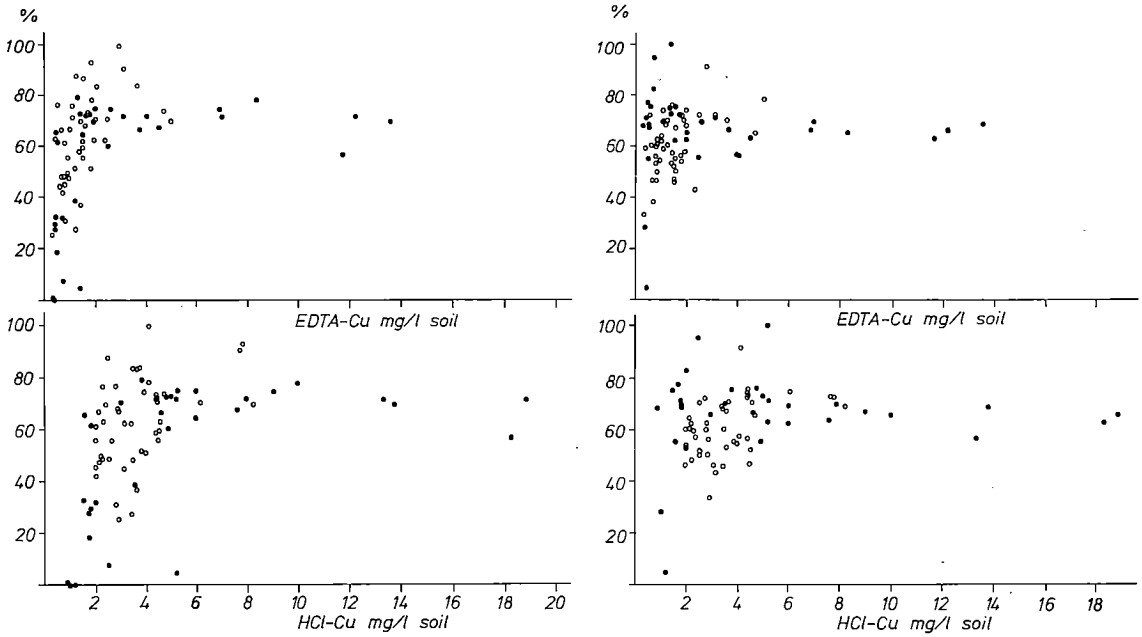

Fig. 2. Dependence of relative grain yield (% of the maximum yield 58,5 g/pot) and straw yield (% of the maximum yield 74,4 g/pot) on EDTA-Cu and HCl-Cu contents of soil.

(○ = coarse mineral soil, ● = peat soil)

Regression equations for absolute yield:

Grain, yield g/pot = 30,9 + 20,1 log EDTA-Cu $r^2 = 0,34$
= 19,0 + 22,8 log HCl-Cu $r^2 = 0,29$

Straw, yield g/pot = 45,6 + 6,1 log EDTA-Cu $r^2 = 0,05$
= 40,5 + 10,8 log HCl-Cu $r^2 = 0,07$

Different factors were obtained for the soil type groups studied, which may show that each soil type needs its own factor. Establishing that would, however, call for extensive material.

The pH(H_2O) or calcium contents of the soil type groups studied differed somewhat (Table 2). Weak correlation between these properties and EDTA-Cu content was observed only in the coarse mineral soils (pH(H_2O): r = 0,21; Ca mg/l: r = 0,44**).

Oats yield

The grain yield of oats varied between 14,7 and 58,5 g/pot with the coarse mineral soils. In some peat soils the copper deficiency was so marked that no grain was obtained at all. The highest grain yield from peat soils was 46,3 g/pot. There was also wide variation in straw yield in both soil type groups (coarse mineral soils 24,7—67,7 g/pot, peat soils 3,4—74,4 g/pot).

A low copper content did not always restrict the grain yield of oats; for example, in soils containing less than 1 mg/l of EDTA-Cu, the relative grain yield varied between 0 and 75 % (Fig. 2), relative yield = 100 (individual yield/highest yield). No grain yield was obtained from oats that grew in peat soils containing less than 0,5 mg/l of EDTA-Cu or less than 1,5 mg/l of HCl-Cu. A low copper content with a high or low pH(H_2O) figure seemed to make for a smaller grain yield. For

instance, less than 40 % of the highest grain yield was obtained in soils in which the EDTA-Cu was below 1,5 mg/l and the pH (H_2O) was over 6,5 (2 samples) or under 5,0 (11 samples). The highest relative grain yields were obtained in seven coarse mineral soils. Their EDTA-Cu contents varied between 1,2 and 3,6 mg/l (HCl-Cu 2,4—8,8 mg/l). In peat soils the relative grain yields of oats were 70—80 % of the highest yield when the EDTA-Cu content of soil varied between 1,3 and 13,6 mg/l.

Irrespective of the soil type, oats produced not more than 50 % of the maximum grain yield when the HCl-Cu content was below 4 mg/l (one exception: 3 % yield, HCl-Cu 5,3 mg/l). When the EDTA-Cu was below 1,5 mg/l, the relative grain yield was without exception the same as above. The copper contents mentioned here can be used as critical limits to estimate the need for copper fertilization when grain yield is regarded as the criterion for fertilization requirement.

The correlation between the absolute grain yield (g/pot) and the soil copper content (log x) was equally close, whether EDTA-Cu ($r = 0{,}58^{**}$) or HCl-Cu ($r = 0{,}54^{**}$) was used. The soil copper content explained some 30 % of the variations in grain yield.

In copper-deficient soils, high straw yield was often connected with low grain yield. However, two peat soil samples contained so little copper available to oats that even the straw yield was only low (Fig. 1). There was loose correlation between the soil copper content and the straw yield, irrespective of the copper extraction method.

Copper content of grain and straw

The average copper content of the oat grain was almost the same in both soil types, whereas the copper content of the straw was slightly higher in peat soils than in coarse mineral soils (Table 3). The variation in the copper contents of the yields in peat soils was wider than in coarse mineral soils, probably as a result of the wide variation in soil copper contents.

A rise in the EDTA-Cu content increased the copper content of oat grain ($r = 0{,}84^{**}$) and straw ($r = 0{,}56^{**}$) significantly in peat soils. No such correlation was apparent in coarse mineral soils (Fig. 3). In the whole material, the linear correlation between the copper content in the plant matter and the EDTA-Cu content in the soil was somewhat closer (grain: $r = 0{,}61^{**}$, straw: $r = 0{,}50^{**}$) than between the plant matter and the HCl-Cu content (grain: $r = 0{,}27^{*}$, straw: $r = 0{,}41^{**}$).

It seemed to be fairly impossible to estimate the need for copper fertilization on the basis of the copper content of the plant mass. The only clue was provided by the grain yields containing less than 1,5 μg/g of copper which were obtained from six coarse mineral soils and five peat soils. In these, the EDTA-Cu content varied between 0,4 and 1,8 mg/l and the pH (H_2O) was usually under 5,0 (4 peat soils) or over 6,0 (1 peat and 5 mineral soils). In these same soils the grain yield of oats was less than 40 % of the maximum yield.

The weak linear correlation between the yield and its copper content was positive in grain ($r = 0{,}44^{**}$) and negative in straw ($r = -0{,}33^{**}$). This result implies that a better copper supply improved the quality of the grain yield.

Copper uptake of oats

In both soil types the average copper uptake of the oat straw exceeded the copper uptake of the grain (Table 3). In peat soils the copper uptakes of the whole crop (grain + straw) and of the straw yield both seemed to be higher than in coarse mineral soils.

The correlation between the copper uptake of the whole crop and the soil copper content (square root conversion) was almost indepen-

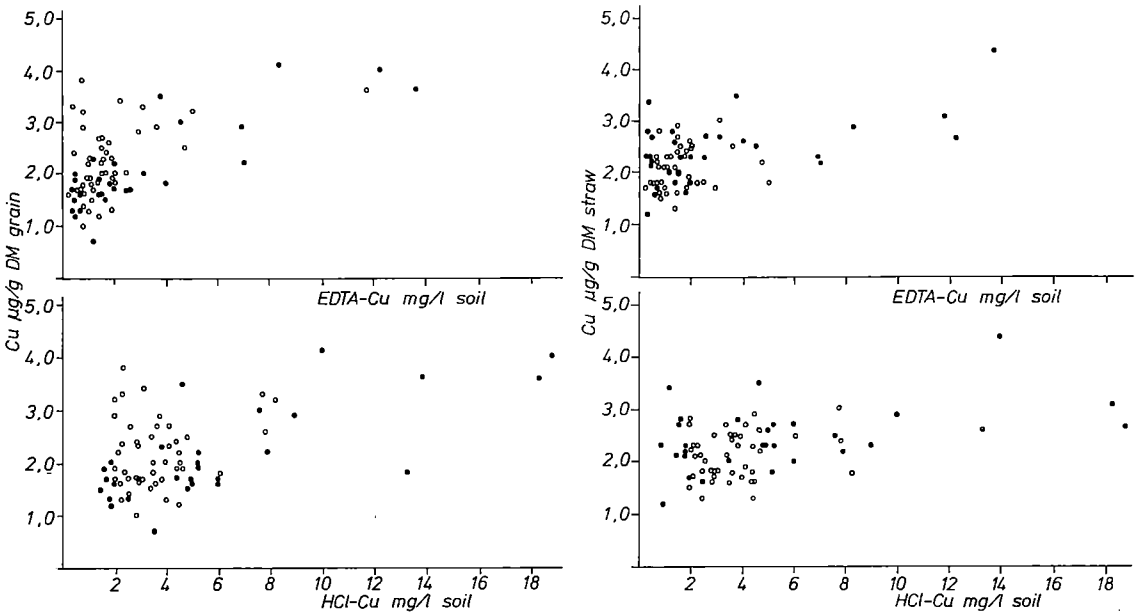

Fig. 3. Dependence of the copper content (µg/g DM) of oat grain and straw on EDTA-Cu and HCl-Cu contents of the soils.

(○ = coarse mineral soil, ● = peat soil)

Regression equations:

Grains, Cu µg/g = 1,77 + 0,17 EDTA-Cu	$r^2 = 0,37$	Straw, Cu µg/g = 2,02 + 0,10 EDTA-Cu	$r^2 = 0,25$
= 1,56 + 0,19 HCl-Cu	$r^2 = 0,07$	= 1,96 + 0,07 HCl-Cu	$r^2 = 0,17$

dent of the extraction method (EDTA-Cu: r = 0,69**, HCl-Cu: r = 0,62**, Fig. 4). A similar dependence was also found between the copper uptake of the grain and the copper contents of the soil (EDTA-Cu: r = 0,51**, HCl-Cu: r = 0,54**).

The copper uptake of the grain yield was higher than the uptake of the straw in 19 coarse mineral soils and in four peat soils. In these 23 soils the EDTA-Cu content of the soil varied between 0,4 and 5,0 mg/l and only six contained less than 1 mg/l of EDTA-Cu. The

Table 3. Copper content and copper uptake of oats (mean, standard deviation, range).

	Coarse mineral soils (n = 45)		Peat soils (n = 32)	
	$\bar{x} \pm s$	range	$\bar{x} \pm s$	range
Cu µg/g DM				
grain	2,2±0,7	1,0—3,8	2,1±0,9	0,7—4,1
straw	2,1±0,4	1,3—3,0	2,4±0,6	1,2—4,4
Cu µg/pot				
grain	82±38	18—176	77±49	6—188
straw	95±27	41—183	177±37	13—224
total	177±58	64—336	187±78	13—369

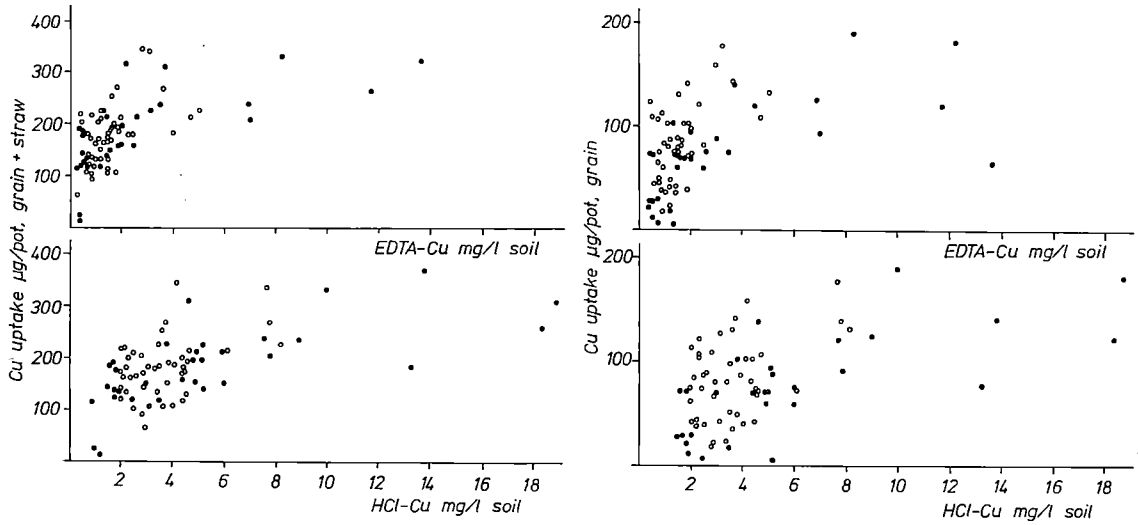

Fig. 4. Dependence of the copper uptake (µg/pot) of oat grain and the whole crop on EDTA-Cu and HCl-Cu contents of the soils.

(○ = coarse mineral soil, ● = peat soil)

Regression equations:

Grain, Cu-uptake µg/pot = 58,6 + 14,2 EDTA-Cu r^2 = 0,26
= 8,5 + 35,1 HCl-Cu r^2 = 0,29

Grain + straw,
Cu-uptake µg/pot = 88,8 + 69,5 EDTA-Cu r^2 = 0,48
= 56,6 + 62,2 HCl-Cu r^2 = 0,38

linear correlation between soil EDTA-Cu content and copper uptake ratio grain to straw was almost non-existent (r = 0,27*). The amounts of copper taken up by the grain yield and the whole crop seemed to imply that some of the soils containing less than 2 mg/l of EDTA-Cu are in need of copper fertilization. The smallest amounts of copper taken up by the crop (grain: under 50 µg/pot, grain + straw: under 150 µg/pot) were measured when the EDTA-Cu content was below the above limit. No conclusions could be drawn from the HCl-Cu content of the soil.

Copper content of soil at the end of the experiment

After harvesting, samples of 32 coarse mineral soils and 16 peat soils were sampled for EDTA-

Table 4. The change in soil EDTA-Cu content (mg/l) during the experiment, on average.

	Coarse mineral soils (n = 32)	Peat soils (n = 16)
Start	1,47 ± 1,07	1,86 ± 2,37
End	1,32 ± 0,98	1,60 ± 1,85
Difference	0,28*	0,39
Difference, %	19	21

*Significant P = 0,05 (t-test)

Cu determinations only. The results were compared with the results obtained for the same soils before the experiment started.

During the experiment the copper content of the peat soils decreased more than that of the coarse mineral soils, although the change was significant only in the latter (Table 4). In some soils containing less than 1 mg/l of EDTA-Cu the content was almost unchanged, even though the grain yield and the copper uptake of the whole crop were high.

DISCUSSION

Altogether 45 coarse mineral soils and 32 peat soils were acquired for the study. Some of them were selected because the copper deficiency there had previously restricted plant growth. The average HCl-Cu content and EDTA-Cu content in both soil type groups were therefore smaller than in corresponding arable soils in Finland (KURKI 1982, SIPPOLA and TARES 1978).

Chelating agents EDTA or DTPA are generally used to extract micronutrients from soil. HAYNES and SWIFT (1983) concluded that the DTPA method used by LINDSAY and NORVELL (1978) is suitable only for almost neutral soils. Finnish arable soils are, however, nearly always acid, and therefore the acidic (4,65) ammonium acetate supplemented with EDTA developed by LAKANEN and ERVIÖ (1971) were shown to be suitable in a study conducted by SILLANPÄÄ (1982).

The changes in soil EDTA-Cu content explained about 30 % of the variations in the grain yield, about 25 % of the variations in the copper uptake by the grain yield and about 45 % in the copper uptake by the whole crop. Similarly, changes in HCl-Cu content explained about 30 %, 7 %, 30 % and 35 % of the variation in the above yield data. The results of the pot experiment imply that the EDTA-Cu content of soil is a somewhat better indicator of the need for copper fertilization than the HCl-Cu content. In addition, EDTA-Cu determination is easy to use in routine analyses.

According to SILLANPÄÄ (1982), the critical area for EDTA-Cu content is under 1 mg/l of soil, if an adjustment for carbon content has been taken into account. If the adjustment is not made, it is probably appropriate to use slightly higher values for the critical content. In this study, the copper content of the grain and the uptake of copper implied that copper fertilization is necessary in soils containing less than 2 mg/l of EDTA-Cu. The grain yield in turn set the critical limit at 1,5 mg/l. The recommendations on copper fertilization issued to Finnish farmers follow the former limit.

SIPPOLA and ERVIÖ (1986) studied ways of extracting copper from soil and the copper uptake of ryegrass with pot experiments. For EDTA-Cu and HCl-Cu, their results resemble those obtained with oats in this study. In a pot experiment, both ryegrass and oats are able to utilize soil nutrients not easily extractable. This seemed to apply to copper uptake by oats as well. When the soil copper content is low (less than 1 mg/l EDTA-Cu), it is perhaps not possible to get good yields from fields as often as in this pot experiment, so 2 mg/l EDTA-Cu may be a suitable critical value for soil to be used for crop farming.

SCHARRER and SCHAUMÖFFEL (1960) and TÄHTINEN (1978) suggested that when copper is scarce, the amount of copper taken up by the straw yield of oats is larger than that taken up by the grain yield. Hence, the supply of copper would be sufficient when the ratio grain/straw exceeds one. On this basis, the supply of copper to the oats in this material would have

been sufficient in four peat soils, in which the EDTA-Cu content varied between 4,5 and 12,2 mg/l, as well as in the 19 coarse mineral soils containing 0,4 to 5,0 mg/l EDTA-Cu. On the other hand, EDTA-Cu contents of 7,0 and 11,7 mg/l in peat soils and 2,5 and 2,9 mg/l in mineral soils would be insufficient. According to this study, the fact that the bulk of copper uptake was in grain did not seem to prove a sufficient copper supply.

The grain yield of oats, copper content of the grain and uptakes of copper followed changes in the EDTA-Cu content of the soil more clearly in the peat soils than in the coarse mineral soils. This may be partly due to the wide range of variation in the copper content of the peat soils. This difference between soil types was also established by ERVIÖ and SIPPOLA (1986) when they studied the copper content of ryegrass.

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SELOSTUS

Karkeiden kivennäismaiden ja turvemaiden kuparipitoisuuden vaikutus kauran kasvuun astiakokeessa

RAILI JOKINEN ja HILKKA TÄHTINEN

Maatalouden tutkimuskeskus

Astiakoetta varten kerättiin 45 kivennäismaata ja 32 turvemaata, kutakin noin 200 litraa. Osa maaeristä otettiin pelloilta, joilla kuparin puute oli vaikeuttanut viljojen kasvua.

Kuparipitoisuus määritettiin tuhkaksi poltetun maan HCl-uutteesta (HCl-Cu) tai maata uutettiin happamalla ammoniumasetaatti-EDTA:lla (EDTA-Cu). Viljavuuspalvelu Oy on käyttänyt ensiksi mainittua menetelmää ennen vuotta 1986 ja jälkimmäistä ko. vuodesta lähtien.

EDTA-Cu-pitoisuuden keskiarvo (2,2 ± 2,6 mg/l maata) oli noin puolet HCl-Cu-pitoisuudesta (4,4 ± 3,4 mg/l maata). Vanhoja HCl-Cu-pitoisuuksia ei kuitenkaan voida muuntaa suoraan uusiksi EDTA-Cu-pitoisuuksiksi, koska muuntokerroin saattaa olla jokaiselle maalajille erilainen. Tässä aineistossa kerroin oli karkeille kivennäismaille 0,44 ja turvemaille 0,63. Kahden menetelmän välinen riippuvuus ($r = 0{,}83^{**}$) jäi epävarmaksi, koska kuparipitoisuuksien vaihtelu oli karkeilla kivennäismailla huomattavasti kapeampi kuin turvemailla. Asian selvittämiseen tarvittaisiin huomattavasti tätä tutkimusta suurempi aineisto.

Näytti siltä, että kriittinen EDTA-Cu-pitoisuuden alue alkaisi 1,5—2,0 mg/l vaiheilla. Pienen kuparipitoisuuden lisäksi maan korkea (yli 6,5) tai matala (alle 5,0) pH (H_2O)-luku saattavat lisätä kuparilannoituksen tarvetta.

Alle 2 mg/l EDTA-Cu sisältävillä mailla kauran jyväsato vaihteli 0:sta 80 prosenttiin kokeessa saadusta suurimmasta sadosta. Myös kasviaineksen kuparipitoisuuden ja kuparin oton vaihtelu oli tällä alueella huomattava. Koko aineistossa maan EDTA-Cu-pitoisuuden vaihtelut selittivät 25—45 % edellä mainittujen satotulosten vaihteluista. Astiakokeen tulokset eivät ehkä kuitenkaan ole suoraan peltoviljelyyn verrattavia.

Astiakokeen edullisissa oloissa kaura otti alle 1 mg/l EDTA-Cu sisältävistä maista uuttumatonta kuparia jonkin verran. Tässä tutkimuksessa jäi selvittämättä, oliko siihen syynä EDTA:n heikko uuttoteho vai kauran kyky ottaa maan vaikeasti uuttuvia kuparifraktioita astiakokeessa.

ANNALES AGRICULTURAE FENNIAE, VOL. 26: 239—249 (1987)
Seria AGROGEOLOGIA ET -CHIMICA N. 147 — Sarja MAA JA LANNOITUS n:o 147

EFFECT OF SOIL COPPER CONTENT AND pH ON THE EFFICIENCY OF COPPER SULPHATE IN A POT EXPERIMENT

RAILI JOKINEN and HILKKA TÄHTINEN

JOKINEN, R. & TÄHTINEN, H. 1987. **Effect of soil copper content and pH on the efficiency of copper sulphate in a pot experiment.** Ann. Agric. Fenn. 26: 239—249. (Agric. Res. Centre, Dept. Agric. Chem. Phys., SF-31600 Jokioinen, Finland.)

In this one-year pot experiment, oats (*Avena sativa*, cv. Pendek) were grown in seventy-seven soil samples and fertilized with copper (25 mg Cu/pot about 5 mg Cu/l soil, as $CuSO_4 = 5H_2O$). The negative correlation between the increase in grain yield (6,3 ± 10,2 g/pot, 14 ± 22 %) and the EDTA-Cu content of soil ($r = -0{,}56^{**}$, log x) was closer than the correlation between the increase in grain yield and the HCl-Cu content ($r = -0{,}13$, log x). The same is true for the increase in the copper uptake of the grain yield (73 ± 47 µg/pot) and the soil copper content (EDTA-Cu: $r = -0{,}65^{**}$, HCl-Cu: $r = -0{,}52^{**}$, log x). The apparent recovery of fertilizer copper was 4 per mille on average. Copper fertilization increased the EDTA-Cu content of soil by an average of 4,9 ± 0,8 mg/l.

In the whole material, an increase in the soil pH alone caused a drop of 13 % in the grain yield (4,4 ± 9,7 g/pot) and 12 % in the copper uptake of grains (10 ± 24 µg/pot). The material comprised six acidic soils, in which liming increased the grain yield and copper uptake. In fifteen soils, liming decreased the grain yield and copper uptake. The positive effect of copper fertilization was highest in the former soils without liming, and in the latter soils with the maximum amount of lime.

Index words: coarse mineral soil, peat soil, liming, copper fertilization, pH(H_2O), EDTA-Cu, HCl-Cu, critical level, oats, yield, copper content, copper uptake.

INTRODUCTION

As the nutrient content of soil increases, the positive effect of fertilization on the quantity and nutrient content of the crop decreases. In the case of large amounts of nutrients, fertilization may even have an injurious effect. According to TÄHTINEN (1971), the increase in the grain yield of cereals was the highest when the copper content of the soil ash extract was less than 4 mg/l. If the extractable copper content rose above 4 mg/l (HCl-Cu) or 2 mg/l (EDTA-Cu), it alone reduced variation in the grain and straw yields of oats (JOKINEN and TÄHTINEN 1987).

In cereals, the advantageous effect of copper fertilization has mainly been observed as an increase in the grain yield (CALDWELL 1971, HARRY and GRAHAM 1981, KARAMANOS et al. 1985). Changes in the straw yield have been

minor or the straw yield has diminished, reducing the proportion of straws to the whole crop (THIEL 1972).

The sorption of copper in soil and its dependence on the soil pH, amount of organic matter, cation exchange capacity, and amount of Al or Fe oxides determine how much of the soil copper and fertilizer copper a plant can recover (McBRIDE and BLASIAK 1979, KUO and BAKER 1980, CAVALLARO and McBRIDE 1984).

The objective of this pot experiment was, by means of oats crops obtained with copper fertilization, to compare the EDTA-Cu and HCl-Cu contents as indicators of copper useful to the plant. In addition, the effect of the soil pH on oats crops was studied without copper fertilization and in soils fertilized with copper sulphate.

MATERIAL AND METHODS

The culture medium of oats (*Avena sativa*, cv. Pendek) in the pot experiment consisted of 45 coarse mineral soil samples and 32 peat soil samples. The average pH (H_2O) of the soils was 5,4 ± 0,7 (variation 3,9—6,8), the copper content of the ash extract, HCl-Cu, 4,4 ± 3,4 mg/l (variation 0,9—18,8 mg/l of soil) and the amount of copper extractable in acidic ammonium acetate EDTA, EDTA-Cu, 2,18 ± 2,60 mg/l (variation 0,28—13,60 mg/l of soil). The properties of the various soil type groups were presented in the first part of the study (JOKINEN and TÄHTINEN 1987). That report also describes the methods applied to soil and plant analyses and the practical details of the pot experiment.

For the present study, each soil was limed with $CaCo_3$ (lab. reag.). The quantities of lime applied varied between 2 g and 48 g, depending on the soil pH. The goal was to raise the pH (H_2O) of the soils but without aiming at a certain figure. The number of liming levels also varied. In seven soils, lime was applied only one amount, one section being left unlimed, because the pH of the soils was six or more. In two peat soils with pH (H_2O) 5,9 and 4,4, four different lime quantities were applied. Generally there were three liming levels. The copper fertilization, 25 mg Cu per pot as copper sulphate, was given to all soils, to both limed and unlimed sections. Lime and copper were mixed into the soil together with the rest of the fertilizers. In three soils, with pH (H_2O) 6,8, 40 ml and 80 ml of 0,5 M H_2SO_4 was added instead of lime. All treatments were repeated three times.

The reliability of the results was studied with an analysis of variance, in which liming, copper fertilization and their interaction were chosen as sources of variation. Differences between treatments ($P = 0,05$) were tested with Tukey's test (STEEL and TORRIE 1960). The correlation and regression analyses indicating the dependences between soil (x) and yield properties (y) were calculated according to a linear model and logarithmic or square root transformation models. The results of the model giving the highest coefficient of determination are presented.

Copper fertilization without liming

In the whole material, the absolute (g/pot) or relative (% of the maximum in the experiment) change in grain yield obtained with copper fertilization was positive (Table 1). In some individual soils, copper fertilization decreased the grain yield a little (Fig. 1).

The correlation between the soil EDTA-Cu content (log x) and the increase in grain yield obtained through copper fertilization was closer ($r = 0{,}56^{**}$) than the correlation between HCl-Cu content and the increase in yield ($r = 0{,}13$, Fig. 1). The coefficient of multiple determination was not increased even though the soil pH(H_2O) was taken as the second independent variable.

Copper fertilization caused the smallest increase in grain yield in peat soils (0,3 ± 2,6 g/pot, n = 9) in the pH(H_2O) range 5,0—5,5 and in coarse mineral soils (3,2 ± 4,0 g/pot, n = 30) in the pH(H_2O) range 5,0—6,0. In both soil types, a change in the pH in either direction improved the increase in grain yield obtained with copper fertilization.

In all mineral soils, copper fertilization increased grain yield significantly less (4,4 ± 5,3 g/pot) than it did in peat soils (9,2 ± 14,2 g/pot). In soils containing less than 2 mg/l of EDTA-Cu, the increase in grain yield was 5,3 ±

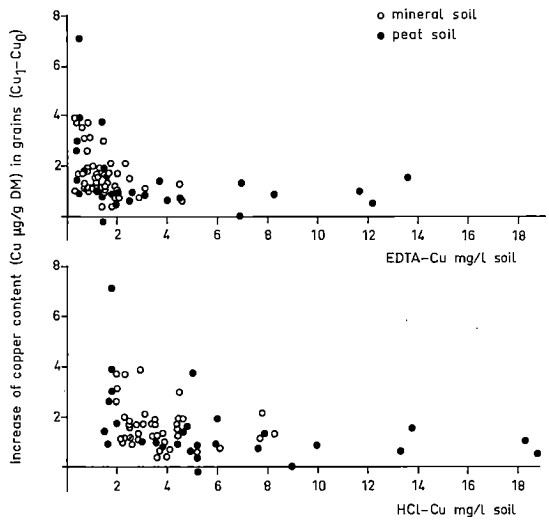

Fig. 1. Effect of extractable copper content of soil on the relative change (Cu_1—Cu_0) in oats grain yield obtained with copper fertilization (25 mg Cu/pot). The highest increase in yield = 100. EDTA-Cu = Cu extractable in acidic ammonium acetate-EDTA. HCl-Cu = HCl extract of soil burned to ash.

Yield increase g/pot = 5,5—10,7 x log EDTA-Cu; $r^2 = 0{,}28$
" " = 10,3—11,4 x log HCl-Cu ; $r^2 = 0{,}12$

Table 1. Changes in oats grain and straw yield, copper content and copper uptake caused by copper fertilization (25 mg Cu/pot) without liming.

	Without copper $\bar{x}\pm s$	Change (Cu_1—Cu_0) $\bar{x}\pm s$	variation	%
Grain yield, g/pot	34,0±13,1	6,3±10,2	−6,9—46,2	19
Grain yield, % max.		14±22	−11—100	
Straw yield, g/pot	46,5±10,3	−1,1±6,3	−19,3—27,4	2
Grain, Cu µg/g	2,2±0,7	1,5±1,1	−0,2—7,1	68
Straw, Cu µg/g	2,1±0,4	0,9±0,8	0,1—5,4	43
Grain, Cu µg/pot	82±38	73±47	−9—232	89
Straw, Cu µg/pot	95±27	39±37	−6—209	41
Whole crop, Cu µg/pot	177±58	112±75	20—441	63
Apparent recovery of fertilizer Cu, per mille				
Whole crop 4,5±3,0				
Grain yield 2,9±1,9				

5,1 g/pot in mineral soils and 15,6 ± 15,1 g/pot in peat soils. When the relative yield increase obtained with copper fertilization was over 36 % (mean + standard deviation), soils contained less than 1,5 mg/l of EDTA-Cu (Fig. 1). In addition, the peat soils were acidic (8 soils, pH(H_2O) below 5) and the mineral soils almost neutral (2 soils, pH(H_2O) over 6,5).

In soils containing less than 2 mg/l of EDTA-Cu, copper fertilization increased grain yield almost invariably, but when the content was higher, the effect of copper fertilization on grain yield was uncertain (Fig. 1). The critical limit for HCl-Cu content, 4 mg/l, did not seem to be as good an indicator of the copper fertilization need as 2 mg/l of EDTA-Cu, because the relative yield increase obtained, for example, in a soil containing 5,2 mg/l of HCl-Cu, was 88 %.

The straw yield of oats decreased only slightly with copper fertilization (Table 1), and there was no significant difference between the soil types. The differences between the soil types were almost non-existent in soils containing less than 2 mg/l of EDTA-Cu. However, in the whole material, changes in yield had a wider range of variation in peat soils (between −19,3 and 27,4 g/pot) than in mineral soils (between −14,1 and 3,3 g/pot).

The increase in the copper content of both grain and straw caused by copper fertilization was highly significant (Table 1). The increase in the grain copper content was independent of the soil type (Fig. 2). The straw copper content, however, increased somewhat more in mineral soils (1,1 ± 1,1 µg/g) than in peat soils (0,8 ± 0,5 µg/g). In soils containing less than 2 mg/l of EDTA-Cu, the increase in the grain copper content (1,8 ± 1,2 µg/g) was higher than in other soils (1,0 ± 0,5 µg/g). This also applies to the increase in the straw copper content (1,0 ± 0,9 µg/kg and 0,7 ± 0,4 µg/kg, respectively).

The negative correlation between the soil EDTA-Cu content (log x) and the increase in grain copper content (r = −0,47**) was closer than the corresponding correlation with the HCl-Cu content (r = −0,30, Fig. 2).

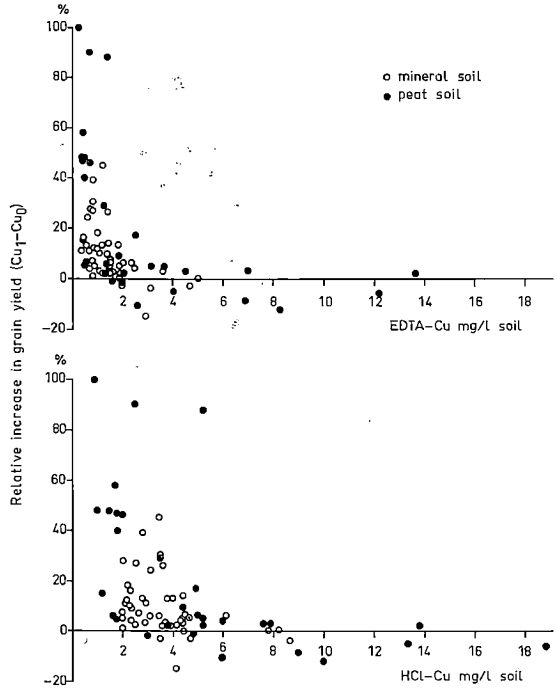

Fig. 2. Effect of extractable copper content of soil on the change (Cu_1—Cu_0) in oats grain copper content (µg) obtained with copper fertilization. EDTA-Cu = Cu extractable in acidic ammonium acetate-EDTA. HCl-Cu = HCl extract of soil burned to ash.

Cu µg/g = 1,67—0,23 x $\sqrt{\text{EDTA-Cu}}$; $r^2 = 0,17$
" " = 2,96—0,68 x $\sqrt{\text{HCl-Cu}}$; $r^2 = 0,13$

Copper fertilization increased the copper uptake of oats significantly (Table 1). The increase in the grain copper uptake was independent of the soil type. The increase in the straw copper uptake was significantly greater in peat soils (48 ± 50 µg/pot) than in mineral soils (32 ± 23 µg/pot).

The increase in copper uptake also indicates the apparent recovery of fertilizer copper. The whole crop took 4,5 ± 3,0 per mille of the fertilizer copper; and the grain yield took 2,8 ± 1,9 per mille.

In soils containing less than 2 mg/l of

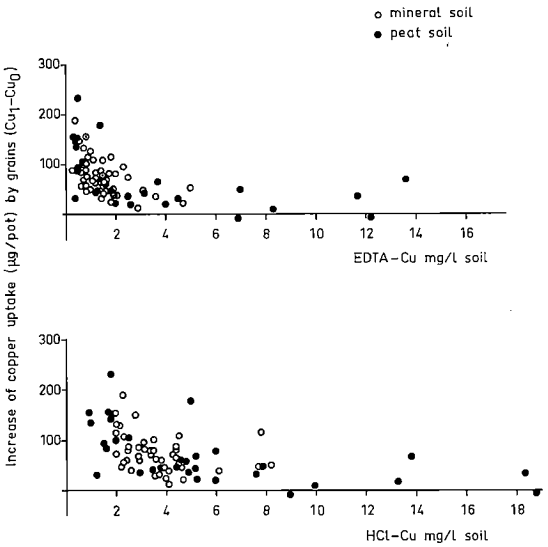

Fig. 3. Effect of extractable copper content of soil on the change (Cu_1—Cu_0) in oats grain copper uptake (μg/pot) obtained with copper fertilization. EDTA-Cu = Cu extractable in acidic ammonium acetate-EDTA. HCl-Cu = HCl extract of soil burned to ashes.

Cu μg/pot = 86,2—35,4 x log EDTA-Cu; $r^2 = 0,43$
" " = 129,9—43,8 x log HCl-Cu ; $r^2 = 0,31$

EDTA-Cu, copper fertilization increased the grain copper uptake by an average of 87 ± 46 μg/pot, and in other soils by 36 ± 26 μg/pot (Fig. 3). The greatest increases in the copper uptake of grain yield were obtained in peat soils containing less than 0,5 mg/l of EDTA-Cu, in which the pH (H_2O) was under 5. In two peat soils (pH (H_2O) 5,45 and 5,10) copper fertilization decreased the copper uptake of grain yield. A high EDTA-Cu content of soil did not impede the positive effect of copper fertilization on the grain copper uptake, when the soil pH (H_2O) was close to five (two peat soils).

The increase in the grain copper uptake caused by copper fertilization had a somewhat closer correlation with the soil EDTA-Cu content ($r = -0,66^{**}$, log x) than with the HCl-Cu content ($r = -0,55^{**}$, Fig. 3). When the soil pH increased the uptake of fertilizer copper decreased ($r = -0,40^{**}$). Variations in the EDTA-Cu content (log x) and in pH together explained 52 % of the variations in the grain copper uptake obtained with copper fertilization ($r_{y.12} = 0,72^{**}$).

After the crop had been harvested, 16 peat soils and 32 coarse mineral soils were determined for EDTA-Cu. Copper fertilization increased (Cu_1—Cu_0) the extractable copper content in peat soils (by 5,8 ± 0,8 mg/l) significantly more than in coarse mineral soils (by 4,4 ± 0,8 mg/l). However, in mineral soils the increase in copper content varied (2,53—6,46 mg/l) more than in peat soils (3,83—6,87 mg/l).

The amount of fertilizer copper — 25 mg Cu/pot — approximately corresponds to 5 mg/l of soil. In some peat soils the effect of fertilization on the copper content was greater than the amount of copper applied. On the other hand, in some soils the EDTA-Cu content decreased more than one would assume from the copper uptake of the crop.

There was no clear correlation between the increase in the soil EDTA-Cu content and the corresponding content or pH of unfertilized soil.

Liming without copper fertilization

Liming without copper fertilization caused a significant positive or negative change in the oats grain yield in 21 soils. As the soil pH (H_2O) increased, the yield was reduced in seven mineral soils and in eight peat soils, in which the EDTA-Cu content was mostly below 1 mg/l (Fig. 4, some results). In four peat soils, the EDTA-Cu was between 1,5 and 2,5 mg/l. In most cases straw yield seemed to increase when grain yield decreased.

In six very acidic soils, grain yield increased along with a rise in pH (Fig. 5). The greatest increases in yield were 155 % and 388 %, when the soil EDTA-Cu content was about 0,4 mg/l (soils 3 and 87). However, it should be noted that a higher pH had a positive effect on grain

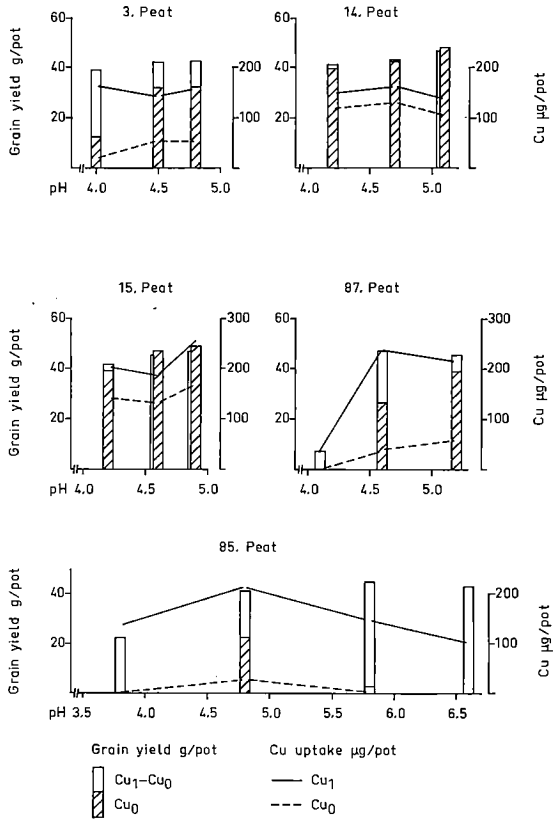

Fig. 4. Negative effect of increasing the soil pH(H_2O) on the oats grain yield (g/pot) and the consequent changes in straw yield (g/pot) and yield copper uptake (µg/pot) (without copper fertilization). EDTA-Cu = Cu extractable in acidic ammonium acetate-EDTA.

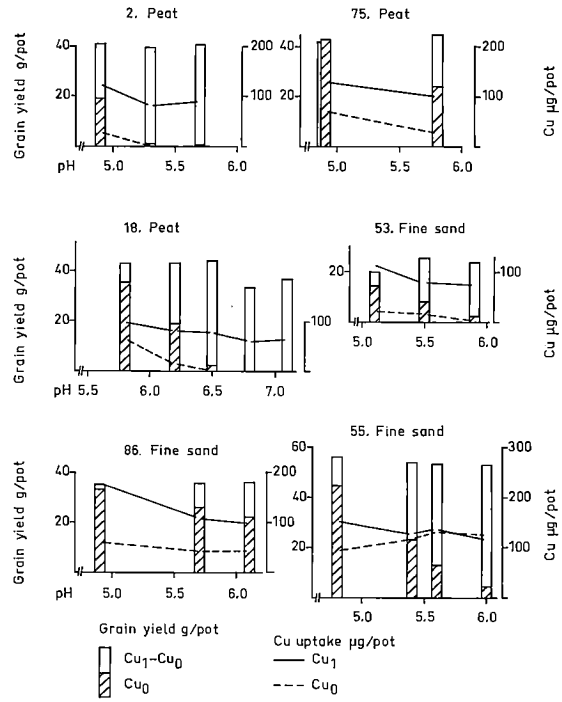

Fig. 5. Positive effect of increasing the soil pH(H_2O) on the oats grain yield (g/pot) and the consequent changes in straw yield (g/pot) and yield copper uptake (µg/pot) (without copper fertilization). EDTA-Cu = Cu extractable in acidic ammonium acetate-EDTA.

yield also in soils with a sufficient amount of EDTA-Cu (soils 14 and 15). Changes in straw yield were usually minor, with the exception of an acidic peat soil low in copper (85).

The addition of sulphuric acid, which is the opposite measure from liming, lowered the soil pH from 6,8 to 6,2, but only in one soil was it possible to get a significant increase in grain yield, 11,8 g/pot, while straw yield decreased by 11,0 g/pot.

In all limed soils, grain yield decreased by an average of 4,4 ± 9,7 g/pot (Table 2). The correlation between the soil pH and the change in crop caused by liming was rather weak (r = −0,38*).

The grain copper content, like the straw copper content, was lower in limed soils than in unlimed soils (Table 2). The correlation between the soil EDTA-Cu content and the grain copper content (r = 0,37*) or straw copper content (r = 0,31*) in limed soils was not particularly close. The negative correlation between the soil pH and the copper content of the grains and straw was weak (grain: r = −0,11, straw: r = −0,10).

In limed soils the copper uptake of the whole oats yield was only 11 µg/pot (6 %) lower than in the corresponding unlimed soils (Table 2). Of this, grain yield accounted for 10 µg/pot and straw yield 1 µg/pot.

When liming increased grain yield, the grain

Table 2. Changes in oats grain and straw yield, copper content and copper uptake caused by liming without copper fertilization.

	Without lime $\bar{x}\pm s$	Change ($Ca_n - Ca_0$) $\bar{x}\pm s$	variation	%
Grain yield, g/pot	34,0±13,1	−4,4±9,7	−34,9—38,8	13
Straw yield, g/pot	46,5±10,3	0,8±10,5	−29,7—48,3	2
Grain, Cu µg/g	2,2±0,7	−0,5±0,5	−1,9—1,8	23
Straw, Cu µg/g	2,1±0,4	−0,2±0,4	−2,0—1,1	10
Grain, Cu µg/pot	82±38	−10±24	−91—101	12
Straw, Cu µg/pot	95±27	−1±27	−64—139	1
Whole crop, Cu µg/pot	177±58	−11±38	−171—159	6

Table 3. Changes in oats grain and straw yield, copper content and copper uptake caused by copper fertilization (25 mg Cu/pot) in limed soil.

	Without copper $\bar{x}\pm s$	Change ($Cu_1 - Cu_0$) $\bar{x}\pm s$	variation	%
Grain yield, g/pot	30,8±23,2	11,9±14,7	−7,8—48,8	39
Straw yield, g/pot	46,9±9,5	−2,0±7,3	−31,7—30,0	4
Grain, Cu µg/g	2,1±0,7	1,2±0,9	−0,6—6,8	55
Straw, Cu µg/g	2,2±0,5	0,6±0,5	−0,9—3,3	28
Grain, Cu µg/pot	71±45	64±43	−16—239	90
Straw, Cu µg/pot	95±31	27±36	−122—162	28
Whole crop, Cu µg/pot	166±56	91±61	−46—376	
Apparent recovery of fertilizer Cu, per mille				
Whole crop 3,6±2,0				
Grain yield 2,6±1,7				

copper uptake did not follow the changes in the yield (Fig. 5). The negative effect of liming on grain yield was observable as a similar change in copper uptake (Fig. 4).

The negative correlation between the soil pH and the grain copper uptake ($r = -0,16$) was not significant.

Liming and copper fertilization

In limed soils, copper fertilization had a positive effect on the oats grain yield, on the copper content of plant matter and on the yield copper uptake; the exception was a decrease in straw yield (Table 3). When compared with unlimed soils, the changes in copper content and copper uptake were smaller in limed soils. Similarly, the apparent recovery of fertilizer copper decreased.

The simultaneous application of lime and copper fertilization had a significant interaction effect on the oats grain yield in twenty soils. Most of them were peat. In soils in which the grain yield decreased as the soil pH rose, copper fertilization levelled yield differences (Fig. 6). The increase in the grain copper uptake caused by copper fertilization (area between the continuous and dashed lines in the figure), varied considerably in different soils. The grain copper uptake was often lowest in yields that had received copper fertilization and

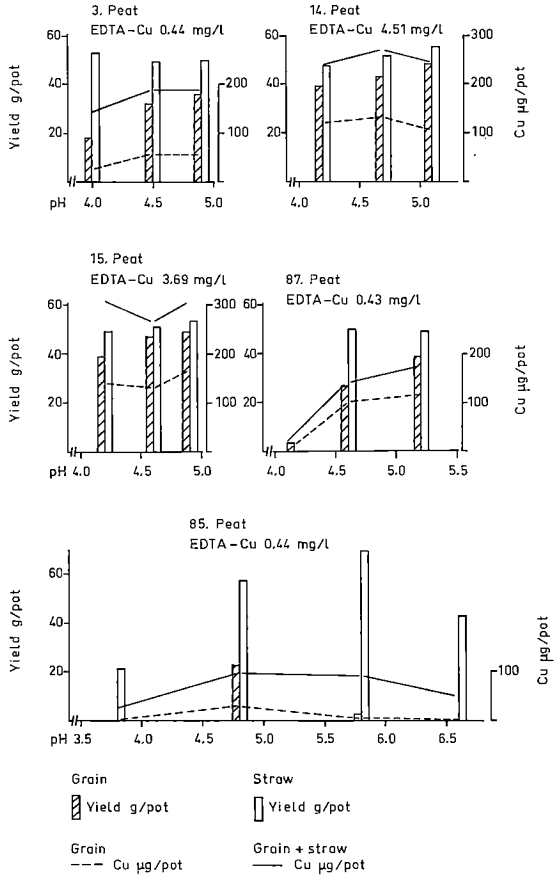

Fig. 6. Changes in oats grain yield and in grain copper uptake obtained with copper fertilization at different levels of pH(H_2O) when liming alone decreased grain yield. EDTA-Cu = Cu extractable in acidic ammonium acetate-EDTA.

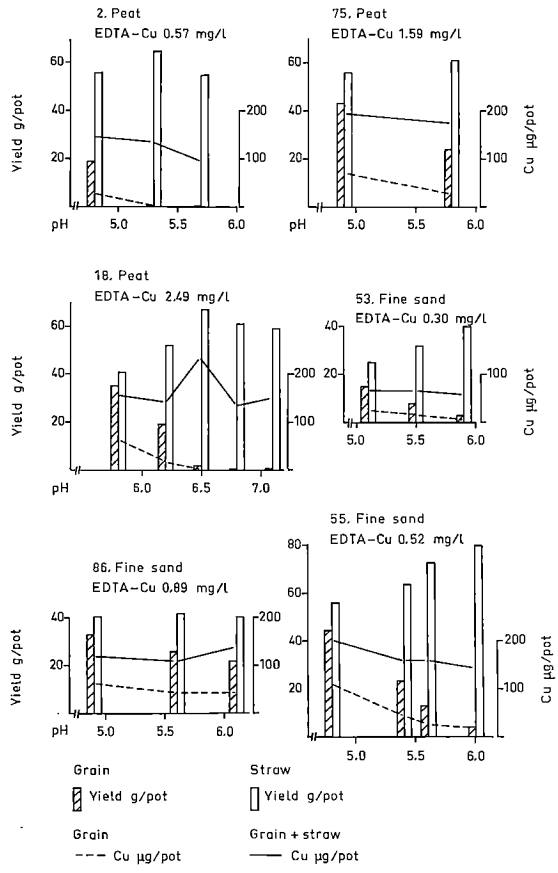

Fig. 7. Changes in oats grain yield and in grain copper uptake obtained with copper fertilization at different levels of pH(H_2O) when liming alone increased grain yield. EDTA-Cu = Cu extractable in acidic ammonium acetate-EDTA.

a large amount of lime, for liming had a negative effect on the grain copper content irrespective of copper fertilization.

Copper fertilization could level yield differences even when liming alone increased grain yield (Fig. 7). In a few soils rich in copper (soils 14 and 15), copper fertilization had a negative effect on grain yield. The increase in the grain copper uptake caused by copper fertilization (Cu_1-Cu_0) varied in different soils.

Sulphuric acid, added to the soil to reduce its pH, and copper fertilization gave equally high grain yields at all pH levels. Compared with soils not treated with the acid, the grain copper content and the amount of copper taken by grain yield increased when pH dropped from 6,8 to 6,2.

At the end of the experiment, the effect of copper fertilization on the EDTA-Cu content of soil was independent of the soil pH, of the EDTA-Cu content of unfertilized soil or of the yield copper uptake.

DISCUSSION

The effect of copper fertilization and liming on the yield and copper uptake of oats was studied in a pot experiment during one growing season. It had been shown that in the 77 soil samples used as culture medium, copper deficiency restricted the formation of the grain yield and copper uptake of oats most when the soil EDTA-Cu content was below 1,5 mg/l (JOKINEN and TÄHTINEN 1987).

Copper deficiency restricted the formation of the grain yield and the grain copper uptake of cereals more effectively than it limited straw yield (THIEL 1972, KARAMANOS et al. 1985). So the vegetative plant parts showed little response to copper fertilization. The positive effect of copper fertilization was primarily observed as an increase in grain yield and as an increase in the proportion of grains of the total yield (THIEL 1972).

The effect of copper fertilization on the grain yield and grain copper uptake of oats had a clearer correlation with the soil EDTA-Cu content than with the soil HCl-Cu content. Changes in the EDTA-Cu content explained some 30 % of the variation in the grain yield increase and 43 % of the variation in the grain copper uptake. According to TÄHTINEN (1971), variations in the soil HCl-Cu content explained only about 10 % of the variation in the yield increase in field experiments. The coefficient of determination (12 %) obtained in our pot experiment is consistent with the above-mentioned study.

Results obtained without copper fertilization (JOKINEN and TÄHTINEN 1987), as well as the results of the present study, suggest that 1,5—2 mg/l could be a suitable critical limit for the EDTA-Cu content. In this pot experiment, a low EDTA-Cu content of the soil did not alone in all cases indicate a need to fertilize oats with copper, because the effect of copper fertilization on grain yield and on copper uptake also varied in soils low in copper (below 2 mg/l of EDTA-Cu).

In the pot experiment the increases in grain yield and in copper content caused by copper fertilization were weaker dependent on soil EDTA-Cu than the respective increase in copper uptake. Thus, the copper uptake is the best indicator of the effect of fertilization. The oats grain yield and the grain copper uptake were equally good indicators of the effect of the soil EDTA-Cu content (JOKINEN and TÄHTINEN 1987). However, in field experiments the dependences can differ from those in pot experiments.

According to CALDWELL (1971) and HARRY and GRAHAM (1981), the grain yield and copper uptake of cereals were at their highest when the soil pH was about 5. The same is suggested by the significant yield results obtained in the present study in limed soils (without copper fertilization). The positive effect of copper fertilization on copper uptake also seemed to decrease as the soil pH became higher. McBRIDE and BLASIAK (1975), KUO and BAKER (1980), JEFFREY and UREN (1983) and CAVALLARO and McBRIDE (1984), among others, have shown that the sorption of soil copper or added copper into organic matter as complex compounds, on the surface of Fe or Al oxides or on cation exchange sites was strongest between pH 6 and 7.

In very acidic soils, the positive effect of liming on the copper uptake of oats is probably due to improved growth conditions of the roots and not to copper's reactions in the soil. Plants take almost all their copper through root interception (OLIVER and BARBER 1966), and therefore the development of roots is of great importance.

The soil samples in our study were not determined for any other properties affecting copper reactions besides pH. According to SILLANPÄÄ (1982), the quantity of organic carbon is the most important soil property

affecting the recovery of copper. In SILLANPÄÄ's study, changes in the copper content of wheat (growing time 36 days) were better explained by variations in the EDTA-Cu content, adjusted by the content of organic carbon, than by variations in the unadjusted content.

In peat soils, copper forms permanent complex compounds with humus and fulvic acids (KERVEN et al. 1984). Copper retention is greatest in soils containing large amounts of soluble organic matter, and this causes the differences in copper sorption between peat varieties. The advantageous effect of copper fertilization in limed soils is based on a reduction in the formation of complex compounds after the exchange sites have been filled. The rest of the copper remains in the soil in ionic form (KERVEN et al. 1984, NIELSEN 1986). Retention of copper in soil is probably the main reason for the variations observed in the increase in the EDTA-Cu content caused by copper fertilization in the various soil samples of this experiment.

The fact that the increase in the EDTA-Cu content of some soils exceeded the amount of copper added is probably caused by variations in the dryness/moisture of the soils during the experiment (WILLIAMS and MCLAREN 1982).

Various solutions are used to extract the copper that can be recovered by plants from soil. Each of these solutions extracts different fractions of the total copper in soil. LEVESQUE and MATHUR (1986) showed that water alone extracts from peat soil those copper fractions that plants take.

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SELOSTUS

Maan happamuuden ja kuparipitoisuuden vaikutus kuparilannoituksella saatuun tulokseen astiakokeessa

RAILI JOKINEN ja HILKKA TÄHTINEN

Maatalouden tutkimuskeskus

Kuparilannoituksella (25 mg/astia Cu, $CuSO_4 = 5H_2O$:na) saadun kauran sadon, kuparipitoisuuden ja kuparin oton riippuvuutta maan kuparipitoisuudesta ja happamuudesta tutkittiin astiakokeessa 45 karkealla kivennäismaalla ja 32 turvemaalla. Happamien maiden pH-lukua kohotettiin yhdellä tai useammalla kalsiumkarbonaattimäärällä. Muutaman maan pH-lukua alennettiin kahdella määrällä 0,5 M rikkihappoa.

Maan EDTA-Cu-pitoisuuden vaihtelut (log x) selittivät noin 30 % ja HCl-Cu-pitoisuuden vaihtelut (log x) noin 10 % kuparilannoituksella saadun jyväsadon lisäyksen muutoksista. Myös lannoituksen aiheuttama jyvien kuparin oton muutosten riippuvuus maan EDTA-Cu-pitoisuudesta ($r = -0{,}66$) oli hieman HCl-Cu-pitoisuutta ($r = -0{,}56$) kiinteämpi. EDTA-Cu-pitoisuuden kriittinen raja-arvo näytti olevan 1,5—2,0 mg/l, sillä kuparilannoituksen vaikutus kauran satotuloksiin oli selvin tämän rajan alapuolella. Niukkakupariset turvemaat tuottivat kuparilannoituksella kivennäismaita suuremmat kauran jyväsadon lisäykset. Kauran koko sato otti keskimäärin 4 % lannoituksena annetusta kuparista.

Maan pH-luvun kohottaminen yksinään lisäsi kuudella maalla kauran jyväsatoa merkitsevästi, mahdollisesti kauran juuriston parantuneiden kasvuolojen vuoksi. Maat olivat erittäin happamia (pH alle 5). Toisaalta kalkkimäärillä oli myös negatiivinen vaikutus kauran jyväsatoon 15 maalla, joiden alkuperäinen pH-luku oli yli 5. Maan kuparin muuttuminen kauralle osittain käyttökelvottomaksi näytti olevan voimakkainta pH (H_2O) 6:n yläpuolella.

Rikkihapolla aiheutettu maan pH-luvun aleneminen 6,8:sta 6,2:een tuotti merkitsevän jyväsadon ja kuparin oton lisääntymisen sekä jyvien kuparipitoisuuden kohoamisen.

Kuparilannoitus yhdessä kalkituksen kanssa tasoitti pH-luvun negatiiviset tai positiiviset vaikutukset satoon. Korkeassa pH:ssa lannoituksena lisätty kupari ei ollut samassa määrin kauralle käyttökelpoista kuin pH 6:n alapuolella.

Tutkimuksen maanäyteaineiston perusteella ei voitu käsitellä maan muiden ominaisuuksien kuin pH-luvun ja uuttuvan kuparipitoisuuden vaikutusta kauran kuparin saantiin.

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