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STUDIES ON THE BIOLOGY AND CONTROL
OF MARSH HORSETAIL (*EQUISETUM
PALUSTRE* L.)

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Agricultural Research Centre, Department of Plant Husbandry
Tikkurila, Finland

Selostus:

Suokortteen (*Equisetum palustre* L.)
biologiasta ja torjunnasta

HELSINKI 1963

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I. Introduction

The marsh horsetail (*Equisetum palustre* L.) is a circumpolar species occurring in the temperate zone of the northern hemisphere (Fig. 1, HULTÉN 1962). In Finland it is distributed throughout the country (UOTILA 1956). The species is poisonous, especially to cattle. Its natural habitat consists principally of marshy and swampy land, in Finland primarily spruce-broadleaved tree swamps, fens and high-quality pine bogs (UOTILA 1957). The marsh horsetail is also found growing as a weed on cultivated land and is especially harmful in fodder production in Central Europe (e.g. NOZEMAN 1782, MEYER 1832, WEBER 1903, von KRIES 1962), in the U.S.S.R. (e.g. MAKSIMJUK 1953, CHOTEJEV and TSCHEWGUS 1960), in Scandinavia (SEMB 1960) and in Finland (UOTILA 1956). The species apparently thrives well on farmlands and persists when virgin soil is tilled. The number of hay fields infested by marsh horsetail in Finland has been estimated at 1 % of the total, and the average abundance of marsh horsetail shoots in each field at 0.7 % of the stand (PAAATELA 1953). Of the cereal fields in Finland, about 7—8 % have been proved infested; the average abundance of shoots in these fields has been found to vary from 1 to

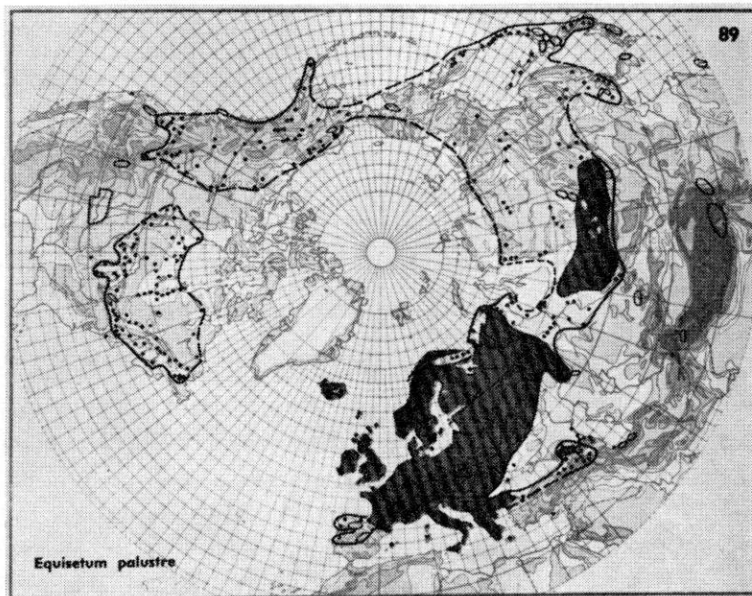


Fig. 1. Distribution of *E. palustre* (HULTÉN 1962).

5 per 10 m² (MUKULA and LALLUKKA 1962, MUKULA, LALLUKKA and RAATIKAINEN 1962). In these estimates the banks of open-drainage ditches, where marsh horsetail occurs even more abundantly, were not taken into consideration. Since the proportion of open-drained fields in Finland amounts to as much as 85 %, it can be readily understood that this plant constitutes a typical and serious problem in Finnish agriculture.

The main poisonous compound in marsh horsetail is believed to be an alkaloid called *palustrine* (equisetine) C₁₇H₃₁N₃O₂ (LOHMANN 1904, EUGSTER *et al.* 1953, KERN 1957, DIETSCHKE and EUGSTER 1960). In cattle feeding trials in Finland, carried out by the Animal Husbandry Department of the Agricultural Research Centre in the years 1949—56, it was found that as little as 2 grams of air-dried marsh horsetail shoots in the daily fodder of cattle caused a decrease in milk production. Larger amounts produced lack of appetite, diarrhoea, and general indisposition in the animals (UOTILA 1956).

Horses are not susceptible to small amounts of marsh horsetail shoots. However, when fed with exceptionally large amounts for long periods of time and under certain unsatisfactory conditions, horses may become seriously poisoned. Other horsetail species, e.g. *E. arvense* L., have a similar effect. The main symptoms of this disease in horses are disturbances of the central nerve system (cf. von KRIES 1962).

The elimination of the poisonous alkaloid of marsh horsetail by heating the fodder in a silo, often recommended by German workers (e. g. BÜNGER and GLET 1934), does not seem reliable or advisable if the milk is to be used for high-quality cheese production (UOTILA 1956). The taste of marsh horsetail is apparently unpleasant to cattle. As a result, animals on pasture can select their food to a certain extent and avoid eating the plant, at least when the shoots are sparse. In the case of cut fodder, either dried or fresh, no such selection is possible. Since about 1.2 million hectares of grassland in Finland (45 % of the cultivated area) are harvested by mowing and only 0.25 million (9 % of the total area) are pastured, it is obvious that marsh horsetail probably constitutes a more serious problem in Finland than, for instance, in Central Europe, where most of the grasslands are utilized for grazing. Because of its poisonous qualities, marsh horsetail actually prevents successful cattle raising on many farms in Finland.

In the years 1956—62, the Department of Plant Husbandry organized investigations in southern Finland dealing with the taxonomy, reproduction and control of marsh horsetail. These studies, which were carried out in the communes of Iitti, Kitee, Lapinjärvi and Pernaja, as well as at Rekola, near Helsinki, and at Puistola in the city of Helsinki, are described in the present paper. The preliminary results of these studies have already been published in the yearbook, *Maatalous ja Koetöimintä*, of the Agricultural Research Centre (MUKULA 1963). The geographical distribution of marsh

Year	May	June	July	Aug.	Sept.	Ave.
Mean temperature (° C)						
1956	8.6	15.7	15.3	12.6	8.6	12.2
1957	8.8	12.5	17.7	15.3	9.7	12.8
1958	8.2	13.4	15.2	14.4	10.4	12.3
1959	9.8	15.1	17.9	17.0	8.7	13.7
1960	10.7	16.0	17.7	15.2	10.2	14.0
1961	9.9	16.8	15.9	14.0	9.8	13.3
1962	8.6	11.8	14.7	12.9	9.5	11.5
Normal	9.0	13.5	16.7	15.0	10.7	13.0
Precipitation (mm)						
1956	19.1	36.8	121.3	174.8	25.3	377
1957	48.7	56.6	78.9	129.9	108.2	422
1958	67.8	38.1	90.4	45.6	16.5	258
1959	25.6	33.2	68.0	36.0	7.0	170
1960	24.8	97.7	102.5	152.4	58.8	436
1961	38.5	55.7	91.1	96.3	26.2	308
1962	48.0	60.7	72.8	106.3	144.3	432
Normal	49	52	67	77	72	317

horsetail, as well as the influence of soil, climate and weather conditions upon its occurrence, have not been included in these studies. In connexion with the weather factor, the following figures from Tikkurila, near Helsinki, may be given here (above).

II. Taxonomy of marsh horsetail

The marsh horsetail, *Equisetum palustre* L. (1753) is at the present time placed in the subgenus *Enequisetum* (Sadebeck) Rouy (1913). It is assumed to be descended from the water horsetail, *E. fluviatile* (L.) Ehrh. (SCHAFFNER 1930), and to be able to hybridize with both the giant horsetail, *E. telmateia* Ehrh. (syn. *E. maximum* Lam.), and the field horsetail, *E. arvense* L., belonging to the above-mentioned subgenus, as well as with the variegated horsetail, *E. variegatum* Schleich., of the subgenus *Hippochaete* (Milde) C., T. & W. (1952). The former two hybrids have been noted in Central Europe (ROTMÄHLER 1951) and the latter in Sweden (HYLANDER 1953). In order to verify the nature of such hybrids, it would be advisable to perform artificial crossings. However, in view of the weak sexual reproduction of horsetails, the accomplishment of such crossings may prove too difficult to carry out successfully.

The shoots of marsh horsetail are extremely variable in habit, and several varieties, forms and sub-forms have been described in the literature (especially MILDE 1867, KLINGE 1882, LUERSEN 1889 and MARIE-VICTORIN 1927). However, much confusion exists in the pertinent taxonomic treatments of this subject. FERNALD (1947), in reviewing the literature, has devised the following list of forms of the American *E. palustre*:

- "a. Stem with whorls or tufts of branches borne regularly from the nodes b.
- b. Nodal branches all simple c.
- c. Stem erect, with 3-many branches diverging symmetrically as whorls d.
- d. Cone borne only from summit of stem e.
- e. Branches from median and upper nodes (above submerged-level)
 - strongly arched-ascending to suberect f.
 - f. Branches 1.5—6 cm long
 - Teeth of sheaths white-margined *E. palustre* (typical).
 - Teeth blackish, without white margins forma *nigridens*.
 - f. Branches 0.7—3 dm long, very strongly ascending
 - forma *verticillatum*.
- e. Branches from median and upper nodes horizontally or
 - subhorizontally divergent forma *arcuatum*.
- d. Cones borne at tips of many ascending branches forma *polystachion*.
- c. Stem prostrate, greatly elongate, its elongate (up to 4 dm),
 - strongly ascending or erect branches mostly in pairs (1—5) forma *fluitans*.
- b. Nodal branches (at least the lower ones) with short branchlets forma *ramulosum*.
- a. Branches only 1 or 2 (rarely 3) at a node, irregularly scattered, or none.
 - Main or principal stem elongate, with many nodes, 2—4 mm thick,
 - with or without more slender secondary stems forma *simplex*.
 - Main axis nearly suppressed, the very numerous slender erect stems
 - or branches nearly uniform and 1—2 mm thick forma *filiforme*.

EQUISETUM PALUSTRE L. Sp. Pl. 1061 (1753); Duval-Jouve, Hist. Nat. Equiset. 246 (1864) with detailed European bibliographic citations; Milde, Mon. Equiset., t. xiii, fig. 4 ("Normale, gewöhnliche Form"). Forma *verticillatum* Milde, forma a. *breviramosum* Klinge in Archiv. Naturk. Liv.-Esth. u. Kurland, ser. 2, viii. 401 (1882); Luerss. Farnpfl. 709 (1889). Var. *americanum* Victorin, Équisét. Quebec, Contrib. Lab. Bot. Univ. Montréal, no. 9:51 (1927) in part, not the type.

Forma NIGRIDENS (St. John) Victorin. Var. *nigridens* St. John, Bot. Expl. Gulf St. Lawr. Reg.-Victoria Mem. Mus. Mem. 126:42 (1922). Var. *americanum* forma *nigridens* (St. John) Victorin, l. c. 63 (1927).

Forma VERTICILLATUM Milde, Gefäss-Cryptog. Schles.-Nov. Act. Acad. Caes. Leopold. Carol. Nat. Cur. xxvi. 460 (1858). Forma *verticillatum* forma b. *longeramosum* Klinge, l. c. 402 (1882). Forma *longiramosa* Luerss. l. c. 709 (1889). Var. *americanum* Victorin, forma *luxurians* Victorin, l. c. 56, in part (excl. synonym and type).

Forma ARCUATUM Milde, Gefäss-Cryptog. Schles.-Nov. Act. Acad. Caes. Leopold. Carol. Nat. Cur. xxvi. 461 (1858). *E. palustre*, 4. *arcuatum* Milde, Höheren Sporenpfl. 109 (1865). Var. *arcuatum* Milde, Mon. Equiset. 328, t. xiii, fig. 1 (1865). Var. *americanum*, f. *luxurians* Victorin, l. c. 56, fig. 11 on p. 59 (1927).

Forma POLYSTACHION (Weigel) Duval-Jouve, Hist. Nat. Equiset. 247 (1864) as f. *polystachyon*. *E. palustre* β. *Equisetum palustre minus polystachyon* L. Sp. Pl. 1061 (1753); Villars, Hist. Pl. Dauph. iii². 835 (1789). *E. palustre*, (B) *polystachion* Weigel, Fl. Pomerano-Rugica, 187 (1769). *E. palustre*, 7. *polystachyum* "Vill." with forma *corymbosa* (Bory ex Milde) and f. *racemosa* Milde, Höheren Sporenpfl. 110 (1865). *E. corymbosum* Bory ex Milde, l. c. (1865). Var. *casuarinaeforme* Schur as syn. ex Milde, l. c. (1865). Var. *polystachium* A. Br. in Am. Journ. Sci. xlv. 85 (1844); "Vill." ex Milde, Mon. Equiset. 329 (1865) including f. *corymbosa* and f. *racemosa*. Further twists of the bibliography by various later students include such distortions by Klinge as forma "polystachium Vill. ... a. *corymbosum* Bory (als Art)".

Forma FLUITANS Victorin. Var. *americanum*, f. *fluitans* Victorin, l. c. 60, fig. 13 on p. 62 (1927).

Forma RAMULOSUM (Milde) Klinge, l. c. 404 (1882), wrongly ascribed to Milde. Forma *ramulosa* Luerss. l. c. 710 (1889), wrongly ascribed to Milde. *E. palustre*, 5. *ramulosum* Milde, Höheren Sporenpfl. 109 (1865). Var. *ramulosum* Milde, Mon. Equiset. 328 (1865). Var. *ramosissimum* Peck, Ann. Rep. N. Y. State Mus. Nat. Hist. 107 (1873). Var. *americanum* f. *ramosissimum* (Peck) Broun, Index N. Am. Ferns, 92 (1938).

Forma SIMPLEX Milde, Gefäss-Crypt. 460 (1858). Var. *tenuis* Döll, Rhein. Fl. 29 (1843); Milde, Mon. Equiset. 327, t. xiii. figs. 2 and 3 (1865). Var. *simplicissimum* A. Br. in Am. Journ. Sci. xvi. 85 (1844). Forma *tenuis* (as *tenuis*) (Döll) Duval-Jouve, l. c. 248 (1864). Forma *simplicissima* (A. Br.) Luerss. l. c. 712 (1889), wrongly ascribed to A. Br. Var. *americanum* Victorin, l. c. 51 (1927) in part, including type. Var. *americanum*, forma *tenuis* (Döll) Broun, Index N. Am. Ferns, 92 (1938).

Forma FILIFORME Lacks, ex Klinge, l. c. 406 (1882). Var. *nanum* Milde, Verhandl. Zool.-bot. Gesellsch. Wien. xiv. 13 (1864), Höheren Sporenpfl. 109 (1865) and Mon. Equiset. 328, t. xiii, fig. 6 (1865). Forma *nanum* (as *nana*) (Milde) Luerss. l. c. 713 (1889), wrongly ascribed to Milde, who had it as a var."

As far as the variants of the marsh horsetail are true forms, the above list of Fernald may also be applicable in Europe, even though it differs from the lists of BERGDOLT (1936) and CHRISTIANSEN (1953). Some authors, however, are very cautious in regard to the taxonomic nature of the *Equisetum* variants. For instance, DUVAL-JOUVE (1864) has asserted that morphologically different horsetail shoots may arise from the same rhizome and are not recurrent in different years. He listed only two forms of *E. palustre*, f. *polystachyon* (= f. *polystachion*) and f. *tenuis* (= f. *simplex*). The Finnish workers CAJANDER (1906) and HIITONEN (1933) also mentioned the above two forms. Cajander used the names f. *polystachya*

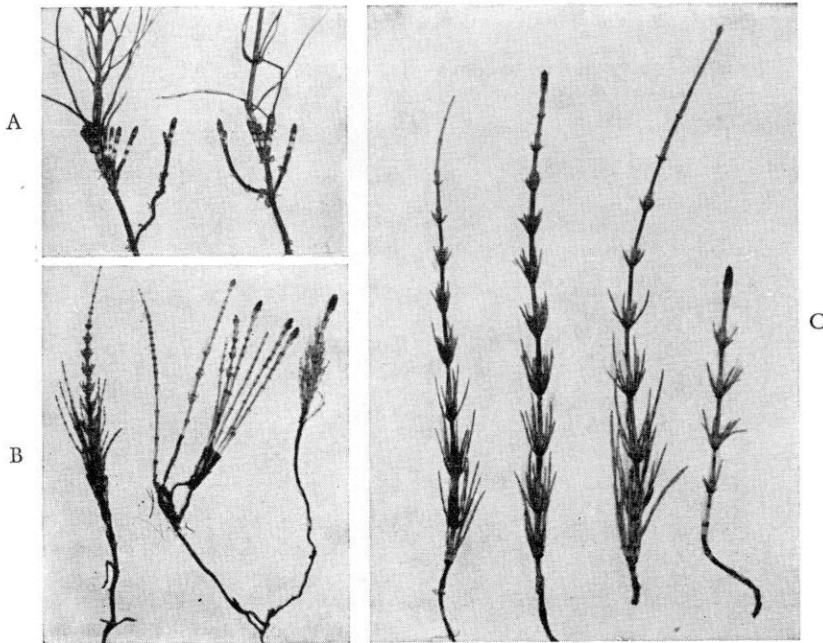


Fig. 2. The initials of the aerial shoots of *E. palustre* are usually produced in September—November (A). The shoots emerge in May (B) and elongate in June (C).

Weig. and f. *simplicissima* ABr., while Hiitonen used the names f. *polystachyum* Weig. and f. *simplicissimum* ABr. GLEASEN (1952) in Canada mentioned f. *verticillatum* Milde and f. *arcuatum* Milde. LID (1952) and HYLANDER (1953) did not include any forms in their manuals on Scandinavian flora. TUOMIKOSKI (1958) in Finland is of the opinion that most of the different forms of horsetails described in the literature are without significance from the standpoint of taxonomy and geography. He believes that many so-called forms are modifications produced by the habitat of the plant and result in differences in size, colour, growth habit, branching, number and structure of branches, their length and position, etc. Others are abnormal plants, such as those with branched strobili or those which diverge in their development from the normal habit of the species. The same thought has been presented by BOVER (1959) in his comments on the experimental results of LUERSSEN (1894) concerning the form *polystachion* of *E. silvaticum* L.

According to the studies conducted at the Department of Plant Husbandry in the years 1956—62, the characteristics of the typical marsh horsetail growing in South Finland are as follows:

Fertile and vegetative shoots (Figs. 2—4) similar and simultaneous in emergence, annual, green, erect or at least strongly ascending, at most 20—55 cm in height, varyingly branched (from unbranched to highly branched). Stem at most 2—3 mm thick with 7 (8) grooves. Central cavity of stem small,

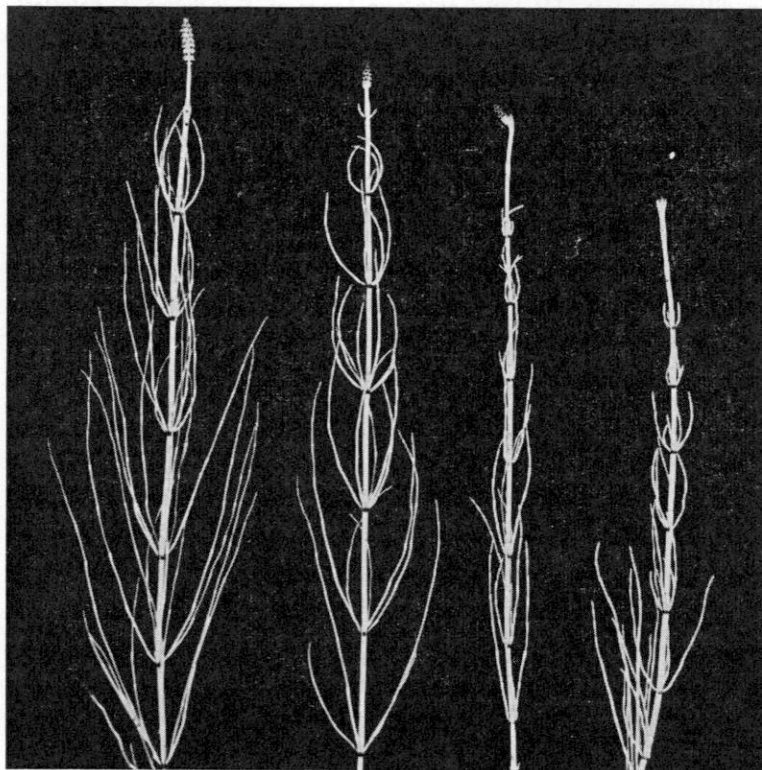


Fig. 3. The stems of normal *E. palustre* shoots cease to elongate in July while the growth of the branches continues.

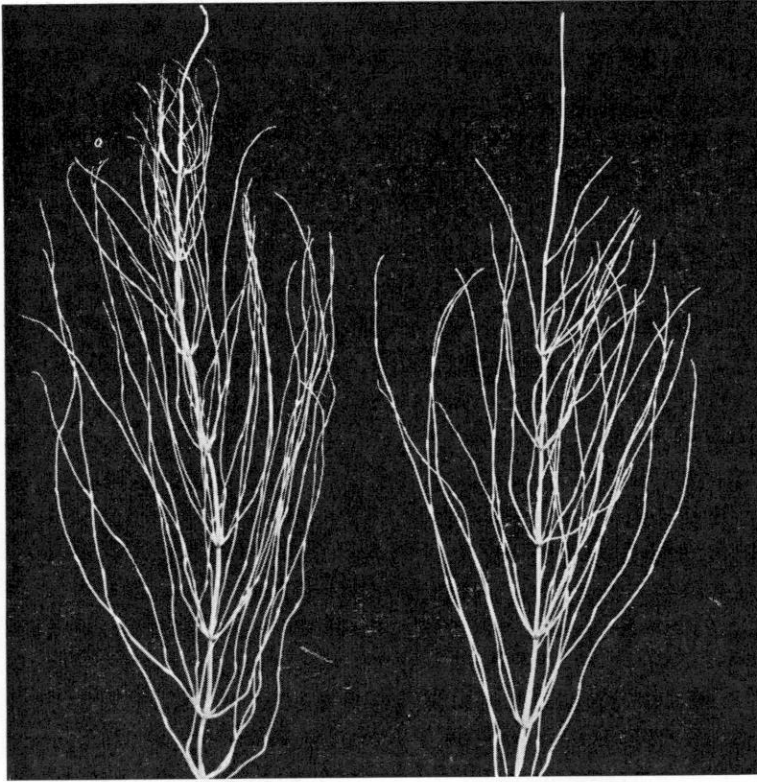


Fig. 4. In August the branches of normal *E. palustre* shoots continue to elongate. — Described in the literature as a form (f. *verticillatum*).

vallecular cavities numbering 7 (8) large. Leaf-sheath of stem including teeth 5—10 mm long, green, close to stem. Teeth of leaf-sheath 1.5—3.5 mm long, green with white margins, upper part black, sharply 3-angled, 7 (8) in number. Branches simple, usually not more than 6 cm in length, occasionally up to 10—25 cm, 5 (4—6)-angled, symmetrically attached to the nodes of the stem, usually 3 or more at the same node, ascending, straight or arched. Basal sheath of the branches brown or black, first internode usually shorter than the leaf-sheath of the stem. Strobilus appearing in June—September, 0.5—2.5 cm long, usually only on the apex of the stem. Spores spherical in shape, 35—45 μ in diameter. Rhizomes perennial, horizontal main branch (Fig. 5 A) growing at a maximum depth of 150 (175) cm, thickness at most 10 (13) mm, internode distance at most 25 (30) cm, weakly branching and rather straight. Secondary vertical and horizontal branches (Fig. 5 B) more slender, only 1.5—2 mm thick near the surface of the ground, with shorter internode distance, very sinuous in dry and compact soil. Young rhizomes circular in cross-section, older ones 7 (8)-angled. Surface of rhizomes generally smooth and glossy, colour white near the growing point, tan further back, older parts dark brown or dark

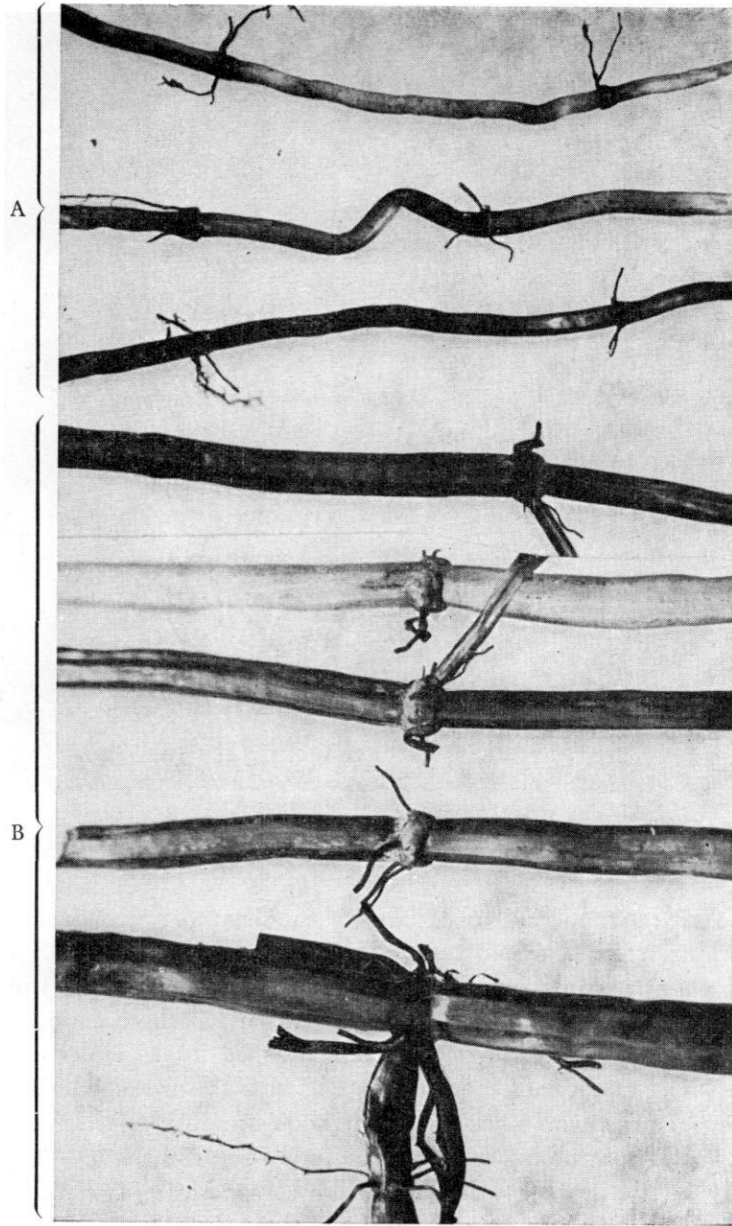


Fig. 5. Rhizomes of *E. palustre* from different depths of fen peat. A = secondary branches from depths of 20—60 cm, B = main branches from depths of 60—120 cm. Sclerotized thickenings (cf. p. 23) are seen in most of the nodes of the main rhizomes. — Natural size.

purple and finally black. Dead rhizomes usually black. No central cavity in rhizomes, vallicular cavities very large, numbering 7 (5—8). No tubers.

The above measurements of marsh horsetail growing in South Finland differ from those mentioned by certain authors in regard to both aerial shoots and rhizomes. For instance, the maximum length of the stem (55 cm) is less than that (1 m) reported by MILDE (1867), LUERSSEN (1889), BERGDOLT (1936) and FERNALD (1950), the maximum thickness of the stem (3 mm) is less than that (4—5 mm) mentioned by LUERSSEN (1889), and the maximum length of the sheaths (10 mm) is less than that (13—18 mm) mentioned by MILDE (1867), LUERSSEN (1889) and BERGDOLT (1936). The number of grooves on the stem (mostly 7, occasionally 8) is more constant than the corresponding figures (4—12) reported by MILDE (1867), LUERSSEN (1889), HIITONEN (1933), BERGDOLT (1936), FERNALD (1950) and HYLANDER (1953). The maximum thickness of the rhizomes (13 mm) is slightly greater than that (1 cm) mentioned by DUVAL-JOUVE (1864) and KORSMO (1954), and differs very much from the figure (1 ½" = 3.8 cm) given by MILDE (1867). Furthermore, the maximum length of the rhizome internodes (30 cm) is twice as long as the corresponding figure (15 cm) given by DUVAL-JOUVE (1864) and KORSMO (1954) and much longer than that (1" — 1" 10'" = 2.5 — 4.1 cm) mentioned by MILDE (1867). However, it may be concluded that the differences do not exceed those normally caused by differences in soil and climate. The significance of tubers and their absence will be discussed in detail on p. 22.

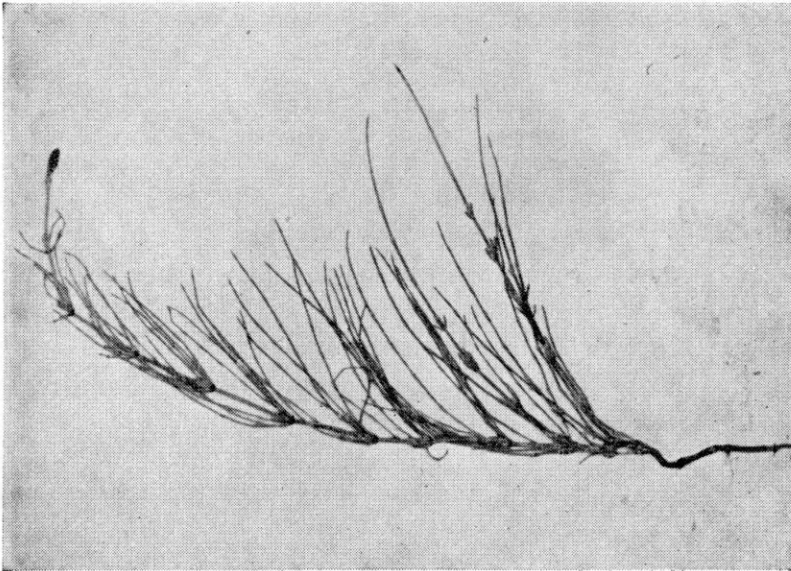


Fig. 6. Along the edges of railways and highways *E. palustre* shoots are often prostrate or bushy and have secondary branchlets. A small application of MCPA also causes the same effect. — Described in the literature as a form (e.g. f. *decumbens*, f. *ramulosum* etc.).

Studies concerning the variation in habit of shoots revealed that all types corresponding to the forms of FERNALD (1947) are to be found in South Finland. Detailed observations, however, established that the different types of shoot did not usually represent true forms but rather modifications. The appearance of such modifications is easily understood in the case of cultivated fields, where the growth of the horsetail is controlled by one means or another. Certain types, especially those with prostrate or bushy shoots, usually proved to be malformations produced as a result of damage to the growing point caused by mechanical means, such as trampling and mowing, or by spring frosts, or chemical injury from herbicide sprays. Exceptionally large numbers of prostrate-bushy shoots (Fig. 6) were found adjacent to railway tracks and in the immediate vicinity of highways. One factor partly responsible for the prostrate-bushy appearance of these shoots is apparently the strong air current produced by rapidly-moving vehicles, although other factors may also contribute to the effect. For example, by some secondary railway tracks where there was no fast traffic, prostrate-bushy shoots were scarce or did not occur at all. Along the edge of the Kouvola—Loviisa highway, in the district of Lapinjärvi, most of the shoots growing immediately adjacent to the road resembled f. *polystachion* (Fig. 7). Further from the edge of the road the shoots resembled f. *verticillatum* (Fig. 8), and at the bottom of the adjoining ditch, near the level of the standing water, they resembled f. *simplex* (Fig. 10 A). All these various types of shoots were shown, by digging up the rhizomes, to belong to the same individual plant.

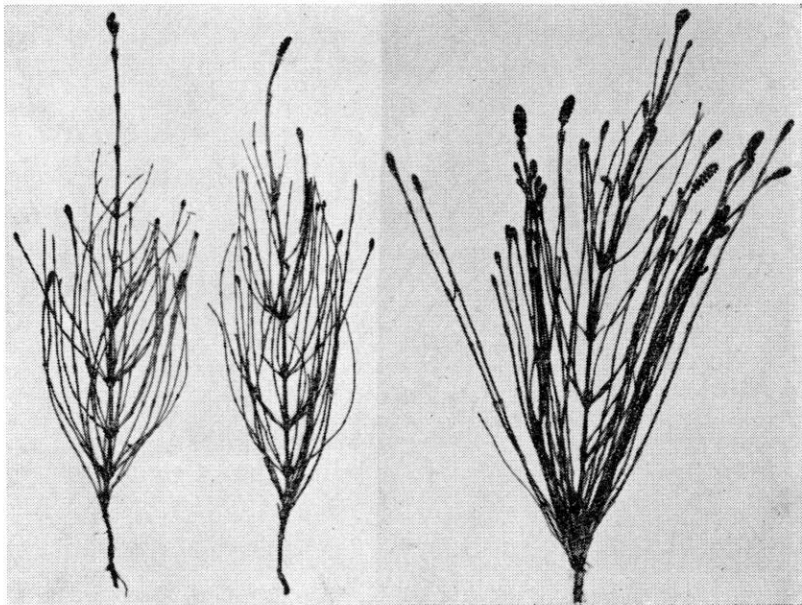


Fig. 7. The development of strobili on the branches of shoots is not a common phenomenon. — Described in the literature as a form (f. *polystachion*).

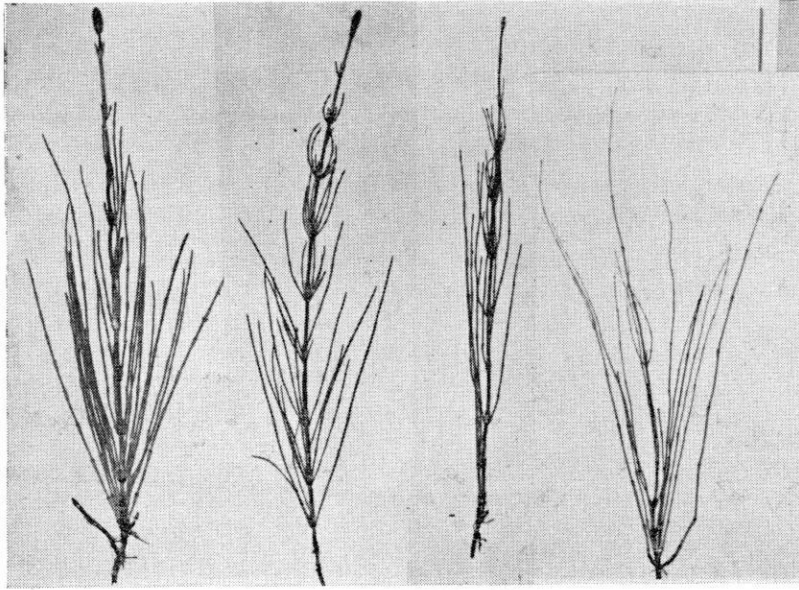


Fig. 8. The lower branches of the shoots often become very long, especially in shady habitats. — Described in the literature as a form (e.g. f. *verticillatum*, f. *longiramosum* and f. *pauciramosum*).

The commonest difference in the habit of the shoots proved to be correlated with the natural rhythm of shoot development and was characterized by delayed development of branches. In untilled soil, primordia of both fertile and sterile shoots developed in the autumn (Fig. 2 A). Sometimes, when weather conditions were mild, such primordia produced shoots before the arrival of the snow. These young shoots, emerging in October—November, were always almost unbranched (Fig. 10 B). Shoots which developed in the early spring, especially fertile shoots, had stems which were thicker than usual and were at first almost without branches (Fig. 2 B). In the early part of June they produced branches which were initially shorter and thicker than normal (Fig. 2 C). After normal stem elongation had ceased, the branches continued their growth (Fig. 3) and finally, at the end of the growing season, they reached a length of 1 dm, thus resembling the branches of f. *verticillatum* (Fig. 4). Sometimes, especially in shady places, the elongation of the branches occurred only in the lowest whorls (Fig. 8). In such cases, the maximum length of the branches reached as much as 20—25 cm.

Unsatisfactory growing conditions, especially heavy shading and excessive wetness of the soil, also caused delay or even complete inhibition of the development of the branches (Fig. 10), a phenomenon previously described by LUDWIGS (1911) and GRIER (1920). In other cases, excessive shading inhibited the development of the stem and resulted in the formation of shoots which resembled f. *filiformis* (Fig. 9). On the basis of these observations it may be concluded that

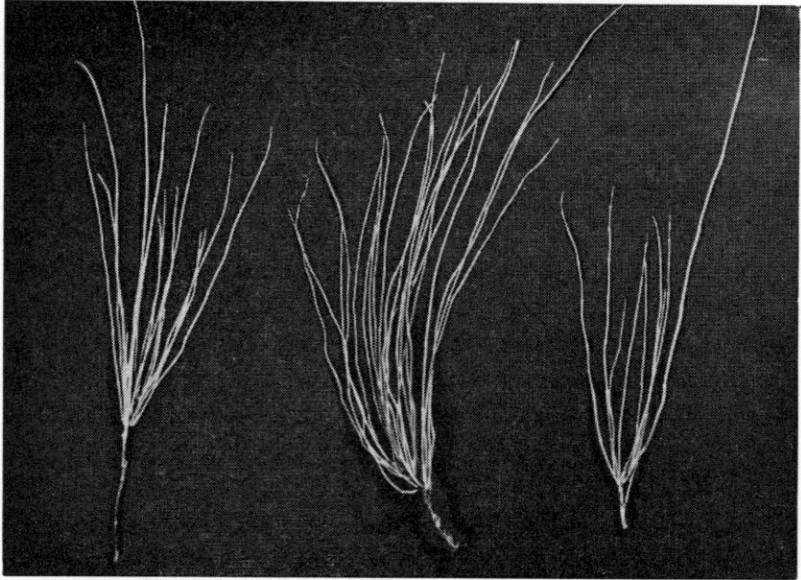


Fig. 9. Unfavourable growing conditions such as heavy shading, frost, or mechanical injuries, sometimes cause a complete stunting of stem of *E. palustre* shoots, and the branched plant takes on a shrub-like appearance. This represents a continuation of the modification types shown in Fig. 8. — Described in the literature as a form (*f. filiformis*).

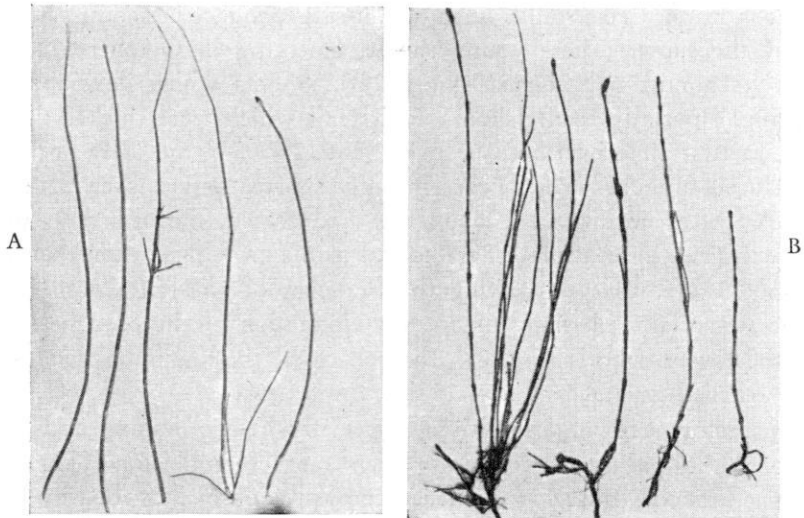


Fig. 10. In shady places or on excessively wet soil (A), as well as when emergence occurs late in the autumn (B), the branches of *E. palustre* shoots develop only slightly or not at all. — Described in the literature as a form (*f. simplex*).

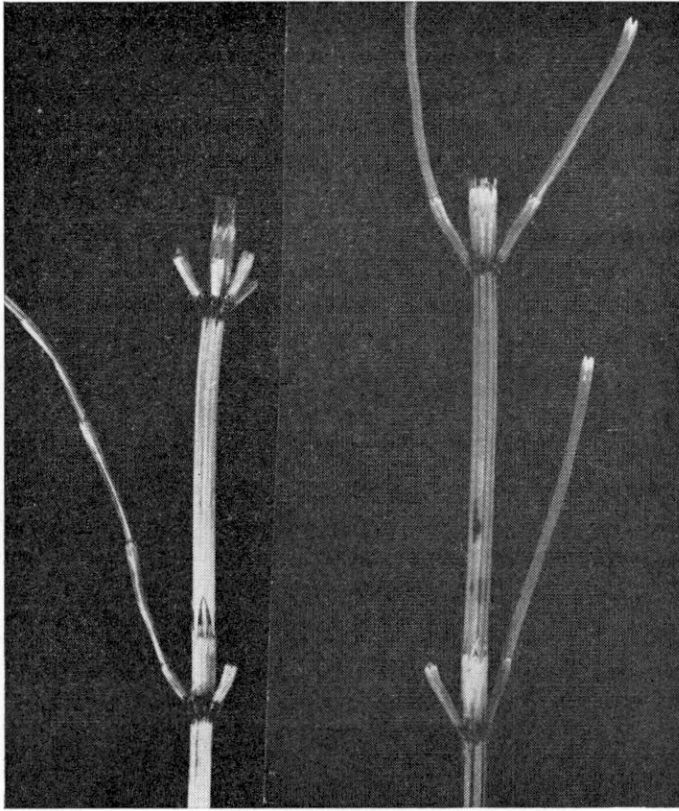


Fig. 11. The first internode of the branches of *E. palustre* shoots is usually considerably shorter than the stem leaf-sheath (left). Sometimes, however, these internodes, or some of them, are as long or slightly longer than the stem leaf-sheath (right). In these cases the other internodes of the branches are also rather long.

in the case of marsh horsetail the terms "stem" and "branches" are relative, i.e. they should be called "relative stem" (or "relative main stem") and "relative branches".

One interesting observation which has not been stressed in the literature was the length of the first internode of the branches of marsh horsetail. In certain localities some of these internodes were found to be as long as, or even slightly longer than, the leaf-sheath of the stem (Fig. 11).

The above-presented observations do not absolutely eliminate the possibility that true forms of the marsh horsetail may occur in Finland. One fact especially worth noting is that shoots of the f. *polystachion* type were found only along the edges of the Kouvola—Loviisa highway in the Lapinjärvi district, although conditions along roadsides are evidently very similar in many localities in South Finland. In order to investigate this problem, growing trials with dif-

ferent types of shoots should be carried out under controlled conditions. Because of the weak rooting ability of marsh horsetail (cf. p. 21) such trials would be very difficult to carry out.

In connexion with the Second German Weed Conference, STÄHLIN (1957) made the proposal that the alkaloid content of different marsh horsetail varieties (evidently meaning forms) should be investigated. The same opinion was later expressed by von KRIES (1962). If true taxonomic variants of this species actually do occur, a thorough study of them would be useful in order that their method of spreading could be determined. Our knowledge of the spread of marsh horsetail is so imperfect that a taxonomic study of this plant would undoubtedly throw much new light on this problem.

III. Reproduction and spread of marsh horsetail

1. Sexual reproduction

The spores of horsetails normally only live for a few days or weeks after their dehiscence from the strobilus (e.g. BUCHTIEN 1887, RUMBERG 1932, MOSEBACH 1943). The germinability of marsh horsetail spores was demonstrated already in the early 1800's (AGARDH 1822, BISCHOFF 1828). In artificial cultures either antheridia or archegonia were found to develop in the prothalli of this species. If fertilization does not occur, the female prothalli may later produce antheridia in addition to archegonia, thus making self-fertilization possible. After fertilization the embryo develops within the archegonium and gradually grows into a new horsetail plant (SADEBECK 1878, RUMBERG 1932, HURLEY-PY 1949). This development normally takes several months.

Light is necessary for the development of the prothalli of horsetails. Direct sunlight, however, is fatal to them. In addition, the prothalli of horsetails are completely unable to resist infection by fungi. They do not survive drying or freezing, and if kept in water they also soon succumb (BUCHTIEN 1887). Therefore, it is understandable that the prothalli of horsetails are very uncommon in nature. Prothalli of marsh horsetail were found by DUVAL-JOUVE (1864) on the shores of the Rhine and the Rhone in Central Europe. Duval-Jouve found that under favourable conditions they survive long enough to be able to grow into new horsetail plants.

In Finland, no prothalli of marsh horsetail have as yet been encountered. During the years 1957—60, the Department of Plant Husbandry performed numerous cultural trials with spores of this species. The culture media tested included both unsterilized and sterilized *Sphagnum* peat, clay, sand, and certain synthetic nutrient media. However, most of the spore samples proved sterile — at least they did not germinate on the test substrates. One fertile spore sample collected from Lapinjärvi in the beginning of September 1960 was obtained in pure culture in the following manner:

A spore suspension was made in sterilized water and a dilution series (1 : 10, 1 : 100, 1 : 1000 etc.) prepared from it. From each dilution 1 ml was put into an 8 cm Petri dish. The substrate used was an agar medium prepared in Moore's solution, as recommended by HEMPSTEAD (1953), and contained the following ingredients per litre:

NH ₄ NO ₃	0.5 g	casein hydrolysate	0.05 g
MgSO ₄ :	0.2 „	sucrose	5.0 „
MgSO ₄ · 7H ₂ O	0.2 „	agar	10.0 „
CaCl ₂ · 2H ₂ O	0.1 „	trace element solution	2 drops

The trace element solution consisted of the following ingredients, expressed in grams per litre: B 5×10^{-5} , Mn 6×10^{-4} , Zn 5.5×10^{-5} , Cu 10^{-5} , Mo 10^{-5} , Fe 10^{-5} , I 10^{-5} , Co 10^{-5} , Ni 10^{-5} .

A volume of 10 ml of the melted nutrient medium at a temperature of 35° C was poured upon the spore suspension in each Petri dish. In this manner the spore concentration became sufficiently dilute and the spores, even though not disinfected, did not become appreciably infected with fungi. Later, the germinated spores were transferred aseptically to single-spore cultures in test tubes. For one or two weeks the young prothalli grew fairly vigorously in the test tubes (Fig. 12). Later their growth began to slacken and within three months they died without having produced sex organs. Evidently the experimental conditions were not sufficiently favourable for the further development of the prothalli. *In view of the results of the above trials as well as those of*

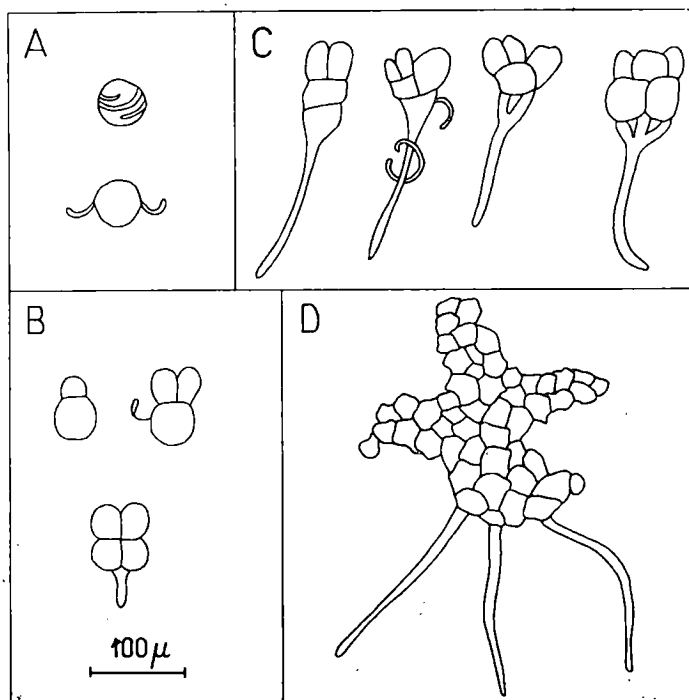


Fig. 12. The first stages in the development of the prothallus of *E. palustre*. A = spore, B = germs 2 days old, C = germs 5 days old, D = prothallus 3 weeks old.

earlier studies (e.g. BUCHTIEN 1887, RUMBERG 1932), the survival of prothalli of the marsh horsetail on cultivated land does not seem very probable, at least under the climatic conditions prevailing in Finland.

3. Growth of rhizomes

The part of the marsh horsetail plant which is mainly responsible for its vegetative propagation is the perennial rhizome. According to MEYER (1832), it can reach a horizontal length of up to 100 feet (about 30 m), according to MILDE (1867) 50 feet (15 m) and WEBER (1903) 100 m. Vertically, the rhizomes can penetrate the soil to a depth of about 150 cm (cf. p. 9), and occasionally to as much as 5 m (MEYER 1832, WEBER 1903). At the nodes of the rhizome, bud primordia are formed which can later develop into new rhizome branches or aerial shoots. Contact with the ground water is apparently essential for the rhizomes of marsh horsetail, and therefore this plant favours moist, boggy land. In extremely wet conditions, however, the species does not thrive. On the other hand, it can grow on fairly dry land when the upper soil layers are loose or permeable (cf. e.g. KURSKIJ 1941, UOTILA 1956, HUSEMANN and BRACKER 1960).

WEBER (1903), in his extensive study, found that the rhizomes of marsh horsetail were able to grow several metres in a horizontal direction during one growing season. In this way the plant could spread as much as 50—100 metres from its original site within a few years. According to Weber, the lifetime of the rhizomes is limited to a few years. Thus the older branches gradually begin to die while the younger ones continue their growth. If the surface layer of soil is especially hard, the rhizomes may grow for long distances in the soft subsoil without emerging to the surface. In order to halt the growth of the rhizomes, NOZEMAN (1782) and WEBER (1903) recommended digging ditches with a bottom width of 1 m and extending to a depth of 0.3 m below the level of the lowermost main branches of the rhizomes.

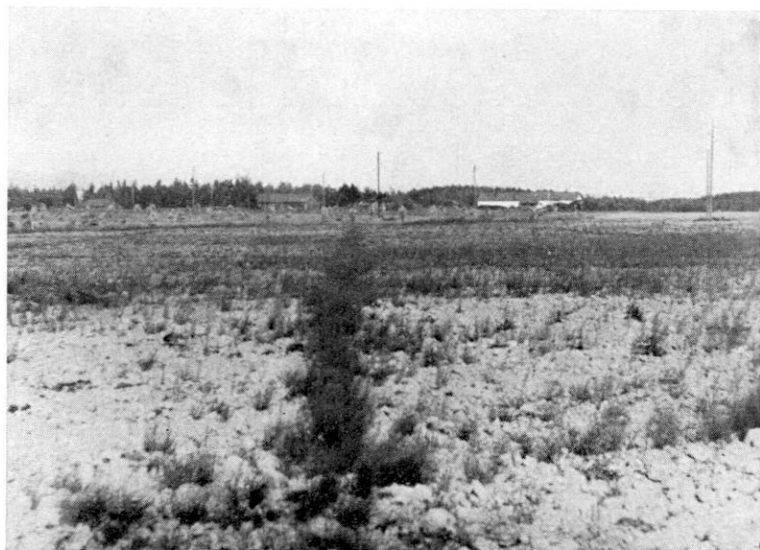


Fig. 13. In the loose filling soil of newly covered drains *E. palustre* grows very vigorously. — A fallow field 2 years after the covering of open ditches.

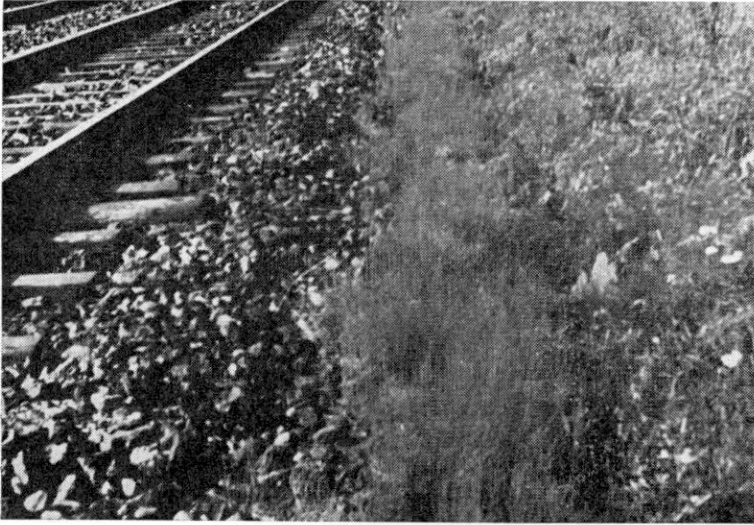


Fig. 14. Along the edges of railways and highways *E. palustre* spreads rapidly.

In studies made at the Department of Plant Husbandry it was found that rhizomes of both field and marsh horsetail penetrated readily into the loose filling soil of underground drains and grew along these for distances of 1—3 metres in the space of one year. As a result of this, after 1—3 years the sites of the underground drains were visible on the surface of the field as long rows of green horsetail shoots (Fig. 13). The same kind of phenomenon was noted on construction sites to which soil had been moved and also in the loose sand along the edges of newly-built railways and highways. Such new roads can thus serve to spread marsh horsetail in low-lying land (Fig. 14).

A slower rate of growth of rhizomes in loose soil was noticed in one trial carried out on fen peat soil. In this trial a black plastic cover which was placed on the ground for four years had caused the death of the rhizomes. During the period of the first two years after the removal of the plastic cover, rhizomes growing horizontally into the treated area from the borders of the plot had extended to a distance of only 70 cm. The reason for this slow growth could not have been the hardness of the soil, since the trial was located on loose fen peat. Apparently other factors were responsible for the poor growth of the rhizomes in this case.

The rate of rhizome growth on compact soil was studied in a trial located on heavy clay. The rhizome branches in the topsoil and in the upper layers of the subsoil had been killed in 1959 by treatment with amitrole (cf. p. 39). The rhizomes at a depth of 100—150 cm in the soft subsoil, however, continued their growth beneath the treated plot (15 × 15 m in size). During the years 1960—62 they did not emerge to the surface of the ground. In the upper layers of the subsoil it was also found that the rhizomes had grown only short distances, 30—70 cm, horizontally from the edges of the plot. In this case the slow growth was probably due principally to the hardness of the soil. Under wet conditions this type of heavy clay was indeed soft, but during the middle of the summer the upper layers of the subsoil had dried so hard it was practically impossible to dig into them with a spade. The results of this particular trial may also have been influenced by the weakened geotropism of the rhizomes in the central part of the plot (cf. SCHAFFNER 1933), as well as by possible amitrole residues in the soil or rhizomes. It was not possible, however, to analyse the individual effects of these different factors.

In addition to being dependent upon the soil type, the rate of growth of the rhizomes was also found to depend on the intensity of growth of their green aerial shoots. In places where removal of other competing vegetation had caused marsh horsetail to produce more abundant shoots than usual, a more profuse rhizome network was also formed. This fact, together with the looseness of the soil, is undoubtedly a factor contributing to the spread of marsh horsetail along the edges of newly-constructed railways and highways. In the case of new open drainage ditches, on the other hand, the increased growth of rhizomes is perhaps due principally to the absence of competing plants, since the soil along these ditches is not softer than elsewhere on the field. *In any case the rapid growth of marsh horsetail along open drains may be considered a basic and vital problem* (Fig. 17, p. 27). It is also evident that this phenomenon must lessen the value of the large "obstacle ditches" recommended by NOZEMAN (1782) and WEBER (1903).

3. Rooting of rhizomes and shoot fragments

In older publications dealing with the control of marsh horsetail (e.g. MEYER 1822, WEBER 1903) attention was drawn to the fact that fragments of the rhizomes may be transported



Fig. 15. The pieces of rhizomes broken up by tillage are usually able to produce only weak "sprouts" which die within a few weeks.

for long distances in water moving in ditches. It was presumed that these fragments would subsequently be able to root and grow into new plants. It was also believed that marsh horsetail could be spread by means of pieces of rhizome transported by tillage implements. In fact, LUDWIGS (1911) showed that pieces of both rhizomes and shoots could root in the greenhouse under favourable conditions.

Tillage trials made at the Department of Plant Husbandry in the years 1956—58 showed that under moist conditions fragments of marsh horsetail rhizomes were able to live for several weeks and produce new branches and even aerial shoots (Fig. 15). Before long, however, the fragments died. In 1957, the Department organized 16 rooting trials with rhizome fragments, but all of these gave negative results. In 1960, the trials were repeated, with the difference that a clump of soil about 20 cm in diameter was included with each rhizome sample. These were then placed in many different types of growing sites, some at water level, others on drier ground. During the first summer a few weak shoots were formed, but in the following spring all the rhizome samples proved to be dead.

On the other hand, pieces of rhizomes which were dug up by an excavating machine at a drainage site at Iitti in the winter of 1957/58, were found to

have continued their growth and to have produced aerial shoots two years after being transported from their original growing site. During the third year the rhizomes gradually began to die, although some of them survived until the fourth summer (1962). In this case the rhizome fragments had been transported in water-saturated soil clumps about $\frac{1}{2}$ — 1 m in diameter. The soil type was heavy clay and the lowest depth of the ground water was about 1 metre.

On the basis of the above observations, *it appears that rhizome fragments of marsh horsetail may root under certain conditions but that their rooting ability is extremely weak. It also seems probable that in South Finland the species is not normally able to propagate and spread on cultivated land by means of transportation of rhizome fragments. The same apparently applies to shoot fragments.*

Since the lifetime of marsh horsetail rhizomes is limited to a few years, the older parts gradually begin to die. As a result, the young rhizome branches soon become separated from one another and from the original mother plant. The question then arises, do these separated rhizome branches continue living and growing, or do they die, like the previously-described transported fragments? Taking into consideration the common occurrence of marsh horsetail, as well as its poor sexual reproduction, it appears likely that the natural death of rhizomes — at least in the case of the main branches growing in the immediate vicinity of ground water — is due only to aging and not to separation from the mother plant. The situation may be different, however, in the case of rhizome branches growing in dry topsoil layers. Under such conditions, if the deeper-growing parts die, the upper rhizome branches may lose contact with the ground water for too long a time and thus be unable to survive.

It is known that the death of rhizomes causes a more or less definite periodicity in the development of perennial, vegetatively-reproducing plants (WATT 1940—56). Observations made in certain of the trials of the Department of Plant Husbandry indicated the possibility of slight, long-term periodicity in the development of marsh horsetail. Considering the sparse occurrence of the rhizomes of this species in the soil, it seems understandable that such a periodicity cannot be very pronounced. It would also be difficult to distinguish this phenomenon from the effects caused by such factors as varying ground water conditions.

4. Significance of tubers

In many species of horsetail, tubers are formed in the rhizomes. These are shortened, swollen internodes consisting of sclerotized tissue, which is resistant to drying. Such tubers serve as organs of storage, reproduction and distribution. In certain districts of Central Europe tubers of marsh horsetail have been found in great abundance (DUVAL-JOUVE 1864, WEBER 1903). In one particular case the species was even given the name "tuber horsetail", *Equisetum tuberosum* Hectot. (de CANDOLLE 1815). Tubers of marsh horsetail have also been

found in Norway (KORSMO 1954), but not in Silesia in northern Germany (MILDE 1867).

The tubers are easily separated from the rhizomes and while floating on the surface of water can be transported for long distances in ditches and rivers. Under favourable conditions they are able to germinate and develop into new horsetail plants. WEBER (1903) was of the opinion that this is a very important method of propagation. He also found that the tubers are able to root more readily than ordinary rhizome fragments.

As far as is known, up to the present time no tubers of marsh horsetail have been found in Finland, nor were such organs encountered during the present investigations. Field horsetail (*E. arvense*) was found in the areas investigated by the Department of Plant Husbandry in 1956—62 to produce tubers on sandy and moraine soils but not on clay or peat soils. Since all the habitats of marsh horsetail studied by the Department were situated either on clay or peat soils or else on filling soil on the top of clay (railway and highway embankments), the absence of tubers may be regarded as a characteristic of a modification caused by soil type rather than of a true form.

Although no tubers of marsh horsetail were found in the studies carried out by the Department of Plant Husbandry, some sclerotinized, starch-containing tissue was observed in some rhizome nodes, especially on peat soil (Fig. 5 B). Such sclerotinized nodes may apparently function as storage organs in the same way as tubers. At least, they proved to be able to germinate even after the tissue of the adjoining internodes had died because of drying. The rooting ability of such sclerotinized parts of rhizomes proved very weak indeed, but they may possibly remain alive and root later when, for example, the rest of the rhizome has died as a result of temporary loss of contact with the ground water during periods of drought.

IV. Control of marsh horsetail

Experimental methods. In most of the control trials the field area was divided into plots of 225—550 square metres in area and with a diameter of at least 12 metres. On ditch embankments, however, the size of the plots was smaller, $2 \times 10 = 20 \text{ m}^2$. Each of the plots represented one experimental unit.

During the course of the investigations the above plot method proved unsuitable, since the rhizomes grew underground from one plot to another and even extended across entire plots. Therefore, in addition to plot trials, some larger trials were established with the entire field as one experimental unit.

Even in the first year of the studies, the necessity for a rapid and accurate method of determining the abundance of marsh horsetail shoots became evident. On the cultivated fields, where shoots of marsh horsetail were usually sparse, counts were made of the numbers of shoots. Since the species mostly grew unevenly, the linear sample method suggested by CLAPHAM (1938) and by URSIC and McCLURKIN (1959), and employed in marsh horsetail studies by VALMARI (1955), was considered to be the most reliable. Linear sample areas

of 0.5×10 m were mostly used in these studies. Counts of the shoots along such lines were made with the aid of a 1/2-metre rule attached perpendicularly to the end of a rod of suitable length. The only difficulty in making these assessments was in the case of bushy shoots. In some instances the numerous stems of a "bush" were counted as individual shoots, in other instances several stems were considered to belong to the same shoot, according to whether the point of branching was located at the surface of the ground or deeper in the soil. When the number of shoots per square metre exceeded 25, the length of the line to be assessed was reduced to 5 metres, and when the number was above 50 per m^2 the line examined was only 2.5 m long.

On the banks of ditches, where marsh horsetail usually grew in dense stands, the abundance of the shoots was estimated visually as a percentage of the vegetation, a method used by, among others, PAAATELA (1953) in his studies on leys. The estimates were made on two-metre lengths of the ditch in question, and the percentages used were 0, 1, 2, 3, 4, 5, 10, 20, 40, 60, 80 and 100. In addition, actual counts of marsh horsetail shoots were also made on the banks by using a circular sampling area $\frac{1}{4} m^2$ in size.

The number of replicates per trial unit for both the linear counts and the visual estimates varied in the different trials. In the plot trials it was at least 4, and in the entire field trials it varied from 10 to 30, depending on the size of the field.

The weight of marsh horsetail shoots was only occasionally determined. For example, in autumn 1962 the average fresh weight of medium-sized shoots of marsh horsetail growing in the fields of the Agricultural Research Centre was about 1 gram and their dry weight was 0.2 g. Thus as few as 10 such shoots (= 2 g dry weight) in the daily fodder of cattle can reduce milk production (cf. UOTILA 1956). As an example, if the hay yield is 4000 kg/ha, each animal will obtain its daily hay ration (6—8 kg) from an area 15—20 m^2 in size. This means that an amount of marsh horsetail shoots of 0.5—0.75 per m^2 represents the lower limit which will cause injurious effects.

Since the methods of assessment were developed during the time of these investigations, they varied from year to year and sometimes even within one trial. As a consequence, the statistical analysis of the results proved complex and difficult. Therefore, it has been omitted from some of the tables in the present paper.

1. Lowering of the ground water

As previously mentioned (p. 18), contact with the ground water appears to be a basic requirement for the growth of marsh horsetail, and as a result this plant favours wet land. On drier locations marsh horsetail grows when the soil is sufficiently loose so that the rhizomes can penetrate down to the level of the ground water. Apparently there is a limit to the downward growth of the rhizomes, since they are not usually found below a depth of 150 cm. On the basis of these observations, it has been presumed that marsh horsetail could be

eradicated by effective drainage of the field. In actual practice, however, drainage investigations concerning the eradication of this species have not given satisfactory results (MEYER 1832, WEBER 1903). According to the studies of VALMARI (1955), cultivated crops suffer sooner than marsh horsetail when drainage is too efficient. On the other hand, Valmari and several other workers, for example JALAS and JUUSELA (1959), HUSEMANN and BRACKER (1960), and von KRIES (1962) report that efficient drainage reduces the abundance of marsh horsetail shoots.

Under the supervision of the Department of Plant Husbandry, drainage trials were carried out at four locations in the commune of Iitti for the purpose of studying the effect upon marsh horsetail of lowering the water table. The results of these trials are described below.

Drainage site 1. Located on fen peat having a thickness of 80—90 cm; subsoil heavy clay; maximum depth of marsh horsetail rhizomes about 1 m.

In the winter of 1957/58 an extensive drainage undertaking was carried out on the area, with the result that the ground water level during the middle of the summer was lowered to about 1 metre where it had previously been 0.3—0.6 m. In autumn 1961, the open drainage ditches were converted into so-called underground brush drains. This latter measure, however, did not lower the water table further. On the contrary, because of the abundant rains in 1962, the minimum ground water level rose about 20—30 cm to a level of 70—80 cm. In all years subsequent to the original drainage, the area was sown to oats, but only in 1962 was it fertilized (PK). One trial plot in the area was treated annually with MCPA.

The abundance of marsh horsetail shoots before drainage had not been determined. In the first year after drainage (1958) the average number of shoots on the main cultivated area (excluding the ditches) was 31.8 per m². In the following three years there were only negligible changes in the

Table 1. The effect of improved drainage, covering of open ditches, PK fertilizing and annual foliar application of MCPA on the abundance of *E. palustre* shoots.

Thick fen peat, subsoil heavy clay, crop oats, date of treatments and countings July 15.

Year	No. of shoots of <i>E. palustre</i> per m ²	
	Untreated	M C P A 2.5 kg/ha
1957/58	improvement of drainage	
1958	31.8	31.8
1959	34.0	10.0
1960	28.0	6.3
1961	23.9	2.5
1961/62	covering of open ditches and PK fert.	
1962	2.0	0.4
LSD 3.78		



Fig. 16. Drainage does not usually result in the eradication of *E. palustre*. In this case, the shoots of *E. palustre* are growing at a height of 2 1/2 metres above the water table.

number of shoots on the untreated area, and these cannot be attributed with certainty to the effects of drainage (Table 1, Fig. 16). In 1962 there was a sharp drop in the abundance of marsh horsetail shoots. However, this sudden decrease was probably not due to the drainage carried out 3 1/2 years previously, but rather to other contributing factors, particularly to the change of the open ditches to underground drains. The application of fertilizers, which improved the competitive growth of the oat crop, may also have contributed to the decrease observed. These factors are discussed in greater detail on page 48.

Drainage site 2. Located on fen peat with a thickness of 30—60 cm; subsoil heavy clay; maximum depth of marsh horsetail rhizomes 50—70 cm.

In the winter of 1960/61, the area was drained by means of damming, and as a result the minimum level of the ground water decreased from 0—0.5 metres to 0.7—1 m. After drainage, open ditches were dug and the site was ploughed and sown to oats.

In the year prior to drainage the number of marsh horsetail shoots on the drier (higher) parts of the area averaged 0.9 per m² and on the lower, water-saturated parts 0.02 per m². The latter figure was probably due to the fact that before drainage this low-lying area was too wet for marsh horsetail because it was covered by water during a large part of the growing season. In the year following damming and the digging of open drainage ditches (1961), large numbers of shoots of marsh horsetail began to appear on the sloping banks of the ditches (Fig. 17). In the following year (1962) the number of

Table 2. The effect of peatland clearing and open ditch drainage on the abundance of *E. palustre* shoots.

Thin fen peat, subsoil heavy clay, no fertilization, crop oats, date of countings Aug. 20.

Year	No. of shoots of <i>E. palustre</i> per m ²	
	Site 1	Site 2
1960	0.90	0.02
1960/61	land clearance and open ditch drainage	
1961	1.10	0.08
1962	22.10	22.05
LSD 2.73		

shoots in the actual cultivated strips was over 20 times greater than originally (Table 2).

Thus in this trial, drainage did not cause a reduction in the abundance of marsh horsetail shoots but instead resulted in their increase. Perhaps the most important reason for the increased abundance of shoots was the fact that the plants became established in the exposed banks of the drainage ditches and the rhizomes grew vigorously thereafter (cf. p. 19).

Drainage site 3. Located on the fields of three different farms; soil type partly heavy clay, partly compact silty clay; maximum depth of marsh horsetail rhizomes 0.7—1.3 m.



Fig. 17. An abundant stand of *E. palustre* in and along the catch drain of a newly cleared field. — Crop oats.

In 1958, the area, about 1×0.4 km in size, was divided longitudinally into two halves, of which one half was drained by means of damming and pumping. The minimum level of the ground water in the lowest places was lowered by drainage from 0—0.5 m to 0.7—1 m. In the year 1961, i.e. three years after damming, counts of the horsetail shoots were made at nine points along both sides of the 1-km long dam.

The assessments of marsh horsetail shoots on heavy clay showed that at four out of five points the shoots were slightly more numerous on the drained than on the undrained side. Because of the small differences and the possibility of systematic errors these results cannot be considered significant. On the compact silty clay, the numbers of marsh horsetail shoots at four points examined were much less on the drained than on the undrained half. Soil profiles examined along the ditches in the drained area showed exceptionally large numbers of dead rhizomes. Because of the lack of observations made before damming, the exact time of death of the rhizomes cannot be stated with certainty. However, it appears most probable that they died after damming and as a direct result of this measure. Evidently in this instance the rhizomes of marsh horsetail were unable to penetrate sufficiently rapidly through the compact silty clay of the subsoil to maintain contact with the gradually lowering ground water.

Drainage site 4. Located on fen peat 30 cm thick; subsoil silty clay; maximum depth of marsh horsetail rhizomes 30 cm.

In this area marsh horsetail occurred in only a relatively narrow zone where the water table during the middle of the summer coincided approximately with the boundary between the clay subsoil and the peat topsoil. During the years 1957—61 the water table fell in certain places as a result of improved ditch-drainage and partly owing to the lowering of the water level in the nearby lake.

Observations made in the years 1958—61 showed that on the drier margins of the marsh horsetail zone, the number of shoots decreased substantially. In some places they disappeared completely from the cultivated areas between the ditches. In the latter cases, it was found that the rhizomes were dead. Apparently this was caused by the lowering of the water table. It is possible that the rhizomes were unable to penetrate through the compact clay subsoil and maintain contact with the ground water.

On the basis of these drainage trials, it appears that *when marsh horsetail grows on loose or permeable soil, drainage of the area is not a practical measure for its eradication, at least not during a period of a few years.* It is not even certain whether this measure will reduce the abundance of marsh horsetail shoots, since the method of open ditches, generally used in this country, exposes the land to invasion by marsh horsetail and thus has an effect opposite to that intended. On the other hand, on hard, compact soil effective drainage may lead to the death of marsh horsetail. However, this last statement can scarcely

have a practical application, since occurrences of marsh horsetail on compact subsoil types probably represent extreme border cases and are relatively rare. It is even possible that on uncultivated land located on such compact soils, a temporary lowering of the ground water may hamper the growth of marsh horsetail or even prevent its occurrence completely.

2. Mechanical control

Several workers (e.g. NOZEMAN 1782, MEYER 1832 and WEBER 1903) considered thorough tilling of fields to be one of the basic conditions for the control of marsh horsetail. Ordinary tillage implements, however, only reach those rhizome branches which grow in the surface soil. Moreover, the rhizomes of marsh horsetail, like those of other species of this genus, are tough and very resistant to pulling and bending (cf. TREITEL 1943). On the other hand, their tissue structure is soft and they may be easily cut. It is evident that the method of tillage as well as the soil type and its physical condition at the time of tilling are important factors in the successful cutting of horsetail rhizomes. For instance, HOLZ (1959) found that tilling with an A-blade cultivator was effective if the soil was sufficiently moist and compact. He even used an A-blade cultivator on unploughed grassland with satisfactory results.

As a mechanical control measure directed toward the aerial shoots, weeding, rolling or intensive pasturing has also been recommended by several workers (e.g. NOZEMAN 1782, MEYER 1832, WEBER 1903, FISHBACH 1927, GLET 1930 and GÜNTHER 1932).

If mechanical control measures, whether directed toward the rhizomes or the shoots of marsh horsetail, could completely prevent the development of the photosynthesizing shoots of this plant for long periods of time, this would soon lead either to depletion of the storage reserves in the rhizomes or to the natural death of these organs by aging. However, when such measures have been aimed at the complete eradication of marsh horsetail, they have proved very difficult to put into actual practice (NOZEMAN 1782, WEBER 1903).

In tillage trials carried out by the Department of Plant Husbandry it was found that tilling dry and loose-textured heavy clay soils was quite ineffective in controlling marsh horsetail. In such soil the blades of a revolving harrow were unable to cut the rhizomes, and when an A-blade cultivator (Fig. 18) was used, many of the rhizomes passed undamaged through its blades. On the other hand, autumn ploughing on sufficiently moist and compact soil was effective, since the blade of the plough easily cut the rhizomes at the upper surface of the subsoil.

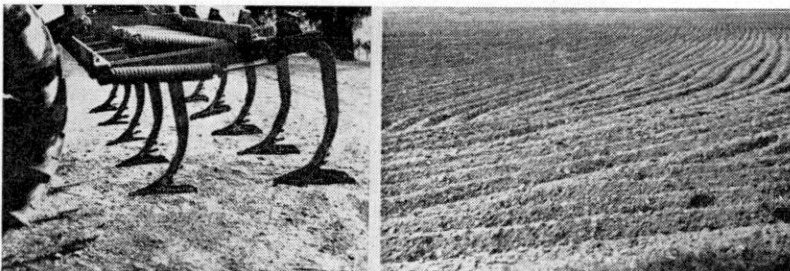


Fig. 18. The A-blade cultivator (left) is able to cut the rhizomes of *E. palustre* in compact and moderately moist soil. In dry, finely-tilled soil (right) this cultivator is inefficient because the rhizomes pass undamaged through the blades.

As has previously been mentioned (p. 21), the capacity for survival and rooting of rhizome fragments separated from the mother plant is extremely weak. Thus autumn ploughing eliminates marsh horsetail rhizomes from the ploughed surface layer of the soil until new rhizome branches grow into it from the subsoil. This is probably the main reason why autumn-ploughed fields contain fewer shoots of marsh horsetail the following year than fields of hay or biennial crops such as winter cereals and winter turnip rape. The time of ploughing also proved to be important. Ploughing late in the autumn or upon sufficiently moist and compact soil in the spring appeared to be more effective than early autumn ploughing under the same conditions. The explanation for this may be that following early ploughing, new rhizome branches grow into the surface soil from the subsoil in the remaining days of the autumn.

On one occasion it was found that soil tillage completely destroyed the rhizomes of marsh horsetail. This field was on a 30 cm thick fen peat with a compact silty subsoil (previously referred to on p. 28). The rhizomes grew only in the topsoil and were unable to penetrate into the subsoil. This site was apparently very unsuitable for marsh horsetail, since even a slight lowering of the ground water resulted in the death of this plant on the drier parts of the field (cf. p. 28). In August 1958 a part of the area was ploughed, and in the following unusually dry summer it was observed that most of the rhizomes in the ploughed area were dead and withered. Such occurrences of marsh horsetail with a shallow rhizome system and growing on a hard subsoil, however, probably represent uncommon borderline cases and are therefore of little practical significance.

Attempts to cause the death of rhizomes by prevention of the development of the aerial shoots were carried out initially by means of fallowing. The trial was begun in the latter part of the summer of 1956 on a heavy clay field with underground ditches. In the previous year the trial field had been in fallow, and during the following winter and early summer of 1956 winter turnip rape was grown on it. At the harvest time of the turnip rape the shoots of marsh horsetail were very abundant in the area; assessments made on four 1-metre quadrats gave an average figure of 5.8 shoots per square metre. The rhizomes were found to extend to a depth of 140—175 cm. After harvest, the field was ploughed in autumn 1956. During the following two growing seasons (1957 and 1958) attempts were made to prevent the growth of marsh horsetail shoots by frequent tillage, carried out at 2 weeks' intervals. There were two areas in this fallow trial, each 12 × 130 m in size, one of which was tilled with a revolving harrow and the other with an A-blade cultivator. Every autumn the areas were ploughed.

During the course of this trial it became evident that it was not possible to prevent the growth of shoots of marsh horsetail completely with the tillage implements used. In the spring, some shoots had already emerged before the

soil had dried sufficiently to be tilled. The same situation occurred during prolonged rainy spells, when the ground was so wet that it could not be harrowed. In addition, it appeared that harrowing actually stimulated the plant to produce new shoots by irritating the bud primordia in the rhizome nodes and causing them to sprout. The absence of shading vegetation was possibly a further contributory factor.

In the beginning of August 1958, tillage in the fallow trial was ended, and in the middle of September assessments of marsh horsetail shoots were made along six 0.5×10 m sampling lines in each of the two trial areas. The area tilled with the revolving harrow gave a count of 9.89 shoots per m^2 and that tilled with the A-blade cultivator 3.64/ m^2 (cf. Table 9, p. 45). On comparing these figures with the counts made before the start of the trial, it appears that the number of shoots in the cultivator-tilled area had decreased by nearly half, while in the revolving harrow-tilled area it had nearly doubled. This comparison cannot be considered dependable, however, since the original method of assessment was not wholly reliable. The result may also have been influenced to some degree by systematic errors.

After fallowing of this trial had been discontinued, spring cereals were grown in both areas the succeeding four years (barley 1959, oats 1960, spring wheat 1961 and 1962). During this time the numbers of marsh horsetail shoots on both areas began to decrease rapidly. Another significant observation was the fact that at the end of the two-year fallowing treatment in 1958, there were fewer shoots in the two adjacent field sites (sites 3 and 4) than in either of the fallowed sites. These adjacent sites had been under rye in 1958 and under barley in 1959. In this case, comparisons between the different sites can be considered more reliable and conclusive, since they are based upon assessments made from six 0.5×10 m sampling lines in each of the sites. At any rate, the results show that *the methods of fallowing used in this trial were very ineffective in controlling marsh horsetail. There is little reason to believe that fallowing in general would be a practical means to control marsh horsetail in South Finland.* In theory, however, this does not rule out the possibility that the rhizomes of marsh horsetail would succumb if continual tilling completely prevented the development of the aerial shoots of this plant. In this case, the tillage equipment would have to be more effective, especially for the cutting of rhizomes.

In order to determine the lifetime of marsh horsetail rhizomes in experiments where the shoots were completely prevented from developing, three trials were carried out in which the ground was covered with black plastic sheeting. Because of the lateral growth of rhizomes into the trial area, the results of such trials cannot be regarded as absolutely conclusive unless the trial plots are made sufficiently large, which would considerably increase the costs of maintaining the trial. However, it was believed that the results obtained even

from small plots might be useful in providing valuable information on the longevity of the rhizomes.

The plastic sheeting trials were established in spring 1958 at the following three locations:

Trial 1. Located at Iitti on fen peat with a thickness of 30 cm; subsoil silty clay; depth of rhizomes 30 cm; size of plots 8×8 m.

Trial 2. Located at Iitti on fen peat with a thickness of 80 cm; subsoil heavy clay; depth of rhizomes 100 cm; size of plots 8×8 m.

Trial 3. Located at Rekola on a field of heavy clay; depth of rhizomes 150 cm; size of plots 15×15 m.

In the first two years following the placement of the plastic covering (1959 and 1960), marsh horsetail rhizomes were found to be alive in all the trial plots. In the spring of the third year (1961) the rhizomes in Trial 1 proved to be completely dead, whereas in Trials 2 and 3 only the rhizome branches located in the uppermost soil layers at depths of 0—50 cm had died. In the fourth year (1962) no change had taken place in Trial 2, and in Trial 3 only a slight increase in the number of dead rhizomes had occurred. A close examination of the living rhizomes growing at depths below 60 cm showed that they had grown into the locations of the trial plots from the surrounding areas.

Control of marsh horsetail shoots by means of pasturing was also studied. The observations made on several farms agreed with reports in the literature (WEBER 1903, FISCHBACH 1927, GLET 1930, GÜNTHER 1932) that shoots of marsh horsetail are easily broken and that even under Finnish conditions, intensive pasturing will gradually decrease the abundance of the shoots of this species. However, in actual practice the complete eradication of marsh horsetail by means of pasturing did not seem possible, i.e. *pasturing reduced the stand of marsh horsetail only in proportion to the intensity of pasturing.*

When viewed in their entirety, the above-described investigations show that, except in certain rare cases, *marsh horsetail is extremely difficult to eradicate by mechanical methods. The rhizomes of this plant would in all probability die within 3—4 years if the growth of the aerial shoots could be completely prevented, but in actual practice this is too expensive.*

3. Chemical control

In this paper the term "chemical control" means the use of phytotoxic compounds or herbicides. In contrast, measures employing fertilizers or chemicals to reduce the acidity of the soil are described in the section on biological control.

The possibility of chemical control of marsh horsetail was considered already by NOZEMAN (1782), MEYER (1832) and BECKER (1840). The first promising results were obtained by MEYN (1854) and HOFFMAN (1870) as well as by PETERSEN and HESSENLAND (1893). All these workers used sodium chloride to kill the marsh horsetail. WEBER (1903), however, considered sodium chloride, as well as several other herbicides known at the beginning of the 1900's, to be rather ineffective.

Renewed interest in the chemical control of marsh horsetail was aroused after the end of World War II by the discovery of the so-called auxin herbicides or aryloxyalkyl-carboxylates. These selective compounds, when sprayed on the foliage, successfully destroy the aerial parts of many weed species with little effect on grass and cereal crops. Auxin herbicides are translocatable, i.e. they are transported in the vascular tissues along with the flow of assimilates into the underground parts of the plant. Here they cause the death of the roots and rhizomes. A characteristic of auxin herbicides is that they are especially toxic to young, actively-growing tissues. Within the plant they are retained in meristematic tissues where cell growth is most vigorous (CRAFTS 1959). To the underground parts of the plant auxin herbicides are translocated most effectively when photosynthesis and the flow of assimilates as well as the growth of the roots and rhizomes are at the stage of maximum activity. On the other hand, vigorous growth of the aerial parts may often retard the movement of the herbicide into the underground parts of the plant. In this case the compound is retained in the growing points of the aerial shoots. On the basis of these facts, it is believed that in order to destroy rhizomes of weeds, auxin herbicides should be applied at the beginning of the growing season before the shoots begin to grow rapidly (CRAFTS 1959). However, there are certain exceptions to this rule. For instance, the rhizomes of Canada thistle (*Cirsium arvense* Scop.) and perennial sow thistle (*Sonchus arvensis* L.) are most effectively killed by relatively late treatment carried out at a time when the elongation of the shoots is in progress or has nearly ended (GRANSTRÖM 1954, VIDME 1961). At any rate, the leaf area of the plant should be as large as possible at the time of foliar treatment so that the leaves may receive and absorb the maximum possible amount of herbicide.

The auxin herbicide which has been most widely tried in attempts to control marsh horsetail and other species of *Equisetum* is 4-chloro-2-methylphenoxyacetic acid or MCPA. Alkaline salts of MCPA are most frequently used. In doses of 1—1.5 kg/ha this compound has been found to rapidly kill the shoots of both field and marsh horsetails (BLACKMAN 1945, BOER 1947). The toxicity of the dead marsh horsetail shoots disappeared within a few weeks after the treatment (HOLZ and RICHTER 1954, 1959, 1960, HOLZ 1957 a, 1957 b, NEURURER *et al.* 1959). Most European workers, e.g. JACKMAN and TINCKER (1949), PLANT (1952), HOLLY (1953) and GALENSA (1959), did not find any decrease in regrowth of horsetails after foliar application of MCPA. In view of the fact that the photosynthesizing organs of horsetail plants, i.e. their stems and branches, are thin and slender and have a relatively small surface area in relation to the length and thickness of the rhizomes, the above unsatisfactory results are easy to understand. However, HOYT and CARDER (1962) in the USA obtained 50—65 % control of regrowth of field horsetail after a single foliar treatment with MCPA. Also NEURURER *et al.* (1959) in Austria found a significant decrease of regrowth of marsh horsetail after four foliar treatments with MCPA in two years. Very promising results were obtained by KORTLANG (1961), who incorporated the MCPA spray into the soil and combined this treatment with cutting of rhizomes 20—50 cm below the surface of the soil. Von KRIES (1962) reported complete eradication of marsh horsetail rhizomes after two years of such treatment.

As to the effect of other auxin herbicides on horsetails, the following notes are to be found in the literature:

2,4-dichlorophenoxyacetic acid or 2, 4 — D

— poor effect (HOLZ and RICHTER 1954)

— less effective than MCPA (HOLZ and RICHTER 1954, HOYT 1956, HOYT and CARDER 1962)

2,4,5-trichloroacetic acid or 2, 4, 5 — T

— poor effect when mixed with 2, 4 — D (HOLZ and RICHTER 1954)

— good effect when mixed with MCPA (von KRIES 1962)

— less effective than MCPA (HOYT and CARDER 1962)

- 4-(4-chloro-2-methylphenoxy)butyric acid or M C P B
 - good effect (HOLZ and RICHTER 1959, von KRIES 1962)
- 2-(4-chloro-2-methylphenoxy)propionic acid or m e c o p r o p
 - more effective than MCPA (VIDME 1960)

Another herbicide which has been widely tested since the middle of the 1950's for the control of field horsetail is 3-amino-1,2,4-triazole or amitrole (e.g. HOYT 1956, ORTH 1959, GRANSTRÖM 1961, HOYT and CARDER 1962, von KRIES 1962). Like MCPA, amitrole is a foliage-applied translocatable herbicide but less selective. Its use on cultivated fields is thus limited to applications before sowing, after harvest or during periods of fallow. Amitrole is more easily translocated in the vascular tissues of plants than auxin herbicides (CRAFTS 1959). It is not retained in the meristematic regions nor is its transport limited to the living tissues. In addition, amitrole produces a toxic effect on old cells which have ceased growing as well as on young, actively-growing cells. It moves most readily into the underground parts of the plant at the end of the growing period (CRAFTS 1959). Amitrole is less toxic to the shoots of horsetail than MCPA. This characteristic may be advantageous, because the shoots treated with amitrole will remain healthy for a longer period and may thus be better able to transport the chemical to the rhizomes. Investigations have shown that rates of 2 ½ — 10 kg/ha of amitrole are very effective in reducing the regrowth of field horsetail (e.g. HOYT 1956, GRANSTRÖM 1961, HOYT and CARDER 1962). The rather high price of the compound as well as its nonselectivity are drawbacks which limit the practical use of amitrole.

Among other herbicides tried for the control of horsetail may be mentioned ammonium sulphamate or AMS. This compound became known in the 1940's mainly as a contact herbicide against woody species of weeds. AMS is weakly translocated but it has a strong although brief soil-sterilizing effect. Investigations carried out in Oregon, U.S.A. in the 1950's showed that AMS at a rate of about 500 kg/ha completely destroyed the rhizomes of field horsetail (FURTICK 1960). Since this herbicide is readily soluble, it is rapidly leached to considerable depths in the soil. This feature, together with its high toxicity, obviously explains the excellent control of the rhizomes of field horsetail. The disadvantages of AMS are that it shows little selectivity, leaves a toxic residue in the soil, and is rather expensive. For these reasons the use of AMS is largely limited to non-cultivated areas.

At the Department of Plant Husbandry MCPA was tested as a foliar spray on the following types of land: a) leys, b) stubble of leys, c) pastures, d) spring cereals, e) stubble of spring cereals, and f) banks of open ditches. It was also applied as an annual treatment on crop rotations.

On leys containing red clover, it proved extremely difficult to obtain satisfactory results with MCPA in the early summer. Treatments made in May were ineffective because the shoots of marsh horsetail had not yet emerged sufficiently. During the month of June, on the other hand, the red clover had grown so profusely and produced such a dense stand that even the largest amounts of spray solution used (up to 1500 l/ha) were unable to penetrate through the clover to the marsh horsetail shoots. On fields with little or no red clover, however, satisfactory control was obtained when spraying was carried out about the middle of June. The effect of MCPA treatment appeared very rapidly; the marsh horsetail shoots died within three days, and at the same time they became dry and very dark in colour. Typical auxin herbicide symptoms, such as stem curvature, were found only in cases when the injury

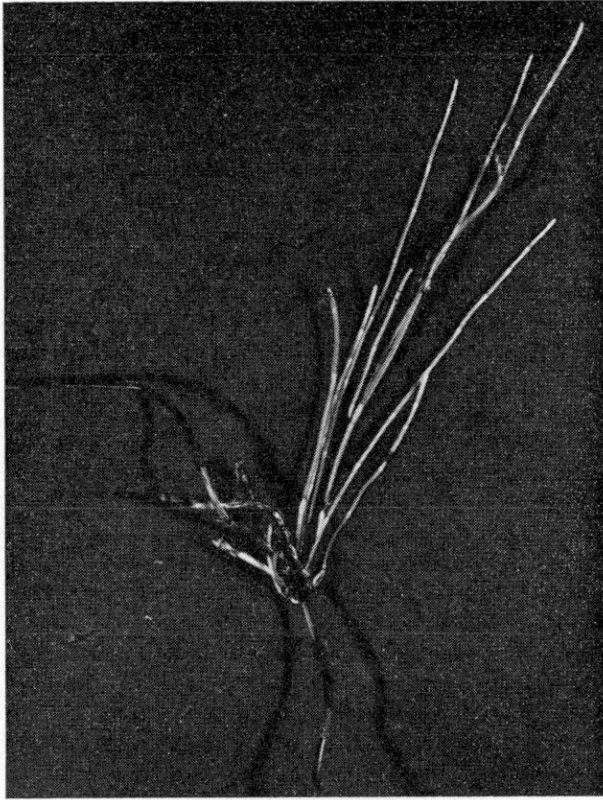


Fig. 19. The conventional dosages (1—3 kg/ha) of MCPA applied on the foliage have only a weak effect in controlling the regrowth of *E. palustre*. — New shoots developing from the uppermost node of the rhizome 5 weeks after MCPA treatment.

was slight (Fig. 6). The rate of MCPA required to destroy the shoots of marsh horsetail proved to be much greater, 2.5 kg/ha (volume 500 l/ha), than had been expected on the basis of reports in the literature. This was probably due to the fact that a considerable amount of the spray fell upon and was absorbed into the leaves of the cultivated plants and only a small amount reached the shoots of marsh horsetail. Under the same conditions, shoots of field horsetail were killed by 1.5 kg/ha MCPA and were thus considerably more susceptible to this herbicide than the shoots of marsh horsetail. Regrowth of marsh horsetail from its rhizomes was only slightly delayed at the rate of 2.5 kg/ha. About six weeks after spraying, new shoots already began to arise from the lowermost, undamaged stem nodes or from the uppermost nodes of the rhizomes (Fig. 19).

In the stubble of ley, MCPA was tested on a field located on heavy clay. The compound was applied at rates of 1—27 kg/ha at the beginning of August, or about four weeks after the main hay harvest. At this time the second growth

of marsh horsetail as well as that of the cultivated ley plants was about 15 cm tall. Rates of MCPA ranging from 3 to 27 kg/ha, which were considerably larger than those necessary for destroying the shoots of marsh horsetail, were found to greatly decrease the regrowth from the rhizomes in the following year. This effect in hindering regrowth was roughly proportional to the rate of MCPA used (Table 3). The highest rate used, 27 kg/ha, reduced the regrowth to 25 % of the untreated control. According to reports in the literature, such good results have not earlier been obtained with foliar sprays of MCPA. The experiment shows that the effect of MCPA in preventing the regrowth of marsh horsetail was almost as great as that of amitrole (also used in the experiment) when the two compounds were used at equal rates. It would be of great interest to know whether these improved results with the high doses of MCPA were caused by its more abundant translocation. It is also possible that some of the MCPA used was leached into the soil and absorbed by the rhizomes. According to the studies made by KORTLANG (1961) and von KRIES (1962) it seems possible that the MCPA which the rhizomes have absorbed from the soil may be very effective. On the other hand, compounds like MCPA are easily degraded by soil microorganisms.

High rates of MCPA killed both red clover and timothy in this experiment.¹⁾ The former plant was killed by a rate of 3 kg/ha, while the latter was killed partially (about 50 %) by 9 kg/ha and completely by 27 kg/ha.

In fields of spring cereals, satisfactory control of marsh horsetail shoots was obtained by spraying with MCPA (2.5 kg/ha) during the first half of July, just before the heading of the cereal. Practical difficulties were encountered in spraying such tall stands of cereals. When applied to spring cereal fields earlier in the season, the chemical proved ineffective because of the late emergence of the marsh horsetail shoots.

In the stubble of a spring cereal (barley) MCPA was tested at the beginning of August on a field located on heavy clay soil. The crop had been cut with a combine harvester at such a height above the ground that the shoots of marsh horsetail were largely intact. The rather high rate of MCPA used, 7.5 kg/ha, gave results similar to those obtained in the trial on ley stubble (Table 3), i.e. MCPA reduced the regrowth of marsh horsetail by about 50 % as compared with the untreated control. The result was almost as good as that obtained with amitrole at the same rate (Table 4).

The effect of annually repeated MCPA treatments was studied in two fields situated on fen peat soil. The rate of MCPA used was 2.5—4 kg/ha. One of the fields was pasture in 1957—59 and was subsequently sown to oats in 1960—61; the other field was sown to oats throughout the trial period (1958—62). In the latter field, previously referred to on p. 25, the main

¹⁾ Under the conditions of these investigations MCPB, which is less toxic to red clover than MCPA, gave less satisfactory control of marsh horsetail than MCPA. Therefore further experimenting with MCPB was discontinued.

Table 3. The use of MCPA and amitrole on stubble of red clover-timothy ley.
Soil heavy clay, date of treatments Aug. 4—8, 1960.

Treatment		No. of shoots of <i>E. palustre</i> per m ² , one year after treatment
Untreated		24.0
MCPA	1.0 kg/ha	20.0
”	3.0 ”	11.9
”	9.0 ”	11.8
”	27.0 ”	6.1
Amitrole	5.0 ”	12.3
”	7.5 ”	11.0
”	10.0 ”	7.0
Amitrole ”T” ¹⁾	10.0 ”	11.6
LSD 5.50		

Table 4. The use of MCPA and amitrole on stubble of spring cereal (barley).
Soil heavy clay, date of treatments Aug. 3, 1961, crop in the following year spring cereal (wheat).

Treatment		No. of shoots of <i>E. palustre</i> per m ² , one year after treatment
Untreated		11.2
MCPA	7.5 kg/ha	5.7
Amitrole	5.0 ”	9.7
”	7.5 ”	5.5
”	10.0 ”	2.8
LSD 3.78		

drainage canal was deepened in winter 1957/58 before the beginning of the trial. In addition, the open drainage ditches in the field were changed to covered brush drains in autumn 1961 and at the same time PK fertilizer (400 kg/ha) was applied.

As a result of repeated MCPA treatment during four consecutive years, the number of shoots of marsh horsetail in both fields gradually decreased to 0.3—0.4/m². This was 1—4 % of the original number present in the field and would not have been likely to cause significant toxic effect on cattle had the field been planted to hay (Table 1, p. 25, and Table 5). It appeared that the regrowth of marsh horsetail was suppressed more quickly in oats than in ley (Table 5).

On the basis of the above trials, no positive conclusions can be drawn concerning the effect of time of application of MCPA treatment. According to HOYT and CARDER (1962) the best control of field horsetail is obtained

¹⁾ With ammonium thiocyanate additive.

Table 5. The effect of annual foliar application of MCPA on the abundance of *E. palustre* shoots.

Thin fen peat, subsoil heavy clay, no fertilization, date of treatments and countings Aug. 10—15 in 1957—59 and July 10—15 in 1960—61.

Year	Crop	No. of shoots of <i>E. palustre</i> per m ²	
		Untreated	M C P A 4 kg/ha
1957	Pasture	not assessed	
1958	„	7.8	7.6
1959	„	7.8	5.2
1960	Oats	4.3	2.3
1961	„	4.7	0.3
LSD 2.34			

when the green shoots are fully developed. It is also noteworthy that the bud primordia of the horsetail shoots which emerge in the following spring are largely developed during the latter part of the growing season. In order to kill these primordia, great significance of the time of MCPA treatment would be expected.

The effect of amitrole as a foliar spray was studied on the following types of land: a) banks of open ditches, b) stubble of leys, c) stubble of spring cereals and d) fallowed fields. A satisfactory control of marsh horsetail shoots was achieved, as in the case of MCPA, when the treatment was carried out during the period June 10 — August 20. The toxic effects of amitrole developed more slowly than those of MCPA; about 5—7 days were required before the shoots died. Also, the rate of amitrole which was necessary to kill the shoots was slightly higher than that of MCPA, or about 3.5 kg/ha. Shoots of field horsetail succumbed after treatment with 2.5 kg/ha of amitrole and thus proved to be more susceptible than the shoots of marsh horsetail. When dying, the shoots became dry and brown or black. The typical chlorotic symptoms of amitrole toxicity were found only in weakly-injured shoots.

Table 6. The use of MCPA and amitrole on a ditch bank.

Soil sandy clay, date of treatments June 27, 1959, no replicates.

Treatment	No. of shoots of <i>E. palustre</i> per m ²	
	After one year	After two years
Untreated	43.6	42.8
MCPA 2.5 kg/ha	40.0	44.2
Amitrole 2.5 „	34.8	44.7
„ 5.0 „	4.7	12.4
„ 10.0 „	1.3	2.7
„ 15.0 „	2.5	2.9



Fig. 20. The effect of amitrole in controlling the regrowth of *E. palustre* is sometimes very pronounced. — A ditch bank one year after treatment with amitrole.

In the stubble of a ley (Table 3, p. 37) and in the stubble of a spring cereal (barley) (Table 4, p. 37), both of which were located on heavy clay soil, amitrole applications at rates of 5–10 kg/ha in the beginning of August gave results similar to those obtained with MCPA. Regrowth of marsh horsetail fell to 25–50 %. The highest rate of amitrole gave the best control. Red clover was killed by all the rates of amitrole tested, but timothy showed only slight injury at the lowest rate (5 kg/ha). On the banks of open ditches on silty clay soil, treatment with amitrole at rates of 5–15 kg/ha carried out at the end of June (Table 6) greatly weakened the regrowth of marsh horsetail. In both the first and second years after treatment its growth was only 3–11 % of that of the untreated control (cf. also Fig. 20).

Table 7. The use of amitrole on a fallow field at Rekola.

Soil heavy clay, foliar application, crop in the following year spring cereal (wheat).

Date or treatment	No. of shoots of <i>E. palustre</i> per m ²	
	After one year	After two years
a. Untreated	8.7	2.1
b. June 22, 1959	0.1	0.1
c. July 25, 1959	3.8	1.1
d. Aug. 18, 1959	5.0	1.3
e. June 28, 1960	0.5	0.4
f. c + e	0.1	0.3
LSD 1.34		

In the trial on untilled fallow on heavy clay, carried out in the years 1959—60, excellent results were obtained with an amitrole application at the rate of 10 kg/ha (Table 7). Treatments repeated in two consecutive years gave slightly better results than those made only in one year. The earliest application (June 26) gave the best control, and the latest application (Aug. 8) the poorest control. However, these experiments do not necessarily indicate that early applications of amitrole are more effective in decreasing the regrowth of marsh horsetail than late applications. In the above trial, the annual weeds had grown so profusely on the plots by the end of the growing season that a large part of the spray fell upon their leaves and thus did not come in contact with the marsh horsetail shoots. The results obtained from the June application were nevertheless unusual, because the number of horsetail shoots was reduced to less than 0.1 per m². This was about 1% of the untreated control. The number of shoots remained at this low level for four years. A careful examination of the rhizomes showed that almost all of them had been killed to a depth of about 60 cm. On the other hand, at depths of 70—140 cm there were almost as many living rhizomes as in the untreated plots. These living rhizomes, however, had grown into the plot in question (measuring 12.5 m on a side) from the surrounding area. It is difficult to discover with certainty why these rhizomes were unable to produce vertical, upward-growing branches in the soil located at the site of the amitrole-treated plot. It is possible that the upper soil layers (heavy clay) became excessively dry and hard during the summer, or perhaps the geotropism of the rhizomes became weakened owing to the effects of amitrole. However, since the phytotoxic effect and persistence of amitrole in the soil are quite small (BURSCHEL and FREED 1959), the latter explanation does not seem very satisfactory.

In a second fallow trial, carried out in 1961—62 on another heavy clay field, much poorer results were obtained (Table 8). Amitrole was used at rates of 3.75—15 kg/ha, but it reduced the regrowth of marsh horsetail to only 17—34% of the untreated control. The best average control was achieved

Table 8. The use of amitrole on a fallow field at Lapinjärvi.

Soil heavy clay, foliar application, crop following the treatments winter rye.

Treatment	Dates of treatment:	No. of shoots of <i>E. palustre</i> per m ² one year after treatments		
		June 29, 1961	July 15, 1961	Aug. 1, 1961
Untreated		3.7	10.7	5.1
Amitrole 3.75 kg/ha		1.4	4.0	1.2
„ 7.50 „		1.9	1.8	0.4
„ 15.00 „		1.3	2.0	1.8
LSD 1.72				

after the August application and the poorest after the June application. This difference, however, was not significant.

In the year following the amitrole applications, the fallowed fields were sown to spring cereals. It was found that wheat and barley suffered considerably from the residual toxic effect of amitrole in the soil. The growth of these crops was slow and the leaves were chlorotic. In contrast, oats showed no injury from the chemical.

Two preliminary trials with AMS were carried out in the years 1961—62 on heavy clay soil. One trial was on banks of open ditches and the other on a fallowed field. In both cases the herbicide was applied at the end of June. One year after the treatment it was found that the heaviest rate of AMS used, 750 kg/ha, had provided almost complete killing of the rhizomes of marsh horsetail, whereas rates of 250—500 kg/ha had affected only the rhizomes growing in the upper soil layers.

On the basis of the above experiments on the chemical control of marsh horsetail, it can be concluded that application of MCPA on timothy leys at rates of 2.5—3 kg/ha is advisable to kill the aerial shoots of marsh horsetail, especially in cases of heavy infestation. When repeated annually, such treatment appears to have a suppressing effect on the regrowth of marsh horsetail. On leys containing red clover, the early and abundant growth of clover makes it too difficult to bring the spray solution into contact with the marsh horsetail shoots. Furthermore, the clover may be either damaged or killed. Likewise in fields of spring cereals MCPA cannot be used because of the late emergence of the marsh horsetail shoots. In the case of stubble and fallowed fields, and particularly on the banks of open ditches, higher amounts of herbicides should be used to prevent the regrowth of marsh morsetail or even to kill its rhizomes. Amitrole, AMS and high rates of MCPA may be used for this purpose. Further investigations should be made in order to determine the efficacy of different rates and times of application as well as the economic practicability of such heavy application of herbicides. The MCPA incorporation method of KORTLANG (1961) should also be studied under Finnish conditions. In addition, the persistence of the residual toxicity of AMS in the soil in this region has yet to be established.

4. *Biological control*

The term biological control, as it is used in this paper, refers to the growing of competitive crops which may successfully smother marsh horsetail, and to the measures taken to improve the ability of these crops to compete with marsh horsetail.

Marsh horsetail itself is not a shade-producing plant, and the growth of its shoots is rather slow. The species is apparently so susceptible to shading that even in its natural habitat, other shade-producing plants will greatly limit the growth of its shoots. Thus it is understandable that attention has long been given to biological control of marsh horsetail. In the 1700's, when certain scientific societies in Central Europe organized contests to discover the best method of eradicating marsh horsetail, one of the prizes was awarded to NOZEMAN

(1782). His investigation demonstrated, among other things, the importance of suitable fertilization. In Nozeman's opinion the principal reason for the abundant occurrence of marsh horsetail in leys was the fact that the farmers used all of their barnyard manure to fertilize their cereal fields. As a result, the unfertilized leys grew poorly and thus offered little competition to marsh horsetail.

Later observations, based upon more scientific investigations (MEYER 1832, WEBER 1903, GALENSA 1959, HUSEMANN and BRACKER 1960), have given strong support to the findings of Nozeman. In Finland, VALMARI (1955) also came to the same conclusion and stated that until suitably effective herbicides against marsh horsetail are available, its control should be attempted by the use of densely-growing, shading crops. The following results are from the timothy ley fertilization trials of Valmari:

Fertilization	Amount of marsh horsetail			Hay yield kg/ha	Content of marsh horsetail %
	in main harvest no/m ²	g/m ²	in aftermath no/m ²		
O	2444	245	6.2	2000 — 2900	11.4
PK	72	107	4.5	3000 — 3900	7.4
PN	67	74	3.6	4000 — 4900	3.5
KN	37	47	5.3	5000 — 5900	2.4
PKN	36	51	2.0	6000 — 6900	1.4
PK ₂ N	22	37	2.0	7000 —	1.5
PKNCu	67	89	4.5		

Although marsh horsetail is a rather eutrophic species and in the natural state prefers to grow on fertile soils (UOTILA 1956), cultivated crops are apparently more benefited by heavy fertilization than marsh horsetail. Thus the growing conditions for this species are less favourable in highly fertilized fields than in poorly fertilized ones (cf. also SONNEVELD 1952, de VRIES *et al.* 1957, SIEBOLD 1958).

BECKER (1840) and MEYN (1954) recommended liming as an effective measure for combatting marsh horsetail. STAUDINGER (1839), WEBER (1903), VALMARI (1955) and de VRIES *et al.* (1957), however, did not find liming effective against this weed. On the contrary, FERNALD (1950), SONNEVELD (1952) and UOTILA (1957) found that under natural conditions marsh horsetail favours limestone soils.

The very abundant shoot growth of marsh horsetail in leys, as shown by the figures of Valmari, is probably due to the fact that this plant, like most horsetail species, begins its growth early in the spring. Since the soil of leys is not ploughed in the autumn, a dense network of rhizomes is able to grow and to occupy the very surface of the topsoil. Bud primordia of aerial shoots are formed in the nodes of the upper rhizome branches in the autumn (Fig. 2 A). In the spring these buds produce new shoots, which begin to grow before the ley plants have been able to form a shading stand. Later a dense stand of ley plants is produced, especially in the case of red clover. This stand covers the shoots of marsh horsetail (cf. p. 34), but does not completely smother them. On the other hand, after the main hay harvest, the competitive growing ability of marsh horsetail is less. At this time the ley plants produce a dense aftermath so rapidly that the growth of marsh horsetail shoots is almost completely checked, as shown by the figures of VALMARI (1955). Another factor which evidently has a considerable effect on the abundance of marsh horsetail is the age of the ley. In old leys this and other species of weeds are known to grow most abundantly (UOTILA 1956). One reason for the success of marsh horsetail in these situations is that the rhizomes may grow freely in the topsoil. Another reason, and perhaps the most important one, is the fact that the number of cultivated plants decreases gradually as the ley ages (cf. PAATELA 1953), and thus there occurs a decline in biological competition. In Finland, the most important

ley crops are timothy and red clover. The former does not produce much shade and shows a poor regrowth, whereas red clover is known for its superior qualities of shading and regrowth. On pastures in Finland, timothy is replaced to a certain extent by meadow fescue (*Festuca pratensis* Huds.) and cocksfoot (*Dactylis glomerata* L.), which, because of their vigorous regrowth, are better competitive plants than timothy. White clover is also used in pasture seed mixtures, but since it is a low-growing species, its competitive ability in regard to the control of marsh horsetail is less than that of red clover.

For economic reasons, biological control of marsh horsetail should be incorporated into the normal crop rotation schemes suitable for this country. In studying the possibilities of marsh horsetail control, consideration must therefore also be given to the growing of other crops besides ley crops, although the toxicity of this species is mainly harmful in leys. In fields of biennial winter crops such as winter cereals and winter turnip rape, marsh horsetail begins its growth in the spring under essentially the same conditions as in leys. Since the ground is ploughed earlier in the summer, the rhizomes are able to develop a network and bud primordia during the autumn. In the early spring, these primordia are ready to produce new shoots. Winter cereals and winter turnip rape, however, have a considerable shading ability if they have overwintered satisfactorily. Furthermore their development in the spring and early summer is very rapid. On the other hand, because of the early harvest time of winter cereals, and especially winter turnip rape, these crops leave the ground exposed to marsh horsetail shoot growth later in the summer. In the case of fields such as spring cereals, which are tilled annually, the starting point for the growth of marsh horsetail in the spring is different. Ploughing cuts the rhizomes at the upper boundary of the subsoil, and as a consequence the young shoots must grow through the layer of topsoil before they reach the surface. As a result the shoots of marsh horsetail do not appear in these fields until the latter part of June or beginning of July, at which time the cereal crop has produced a dense stand.

The favourable growth of marsh horsetail when it had no competition was observed in many instances during the studies made at the Department of Plant Husbandry. For example, the vigorous growth of marsh horsetail (and field horsetail) shoots along the edges of new railways and highways (Fig. 14, p. 19) appeared to be due mainly to lack of competing vegetation. Evidently the sand and gravel along the edges of newly-constructed roads was not a suitable site for rapid invasion by seed-dispersed plant species. The rhizomes of marsh horsetail (and also of field horsetail), however, grew rapidly into the loose zone of sand or gravel from the sides or from below, because there was little competition from other vegetation. The area became very quickly covered with a vigorous growth of aerial horsetail shoots. In later years it was observed that perennial seed plants gradually obtained a foothold in the area, with the consequence that the amount of horsetail began to decrease until finally a certain natural equilibrium was established.

A similar effect was noted when virgin soil containing marsh horsetail was brought into cultivation by digging open drainage ditches. Often it was observed that the first vegetative growth to appear on the bare banks of the ditches was marsh horsetail (Fig. 17, p. 27). Again the reason for this was the lack of competing vegetation. Either the soil of the ditch banks was not suitable for a rapid invasion by seed-propagated annual plants or the dispersal of seeds

to such areas was too slow. As a result of the profuse shoot growth of marsh horsetail, the rhizomes of this plant also grew more vigorously. This, in turn, resulted in an increase in the number of shoots on the strips of land between the ditches (Table 2), where the soil was tilled and cultivated crops provided shade. As the ditches became older, many perennial seed plants, especially grasses, gradually obtained a foothold and began to displace the marsh horsetail. This displacement took place very slowly and was interrupted when the vegetation was removed from the ditches. For these reasons, the eradication of marsh horsetail from open ditches is a very difficult problem. Therefore, *underground drainage of cultivated land can be considered a basic prerequisite for the biological control of marsh horsetail.*

Observations made on fields which had been deepdrained showed that at first marsh horsetail grew vigorously in the loose soil filling the drains (Fig. 13, p. 18). Within 3—4 years, however, the numbers of marsh horsetail shoots along the drain lines began to decrease. This was apparently due to compaction of the soil and to shading by the cultivated crop. At the same time the numbers of shoots in the areas between the drain lines also began to decline. In one field, which was heavily fertilized at the time of underground drainage, the decrease in the number of marsh horsetail shoots was already evident in the following year (Table 1, p. 25).

The observations made at the Department of Plant Husbandry on the significance of biological competition in leys were in close agreement with those of VALMARI (1955), i.e. in dense and vigorously-growing leys, marsh horsetail produced fewer and weaker shoots than in sparse leys. Likewise the species grew less well in the rapidly-developing aftermath than in the main growth of the ley (cf. Table 10, p. 46).

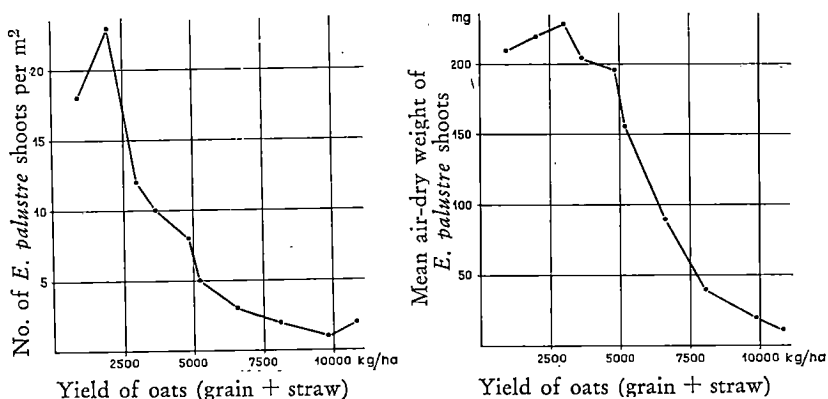


Fig. 21. The relation of the number and weight of *E. palustre* shoots to the yield of oats.

Table 9. The abundance of *E. palustre* shoots on some heavily fertilized fields at Rekola.

Soil heavy clay; the underground drainage system, constructed in 1952, functioned satisfactorily. NPK or PK fertilizers used annually from 1954 to 1962 at rates of 500—1000 kg/ha for the cereals and 2nd and 3rd year timothy (seed), and 1850 kg/ha for winter rape. Second year ley (red clover-timothy) and first year timothy received N-fertilizers 100—200 kg/ha. The cereal yields are given as grains, the winter rape yield as seed and the ley yields as dry hay. The yields of timothy seed field estimated as dry hay.

Year	Crop rotation	Yield of crop plants, kg/ha	No. of shoots of <i>E. palustre</i> per m ²
Whole area			
1954	spring wheat	1900	not assessed
1955	fallow	—	”
1955	winter rape	1100	(5.80)
Site 1			
1957	fallow (rotary harrow)	—	not assessed
1958	”	—	9.89
1959	barley	3000	2.17
1960	oats	3300	0.87
1961	wheat	3650	0.21
1962	”	2000 ¹⁾	0.19
Site 2			
1957	fallow (cultivator)	—	not assessed
1958	”	—	3.64
1959	barley	3000	0.27
1960	oats	3300	0.43
1961	wheat	3650	0.11
1962	”	2000 ¹⁾	0.04
Site 3			
1957	winter rye	2060	3.04
1958	barley	3000	1.72
1959	hay	3650	0.42
1960	”	7400	0.03
1961	wheat	3650	0.03
1962	”	2000 ¹⁾	0.02
Site 4			
1957	winter rye	2060	2.84
1958	barley	3000	1.58
1959	timothy	(2000)	1.49
1960	”	(2500)	1.38
1961	”	(2500)	1.56
1962	”	(4000)	not assessed

¹⁾ Owing to the exceptionally cool weather, the grain yields in 1962 were low, although the stands were dense and had a heavy smothering effect on *E. palustre*.

Table 10. The abundance of *E. palustre* shoots on a heavily fertilized field at Puistola. Soil heavy clay; the underground drainage system, completed in 1924, functioned unsatisfactorily. The use of fertilizers and calculation of yields as in Table 9.

Year	Crop rotation	Yield of crop plants, kg/ha	No. of shoots of <i>E. palustre</i> per m ²
1954	Winter rape	1020	not assessed
1955	a. winter rye	1180	„
	b. wheat	2350	„
1956	oats	3450	„
1957	hay, main crop	2100	30.80
	„ aftermath	not assessed	3.10
1958	„ main crop	5500	22.00
	„ aftermath	not assessed	5.70
1959	barley	4350	1.00
1960	„	4550	1.10
1961	wheat	3280	0.67
1962	„	2000 ¹⁾	1.14

The competitive ability of marsh horsetail on annually tilled land was studied at the Department of Plant Husbandry on fields where oats grew unevenly. In those areas of the field where the stand of oats was dense, the number of marsh horsetail shoots was found to be very low (Fig. 21). The shoots were etiolated (cf. Fig. 10, p. 14) and their weight was negligible. Although in the densest places the oats were too crowded to give good grain yield, yet the trial shows that *on annually tilled fields it is relatively easy to obtain a crop stand which is effective in shading and hindering the growth of marsh horsetail.* In addition to oats, other annual crops may also be used for this purpose.

Observations on the occurrence of marsh horsetail in various crop rotations were made for several years on two heavily-fertilized trial areas.

One of the areas in question, at Puistola (located in the city of Helsinki), was drained with underground ditches in 1924, but the drainage system functioned unsatisfactorily. The lowest soil water level was 60—80 cm. In the second trial area at Rekola (near Helsinki) the underground drainage system was completed in 1952, functioned well and resulted in a lowest soil water level of 100—120 cm. In both areas the amounts of fertilizers applied, as well as the yield levels, had been quite low before the beginning of the trials in 1954. In the 1940's and the beginning of the 1950's chemical fertilizers were not freely available on the market, and the amounts of barnyard manure produced at the Agricultural Research Centre were rather small in relation to the area cultivated. As a result, the yields of spring cereals during this period

¹⁾ Cf. footnote on Table 9, page 45.

were considerably below 2000 kg/ha. After 1954 large amounts of chemical fertilizers were applied annually on both areas. Cereals as well as 1—3-year timothy leys received annual applications of 500—1100 kg/ha of NPK or PK fertilizers, while winter turnip rape received nearly 2000 kg/ha. In addition, 2nd-year hay fields (timothy-clover) and 1st-year timothy leys were given 100—200 kg/ha of nitrogen fertilizers. As a result of this heavy fertilization the yield level began to rise. In the years 1958—61 the yields of spring cereals were without an exception more than 3000 kg/ha, sometimes even exceeding 4000 kg/ha. On one occasion, the hay yield at Rekola exceeded 7000 kg/ha (Table 9, site 3). The smallest grain yields, 2000 kg/ha, were obtained in 1962 as a result of very low summer temperature which prevented ripening of the grain. The stands, however, were very dense in that year and had a very good shading effect. In both the trial areas MCPA was applied to winter cereals at rates of 1.5—2.0 kg/ha at the end of May and to spring cereals at rates of 1.0—1.5 kg/ha at the beginning of June. In addition, the hay field (clover-timothy) at Puistola was given 2.0 kg/ha MCPA in the middle of June in the years 1957—58 and the timothy ley at Rekola received 3.0 kg/ha in the middle of June 1962.

The reliable method of a linear sample area was first used on these fields in 1957. Large numbers of marsh horsetail shoots were found on both areas. In the following years their numbers declined very quickly on most of the sites in the areas (Tables 9 and 10).

On the basis of the above facts it seems unlikely that the striking decrease in the abundance of shoots was due to weather changes (cf. figures on p. 5) or to the water conditions in the soil. It neither seems possible that MCPA was responsible for the decrease, with the exceptions of the hay field at Puistola and timothy seed field at Rekola. The rates of MCPA applied to the cereals were low, and in the light of the experimental results described in the preceding section (Table 3, p. 37 and Table 6, p. 38) they could not have had an appreciable after-effect on the regrowth of marsh horsetail. In addition, the MCPA was applied so early that the marsh horsetail had not yet emerged to any great extent. Thus it seems very probable that the decrease in the abundance of marsh horsetail on the fields in question was primarily due to the increase in biological competition offered by the crops as a result of heavy fertilization. This view is supported by a comparison of the abundance of marsh horsetail in the various sites at Rekola (Table 9). At first it appeared that spring cereals gradually depressed the growth of marsh horsetail. The most striking effect, however, occurred on the vigorously-growing clover-timothy ley (site 3), where the growth of marsh horsetail shoots was checked almost completely. On the other hand, the timothy seed field (site 4) was unable to suppress the growth of marsh horsetail until the year 1962. In this year the field was sprayed with a higher rate of MCPA at a time when the shoots of marsh horsetail had successfully emerged. In addition, the stand of

timothy had become dense by this time as a result of heavy fertilization and the new growth from seeds which had fallen to the ground and germinated. At Puistola (Table 10) the decline in the abundance of marsh horsetail had ceased by 1959. It is possible that this was due to the higher level of the ground water, which had resulted from the inefficiency of the drainage system. This had altered the balance of biological competition among the various plant species in favour of marsh horsetail, and the stand remained at this level.

Similar observations on the occurrence of marsh horsetail in various crop rotations were carried out for several years at three trial areas at Iitti. These were referred to in the previous section (Table 1, p. 25, Table 2, p. 27, and Table 5, p. 38). The yields were not weighed, and the purpose of the trials was more limited, dealing mainly with a study of the effects of drainage and MCPA treatment. In one of the trials a reduction in biological competition (new exposed ditch banks) was probably the reason for an increase in the abundance of marsh horsetail shoots (Table 2, p. 27). In a second area the increase in biological competition (converting open ditches to underground brush drains together with heavy fertilization) was followed by a reduction in the abundance of shoots (Table 1, p. 25).

The above investigations thus agree with reports in the literature that *biological control is an effective means for combatting marsh horsetail*. On the basis of the studies carried out up to the present time, it is still too early to decide whether marsh horsetail can be *eradicated* by biological methods under the conditions prevailing in South Finland. The above observations are based on studies made on only a few fields, and the effects of systematic errors as well as certain factors other than biological competition cannot be determined with sufficient reliability. The results, however, are promising and indicate that under conditions prevailing in South Finland possible *eradication of marsh horsetail through biological competition will require reasonable drainage, intensive fertilization, and above all the cultivation of annual crops and/or short-term leys in the rotation*.

V. Summary

Marsh horsetail (*Equisetum palustre* L.) constitutes a serious problem to Finnish dairy farming because of its toxicity to cattle. The species is common throughout the country, and it is especially prevalent on peat soils. According to studies carried out at the Animal Husbandry Department of the Agricultural Research Centre in the years 1949—56, as little as 2 g of air-dried marsh horsetail shoots in the daily fodder of a cow will cause a decrease in milk production (UOTILA 1956). In the case of normal feeding and normal hay yield the animal will receive approximately this amount of marsh horsetail shoots in its fodder if their number on the hay field is about 0.5—0.75 per m².

In the years 1956—62 investigations were carried out at the Plant Husbandry Department of the Agricultural Research Centre on the taxonomy,

reproduction and spread of marsh horsetail as well as on methods of control. The experimental fields were located in South Finland. The following results were obtained:

1. Most characteristics of the typical shoots of marsh horsetail growing in southern Finland agreed quite closely with those mentioned in the literature. Some minor differences were noticed in the maximum length and thickness of the stem, in the maximum length of the sheaths, and in the number of grooves. Some variation was also noted in the general habit of the shoots. These variations concerned characteristics such as partial or complete lack of branches, stunting of the stem, differences in length, position and form of the branches, development of strobili on the branches, and the general prostrate-bushy appearance of the shoot. Most of these variants resembled one or another of the taxonomic forms of marsh horsetail described in the literature (FERNALD 1949). The taxonomic nature of these variants, however, was not confirmed. On the contrary, in most instances the differences in the habit of the shoots were found to have been caused by environmental influences and also partly by the normal developmental rhythm of the shoots.

2. The rhizomes of marsh horsetail were found to grow to a maximum depth of 150 (175) cm. The maximum thickness of the main horizontal rhizomes and the maximum length of the internodes proved somewhat greater than those mentioned in the literature. Tubers were not found on the rhizomes in these investigations. On the other hand, sclerotized, starch-containing tissue was found in the nodes of rhizomes. Such tissue was most prevalent in plants grown on peat soil. It may function as a storage organ in much the same way as ordinary tubers, which, according to the literature, are typical of this species.

3. Spores of marsh horsetail were successfully germinated on an agar nutrient medium prepared from Moore's solution and supplemented with trace elements. The spores were isolated into pure single-spore cultures by suspending them in sterilized water and preparing a series of progressing dilutions. The features of the prothalli which developed on the nutrient medium agreed with the descriptions in the literature.

4. Prothalli of marsh horsetail were not found under natural conditions. On the basis of the studies carried out on agar medium, it does not seem probable that the species could normally propagate and spread by means of its spores under the conditions usually existing on cultivated lands in South Finland.

5. The principal means of propagation and spread of marsh horsetail was found to be the growth of its rhizomes. Such growth was more rapid in loose, permeable soil than in compact soil. An especially rapid growth of rhizomes was observed in the sand and gravel along the edges of railways and highways, as well as in the filling soil of new underground drains. Rhizomes were seldom able to penetrate into compact silty clay soil. A vigorous shoot growth was found to promote the growth of the rhizomes.

6. The rooting ability of rhizome fragments of marsh horsetail was found to be extremely weak. The fragments which were produced as a result of soil tillage were able to develop only weak sprouts, and usually died within a few weeks. The fragments could not survive when they were removed from their original sites and transplanted into a new area. From these investigations, it seems unlikely that marsh horsetail can normally propagate and spread from rhizome fragments on cultivated land in South Finland.

7. Contact with the ground water appeared to be essential for the successful growth of marsh horsetail, and thus this species favours wet land with a relatively high water table. When growing on permeable soil, the plant was not effectively controlled by drainage of the area. Drainage led to good control of this species in areas having a hard subsoil. However, this latter finding is of little practical significance because marsh horsetail rarely grows on such a soil.

8. Ordinary tillage methods were ineffective in destroying the rhizomes of marsh horsetail when, as is generally the case, they grew below the topsoil layer. The rhizomes proved to be very tough and resistant to pulling and bending. Tillage implements having a sharp cutting blade, such as the A-blade cultivator or the plough, cut the rhizomes easily when the soil was moderately compact and moist. Ploughing gave partial to complete control of rhizomes in the topsoil until new rhizomes grew into it from the subsoil. Thus this measure effectively delayed and weakened the subsequent growth of the shoots.

9. On trial plots 8—12.5 m in diameter, covered with black plastic, the rhizomes of marsh horsetail in the upper 60 cm of the soil died within 3—4 years. Rhizome branches growing below 60 cm remained alive during the entire 4-year trial period; these were found to have grown laterally throughout the covered trial plots from the surrounding area.

10. In agreement with reports in the literature, the shoots of marsh horsetail were found to be rather fragile, with the result that trampling by cattle on pasture considerably weakened the shoot growth of this plant.

11. The aerial shoots of marsh horsetail proved to be somewhat more resistant to MCPA than has been reported in the literature. A foliar spray at the rate of 2.5 kg/ha MCPA was required to kill the shoots. A single treatment had little effect on the rhizomes. When applied repeatedly over a period of several years, however, the treatment greatly reduced the regrowth of marsh horsetail. As a result, in five years the number of shoots declined to less than 0.5 per m² or 1—4 % of the initial amount. This small amount of shoots on a ley would not harm cattle. In spring cereal the effect of repeated MCPA treatment on the regrowth of marsh horsetail was better than in ley.

12. When single foliar applications of MCPA were made at higher rates of 7.5—27 kg/ha, the regrowth of marsh horsetail was greatly reduced, in certain cases to as little as 25 % of the untreated controls.

13. Amitrole as a foliar spray killed the shoots of marsh horsetail at a rate of 3.5 kg/ha. A single treatment delayed the regrowth of the plant. The suppressing effect on regrowth was greater when amitrole was used at rates from 5 to 15 kg/ha. In one instance, a single foliar application reduced the regrowth of marsh horsetail to 1 % of the original stand, and the suppressing effect continued from the time of treatment in 1959 until the end of the trial period in 1962. In most cases amitrole did not control the regrowth of marsh horsetail for so long a period, and its effect in general was about the same as that of MCPA applied at the same rate. Treatment with amitrole carried out for two successive years gave slightly better results than a single application.

14. Preliminary tests carried out with ammonium sulphamate (AMS) indicated that on a heavy clay soil a rate of 750 kg/ha was required to kill the rhizomes of marsh horsetail. This chemical was broadcast over the surface of the soil.

15. Heavy stands of crop plants, resulting from intense fertilization, reduced the number of shoots of marsh horsetail on well-drained land to less than 0.5 per m². This reduction took place over a period of 4—6 years. On wet, poorly drained land the effect of heavy fertilization was less, and the shoot numbers were lowered only to 0.7—1.1 per m². The most effective crop cover for smothering the growth of marsh horsetail in these trials was short-term, densely-growing red clover-timothy ley. Sparsely growing leys containing little or no clover appeared to promote the growth of marsh horsetail. The same was true for spring cereals. Biennial crops such as winter cereals and winter turnip rape, as well as fallowed fields, caused an increase in the stand of marsh horsetail. This was due, in part, to the fact that the ground was without any vegetation during a considerable part of the growing season.

16. The lack of competitive vegetation also allowed marsh horsetail to make good growth along the edges of railways and highways, and on the banks of open drainage ditches. The practice of open ditch drainage in the clearing of new land for cultivation resulted in a rapid increase in the amount of infestation of marsh horsetail. For this reason, underground drainage should be considered a basic requirement for the control of marsh horsetail.

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REFERENCES

- AGARDH, C. A. 1822. Observations sur la germination des Prêles. *Mém. du Mus. d'hist. nat.* 9: 283—292.
- BECKER, W. 1840. Probates Mittel zur gänzlichen Vertilgung des Duwocks (*Equisetum palustre* und *E. arvense*). Bremen. (Ref. C. A. Weber 1903.)
- BERGDOLT, E. 1936. Pteridophyta. Dr. Gustav Hegi's *Illustrierte Flora von Mittel-Europa*. Zweite neubearb. Aufl. 1: 4—100.

- BISCHOFF, G. W. 1928. Über die Entwicklung der Equiseteen, insbesondere des *Equisetum palustre*, aus den sporen. Nova acta Leopold. 14: 779—798.
- BLACKMAN, G. E. 1945. A comparison of certain plant growth substances with other selective herbicides. Nature 155: 500—501.
- BOER, T. A. de. 1947. Het gebruik van groeistoffen bij onkruidbestrijding in grasland. Maandl. landbouwworl. 12: 513—519.
- BOWER, F. O. 1959. Primitive land plants. 658 p. New York.
- BUCHTIEN, O. 1887. Entwicklungsgeschichte des Prothalliums von *Equisetum*. Bibl. Bot. 8: 1—49.
- BÜNGER, H. & GLET, P. 1934. Die Nutzbarmachung von duwockhaltigen Schnittfutter durch Heissvergärung in der Feime. Landw. Jbuch 79: 1001—1017.
- BURSCHEL, P. & FREED, V. H. 1959. The decomposition of herbicides in soils. Weeds 7: 157—161.
- CAJANDER, A. K. 1906. A. J. Melan Suomen kasvio. Suom. kirj. seur. toim. 53: 1—763.
- CANDOLLE, M. de 1815. Flore française 6: 1—662.
- CHRISTIANSEN, W. 1953. Neue kritische Flora von Schleswig-Hollstein. 532 p. Rendsburg.
- CHOTEJEW, W. S. & TSCHEWGUS, F. K. 1960. Slutschaj massowogo otrawlenija loschadej bolotnym chwoschtschom. Veterinaria 1960, 8: 68.
- CLAPHAM, A. R. 1932. The form of the observational unit i quantitative ecology. J. Ecol. 20: 192—197.
- COOPER, G. S. 1955. A progress report. Proc. Nat. Weed Comm. E. Sect. 9: 131—134.
- CRAFTS, A. S. 1959. Further studies on comparative mobility of labeled herbicides. Pl. Phys. 34: 613—620.
- DIETSCH, W. & EUGSTER, C. H. 1960. Zur Structur des Palustrins. Chimia 14: 353—355.
- DUVAL-JOUVE, J. 1864. Histoire naturelle des *Equisetum* de France. 296 p. Paris.
- EUGSTER, C. H. & GRIOT, R. & KARRER, P. 1953. Weiteres über Sumpfschachtelhalmbasen. Helv. chim. acta 36: 1387—1400.
- FERNALD, M. L. 1947. *Equisetum palustre*, example of careless bibliography and phytography. Rhodora 49: 278—286.
- »— 1950. Gray's manual of botany. 1632 p. New York.
- FISCHBACH 1927. Der Sumpfschachtelhalm (Duwock) und seine Bekämpfung. Dtsch. landw. Presse 54: 261.
- FURTICK, W. R. 1960. Verbal communication, Ore. Sta. Coll., March 17.
- GALENSA, F. 1959. Zur Frage der Duwockbekämpfung. Praxis u. Forsh. 11: 203—206.
- GLEASEN, H. A. 1952. Illustrated flora of the north-eastern United States and adjacent Canada 1: 1—482.
- GLET. 1930. Untersuchungen über die Futterschädlichkeit und Bekämpfung des Sumpfschachtelhalms (*Equisetum palustre*). Züchtungskunde 5: 482—490.
- GRANSTRÖM, B. 1954. Chemical control of *Cirsium arvense* Scop. Ann. Roy. Agric. Coll. Sweden 21: 281—285.
- »— 1961. Ogräsbekämpning i fröodlingar. Stat. jordbr.förs. Särtr. o. småskr. 138: 1—18.
- GRIER, N. M. 1920. Light correlated variations of the sterile stem of *Equisetum sylvaticum*. Rhodora 22: 165—167.
- GÜNTHER, E. 1932. Über die Bekämpfung des Duwocks und die Unterschädlichmachung des Duwockgiftes (Equisetin). Fortschr. Landw. 7: 9—11.
- HEMPSTEAD, C. 1953. Notes on the development of the gametophyte of *Equisetum arvense* in sterile media. Bot. Gaz. 114: 323—328.
- HIITONEN, I. 1933. Suomen kasvio. 771 p. Helsinki.
- HOFFMANN, H. 1870. Über Kalk- und Salzpflanzen. Die Landw. Versuchstationen 8. (Ref. C. A. Weber 1903.)
- HOLLY, K. 1953. The effect of synthetic growth regulator herbicides on *Equisetum palustre*. Proc. Brit. Weed Control Conf. 1: 227—233.

- HOLZ, W. 1957 a. Der Alkaloidgehalt des Duwocks (*Equisetum palustre* L.) nach Wuchsstoffbehandlung und die sich daraus ergebenden Möglichkeiten zu seiner Bekämpfung. Mitt. Biol. Bundesanst. Berlin-Dahlem 87: 51—58.
- »— 1957 b. Abnahme des Alkaloidgehaltes im Duwock (*Equisetum palustre* L.) nach Wuchsstoffbehandlung. Verh. IV. intern. Pfl.schutz-Kongr. Hamburg. 1957, 1: 515—518.
- »— 1959. Versuche zur mechanischen Bekämpfung des Duwocks. Paper read at 3rd German Weed Conf. 1959, 3 p. (Ref. Weed Abstr. 8: 1729.)
- »— & RICHTER, W. 1954. Versuche mit Wuchsstoffherbiziden zur Bekämpfung des Duwocks (*Equisetum palustre* L.). Landw. Forsch. 7: 56—58.
- »— & —. 1959. Über Alkaloidgehalt im Duwock (*Equisetum palustre* L.) nach MCPB-Behandlung. Nachbl. dtsh. Pfl.schutzdienstes 11: 115—117.
- »— & —. 1960. Über den Alkaloidgehalt im Duwock (*Equisetum palustre* L.). Angew. Bot. 34: 28—32.
- HOYT, P. B. 1956. Effect of various herbicides on field horsetail, hemp nettle, wild oats and alfalfa. Res. Rep. NthCentr. Weed Contr. Conf. 13: 29.
- HOYT, P. B. & CARDER, A. C. 1962. Chemical control of field horsetail. Weeds 10: 111—115.
- HULTÉN, 1962. The circumpolar plants I. K. sv. vet.akad. handl. IV 8, 5: 1—275.
- HURLEY-PY, G. 1949. La culture des prothalles d'*Equisetum*. C. R. Soc. Biol. 143: 1501—1502.
- HUSEMANN, C. & BRACKER, H. H. 1960. Der (giftige) Sumpfschachtelhalm *Equisetum palustre*, ein Standorts- und Bewirtschaftungsproblem. Kulturtechnik 1: 129—143.
- HYLANDER, N. 1953. Nordisk kärlväxtflora 1: 1—392.
- JACKMANN, G. R. & TINKER, M. A. H. 1949. The use of a selective weed killer in nursery gardens, the control of horsetail (*Equisetum palustre* L.). J. Roy. Hort. Soc. 74: 351—355.
- JALAS, J. & JUUSELA, T. 1959. Unkrautstudien und Bodenuntersuchungen auf den Grundwasserstauparzellen des wasserwirtschaftlichen Versuchsfeldes Maasoja in Vihti, Südfinnland. Ann. Bot. Soc. 'Vanamo' 30, 5: 1—61.
- KERN, H. 1957. Die Gifte von *Equisetum palustre* L. Mitt. Biol. Bundesanst. Berlin-Dahlem 87: 44—51.
- KLINGE, J. 1882. Flora von Est-, Liv- und Kurland 1, 2: 1—664.
- KORSMO, E. 1954. Anatomy of weeds. 413 p. Oslo.
- KORTLANG, H. 1961. Deutsches Bundespatent Nr. 1 106 107.
- KRIES, A. von 1962. Der Sumpfschachtelhalm (*Equisetum palustre* L.). Diss. Techn. Univ. Berlin 148: 1—133.
- KURSKIJ, P. I. 1941. O vegetativnom rasmnoshenii chvoschtschej w polewych uslowijach. Sovj. Bot. 3: 86—96.
- LID, J. 1952. Norsk flora (2. utg.). 771 p. Oslo.
- LOHMANN, C. E. J. 1904. Über die Giftigkeit der deutschen Schachtelhalmarten, insbesondere des Duwocks (*Equisetum palustre*). Arb. Dtsch. Landw.ges. 100: 1—69.
- LUDVIGS, K. 1911. Untersuchungen zur Biologie der Equiseten. Flora 103: 385—440.
- LUERSEN, C. 1889. Equisetinae. Rab. Kryptog.-Flora 2, 3: 622—781.
- »— 1894. Über *Equisetum silvaticum* L. forma *polystachya* Milde. Bibl. Bot. 28: 1—16.
- MAKSIMJUK, O. E. 1953. Chronitschewskow otrawlenie loschadej chvoschtschem. Veterinarija 1953, 8: 55.
- MARIE-VIKTORIN, F. 1927. Les Equisétinées du Québec. Contr. Lab. Bot. Univ. Montréal 9: 1—134.
- MEYER, G. F. W. 1932. Anleitung zur Unterdrückung und Verminderung des Duwocks. 22 p. Hannover. (Ref. C. A. Weber 1903.)
- MEYN, L. 1854. Die nachhaltige Vertilgung des Duwocks. 10 p. Weimar. (Ref. C. A. Weber 1903.)

- MILDE, J. 1867. Monographia *Equisetorum*. Verh. K. Leop.-Karol. dtsch. Akad. Naturforscher 32, 2: 1—605.
- MOSEBACH, G. 1943. Über die Polarisierung der Equisetumspore durch das Licht. *Planta* 33: 340—387.
- MUKULA, J. 1963. Suokorte ja sen torjuntamahdollisuudet. (Summary: Marsh horsetail (*Equisetum palustre* L.) and its control.) *Maatal. ja koetoim.* 17: 201—217.
- »— & LALLUKKA, R. 1962. Kevätviljamaiden rikkaruohot ja niiden esiintymisrunsaus. *Koetoim. ja käyt.* 19: 5, 8.
- »— & — & RAATIKAINEN, M. 1962. Kevätviljamaiden rikkaruohot ja niiden runsaus vuonna 1962 suoritettujen tutkimusten valossa. *Ibid.* 19: 37.
- NEURURER, H. & WICHTL, M. & CREUZBURG, U. 1959. Untersuchungen zur Frage einer chemischen Bekämpfung des Sumpfschachtelhalmes (*Equisetum palustre* L.) und deren Auswirkung auf die Fütterung. *Pfl.schutzber.* 22: 115—124.
- NOZEMAN, C. 1782. Verhandeling over het Heermoes. Verh. uitgeb. Maatschappij Bevordering Landbouw Amsterdam 2, 3. (Ref. C. A. Weber 1903.)
- ORTH, H. 1959. Weed control with chemicals in vegetable products in Germany. *Conf. Intern. Res. Group Weed Control, Stuttgart-Hohenheim, March 3—4, 1959.*
- PAATELA, J. 1953. Maamme heinäniurmien botaanisesta koostumuksesta. (Summary: On the botanical composition of the tame-hayfields in Finland.) *Acta agr. fenn.* 79, 3: 1—128.
- PETERSEN & HESSENLAND. 1893. Betrachtungen über die Natur und die Bekämpfung der Duwock. (*Equisetum*.) *Milchzeitung* 1893: 658—659, 671—672.
- PLANT, W. 1952. The control of horsetail in pastures with MCPA. *Agriculture* 59: 86—88.
- ROTMÄHLER, W. 1951. Pteridophyten-Studien I. *Rep. Spec. Nov. Reg. Veg.* 54: 55—88.
- RUMBERG, J. 1932. Entwicklungsbedingungen der Prothallien von *Equisetum silvaticum* L. und *Equisetum palustre* L. *Planta* 15: 1—42.
- SADEBECK, R. 1878. Die Entwicklung des Keimes der Schachtelhalm. *Jahrb. wiss. Bot.* 11: 574—602.
- SEMB, G. 1960. Myrsnelle, en giftig plante som kan vaere et besvaerlig ugras. *Tidskr. norske landbr.* 67: 335—347.
- SCHAFFNER, J. H. 1930. Geographic distribution of the species of *Equisetum* in relation to their phylogeny. *Amer. Fern J.* 20: 89—106.
- »— 1933. Miscellaneous notes on *Equisetum*. *Ibid.* 23: 18—20.
- SIEBOLD, M. 1958. Der Einfluss langjähriger statischer Düngung auf Pflanzenbestand, Ertrag und Futterwert von Dauerwiesen. *Bayer. landw. Jbuch* 35: 2—58.
- SONNEVELD, F. 1952. Overzicht van de oecologie en bestrijding van de Moeraspaardestaart. *Overdruck C. I. L. O.* 136. (Ref. A. von Kries 1962.)
- STÄHLIN, A. 1957. Ergebnisse der 2. deutschen Arbeitsprachung über Fragen der Unkrautbiologie und -bekämpfung. *Mitt. Biol. Bundesanst. Berlin-Dahlem* 87: 58.
- STAUDINGER, L. A. 1839. Gesammelte praktische Erfahrungen und Beobachtungen in dem Gebiete der Landwirtschaft, I. (Ref. C. A. Weber 1903.)
- TREITEL, O. 1943. The elasticity, breaking stress, and breaking strain of the horizontal rhizomes of species *Equisetum*. *Trans Kansas Acad. Sci.* 46: 122—132.
- T[UOMIKOSKI], R. 1958. *Equisetum palustre* L. — suokorte. *Suuri kasvikirja* 1: 41—42.
- UOTILA, I. 1956. Kortteiden ja erityisesti suokortteen (*Equisetum palustre* L.) vahingollisuudesta kotieläinten ruokinnassa sekä tämän lajin levinneisyydestä Suomessa. (English abstract: On the injuriousness of horsetail, and particularly of marsh horsetail (*Equisetum palustre* L.) in the feeding of domestic animals and on the distribution of this species in Finland.) *Acta agr. fenn.* 90: 1—155.
- »— 1957. *Equisetum palustren* esiintymisestä luonnontilaisilla soilla Keski- ja Pohjois-Suomessa. (Zusammenfassung: Über das Vorkommen von *Equisetum palustre* auf Mooren in Mittel- und Nord-Finnland.) *Maatal.tiet. aikak.* 29: 121—142.

- URSIC, S. J. & McCLURKIN, D. C. 1959. Small plots for measuring vegetation composition and cover. *Techniques and Methods of Measuring Understory Vegetation*, p. 70—78. (Publ. USDA For. Serv. S. and Stheast. For. Exp. Sta.)
- VALMARI, A. 1955. Suokortteen esiintymisestä suoviljelyksillä. *Koetoin. ja käyt.* 12: 15.
- VIDME, T. 1960. Verbal communication.
- »— 1961. Control of *Sonchus arvensis* (L.) with chemicals. *Weed Res.* 1: 275—288.
- VRIES, D. M. de & KKUIJNE, A. A. & MOOIE, H. 1957. Veevuldigheid van graslandplanten en hun aanwijzing van milieueigenschappen. *Jboek Inst. Biol. Scheik. Onderz. Landbouwg. Meded.* 27: 183—191.
- WATT, A. S. 1940—56. Contribution to the ecology of bracken (*Pteridium aquilinum*). I—VII. *N. Phytol.* 39: 401—422, 42: 103—126, 44: 156—178, 46: 97—121, 49: 308—327, 53: 117—130, 55: 369—381.
- WEBER, C. A. 1903. Der Duwock (*Equisetum palustre*). *Arb. Dtsch. Landw.ges.* 72: 1—68.

SELOSTUS

Suokortteen (*Equisetum palustre* L.) biologiasta ja torjunnasta

JAAKKO MUKULA

Maatalouden tutkimuskeskus, Kasvinviljelylaitos, Tikkurila

Karjalle myrkyllinen suokorte (*Equisetum palustre* L.) muodostaa Suomen karjataloudessa vaikean ongelman. Laji on yleinen kautta koko maan erityisesti suoviljelyksillä. Maatalouden tutkimuskeskuksen Kotieläinhoidon tutkimuslaitoksella vuosina 1949—56 suoritettujen ruokintakokeiden mukaan jo 2 g ilmakeuivia suokortteen versoja lehmän päivittäisessä rehussa aiheuttaa maidontuotoksen alentumista. Suunnilleen tällaisen määrän versoja eläin saa normaalin heinäsadon mukana tavanomaisessa ruokinnassa silloin, kun suokortteen versojen kasvutiheys on 0.5—0.75 kpl/m².

Maatalouden tutkimuskeskuksen Kasvinviljelylaitoksen toimesta suoritettiin eräillä Etelä-Suomen paikkakunnilla vuosina 1956—62 suokortteen taksonomiaa sekä lajin lisääntymistä, leviämistä ja torjuntaa koskevia tutkimuksia, jotka antoivat seuraavia tuloksia.

Suokortteen taksonomiaa

Kasvin tyyppillisten versojen tuntomerkit osoittautuivat suurimmaksi osaksi yhtäpitäviksi kirjallisuustietojen kanssa. Vähäisiä eroja todettiin varren maksimipituudessa ja -paksuudessa, lehtituppien maksimipituudessa sekä varren urteiden lukumäärässä. Tyyppillisten versojen lisäksi tavattiin sellaisia, jotka haarojen osittaisen tai täydellisen puuttumisen, haarojen tavallisesta poikkeavan pituuden, asennon tai muodon sekä haaroihin kehittyneiden itiöpesäkkeistöjen tai versojen pensasmaisen ulkonäön perusteella voitaisiin katsoa kuuluviksi kirjallisuudessa kuvattuihin suokortteen taksonomisiin muotoihin. Useimmissa tapauksissa versojen epätavallisen ulkonäön kuitenkin todettiin johtuneen ympäristötekijäin vaikutuksesta ja osittain liittyneen myös versojen luonnolliseen kehityksen rytmiiin.

Kasvin juurakoiden todettiin kasvaneen helposti läpäisevällä maalla 150 (175) cm:n syvyyteen. Juurakoiden vaakasuorien päähaarojen paksuus ja nivelylien pituus osoittautuivat jonkin verran suuremmiksi kuin mitä kirjallisuudessa on kuvattu. Mukuloita ei juurakoista tavattu. Sen sijaan juurakoiden nivelissä todettiin, etenkin turvemilla, sklerotioitunutta tarkkelyspitoista solukkoa, joka mahdollisesti pystyy jossain määrin toimimaan mukuloiden tapaan kestoelimenä.

Suokortteen lisääntyminen ja leviäminen

Kasvin itiöt saatiin itämään hivenaineilla täydennettyyn Mooren liuokseen valmistetulla agaralustalla. Itiöt eristettiin puhtaiksi 1-itiöviljelmiksi sekoittamalla ne steriloituun veteen suspensioksi, josta aseptisesti valmistettiin peräkkäisiä laimennussarjoja. Agaralustalla kehittyneiden alkeisvarsikkojen tuntomerkit vastasivat kirjallisuudessa kuvattuja.

Luonnossa suokortteen alkeisvarsikkoja ei tavattu. Suoritettujen tutkimusten perusteella näyttää siltä, ettei laji viljelysmailla pysty Etelä-Suomen olosuhteissa merkittävästi lisääntymään ja leviämään itiöistä.

Kasvin pääasiallisen lisääntymisen ja leviämisen todettiin tapahtuneen juurakoiden kasvamisen avulla. Pehmeässä maassa juurakoiden kasvu osoittautui nopeammaksi kuin kovassa maassa. Erityisen nopeata kasvu oli rautateiden ja maanteiden varsien hiekka- ja soramaassa sekä uusien salaojien täytemaassa. Tiiviiseen hiesusaveen juurakot eivät sanottavasti pystyneet tunkeutumaan. Maanpäällisten versojen voimakas kasvuintensiiteetti edisti juurakoiden kasvua.

Juurakonkappaleiden juurtumiskyky osoittautui erittäin heikoksi. Muokkauksen yhteydessä katkenneet juurakonkappaleet kehittivät vain heikkoja ituja ja kuolivat useimmiten muutaman viikon kuluessa. Lukuisat alkuperäiseltä kasvupaikaltaan irrotetuilla juurakonkappaleilla suoritettut istutuskokeet johtivat poikkeuksetta istukkaiden kuolemiseen. Tutkimusten perusteella näyttääkin siltä, ettei suokorte Etelä-Suomen olosuhteissa pysty merkittävästi lisääntymään eikä leviämään juurakonkappaleista.

Pohjaveden alentamisen vaikutus

Kosketus pohjaveteen on ilmeisesti suokortteen menestymisen perusedellytys, ja sen vuoksi laji suosii vesiperäisiä maita. Kun suokorte kasvoi helposti läpäisevällä maalla, sitä ei kuitenkaan saatu tuhotuksi parantamalla viljelysmaan kuivatusta. Sen sijaan kovapohjaisella maalla suokorte saatiin tuhotuksi tehostetulla kuivatuksella. Viimeksi mainitulla toteamuksella ei liene suurta käytännöllistä merkitystä, sillä kovapohjaisella maalla kasvavat suokorteesiintymät edustanevat kasvin menestymisen äärimmäisiä rajatapauksia ja lienevät sellaisina suhteellisen harvinaisia.

Mekaaninen torjunta

Kasvin juurakoita ei saatu tavanomaisin muokkausmenetelmin tuhotuksi silloin, kun juurakot kasvoivat ruokamultakerrosta syvemmälle, kuten tavallisesti on laita. Juurakot osoittautuivat hyvin sitkeiksi, venytystä ja taivutusta kestäviksi. Leikkaavin terin varustetut muokkausvälineet kuten ”hanhenjalkakultivaattori” ja aura kuitenkin katkoivat juurakoita helposti, edellyttäen että maa oli melko kiinteätä ja kosteata. Kynnön todettiin puhdistaneen ruokamultakerroksen osittain tai kokonaan suokortteen elinvoimaisista juurakoista siksi, kunnes uusia juurakoita ehti kasvaa pohjamaasta. Siitä johtui, että syksyllä tai keväällä kynnetyillä mailla kuten kevätiljoissa suokorte taimettui myöhemmin kuin nurmissa sekä syysrypsissä ja syysviljoissa.

Mustalla muovilla peitetyissä 8—12.5 m:n läpimittaisissa koeruuduissa suokortteen juurakot kuolivat 2—3 vuoden kuluessa ylimmistä maakerroksista noin 60 cm:n syvyyteen saakka. Sen sijaan syvemmällä kasvaneet juurakonhaarat säilyivät koko 4-vuotisen koekauden ajan elossa. Niiden todettiin kasvaneen muovilla peitettyjen koeruutujen sivuilta.

Suokortteen versot osoittautuivat, yhtäpitävästi kirjallisuustietojen kanssa, niin herkästi murtuviksi, että karjan polkeminen laitumella aiheutti kasvin versonnan huomattavaa heikentymistä.

Kemiallinen torjunta

MCPA:ta vastaan suokortteen versot osoittautuivat jonkin verran kestävämmiksi kuin peltokortteen versot; nurmi- ja viljakasvustoissa niiden tappamiseen tarvittiin MCPA:ta 2.5

kg/ha. Juurakkoihin tällaisella MCPA-annoksella ei kerran käytettynä ollut sanottavaa vaikutusta. Useana vuonna toistettuna käsittely kuitenkin heikensi suokortteen jälleenkasvua, niin että viiden vuoden kuluttua versojen määrä oli alle 0.5 kpl/m² (1—4 % alkuperäisestä) eli niin vähäinen, ettei versoista enää pellon ollessa nurmena olisi huomattavaa haittaa karjataloudelle. Kevätviljassa MCPA:n aiheuttama suokortteen jälleenkasvun heikentyminen oli nopeampaa kuin nurmessa.

Versojen tuhoamiseen tarvittavaa määrää huomattavasti suuremmat MCPA-annokset, 7.5—27 kg/ha, heikensivät voimakkaasti suokortteen jälleenkasvua jo kerran käytettynä, parhaissa tapauksissa 25 %:iin käsittelemättömästä.

Amitrolia tarvittiin suokortteen versojen tappamiseen 3.5 kg/ha. Tämä määrä heikensi myös juurakoiden jälleenkasvua jo kerran käytettynä. Vaikutus suokortteen jälleenkasvuun parani, kun amitrolia käytettiin versojen tappamiseen tarvittavaa suurempina, 5—15 kg/ha vastaavina annoksina. Parhaassa tapauksessa kerran suoritettu amitrolikäsitteily heikensi jälleenkasvun 1 %:iin alkuperäisestä ja vaikutus säilyi tällöin käsittelyvuodesta 1959 kokeauden loppuun 1962 saakka. Useimmissa tapauksissa amitrolin jälkivaikutus oli kuitenkin heikompi eikä sanottavasti ylittänyt vastaavansuuruisilla MCPA-annoksilla saatua tehoa. Kahdena vuonna toistettu amitrolikäsitteily antoi hiukan paremman tuloksen kuin kertakäsittely.

Ammoniumsulfattia tarvittiin suokortteen juurakoiden tappamiseen savi- maalla suoritettussa alustavassa kokeessa 750 kg/ha.

Biologinen torjunta

Viljelykasvien varjostus sekä viljelykasvien menestymistä parantavat toimenpiteet heikensivät suokortteen versomista. Voimakkaan lannoituksen aiheuttamasta viljelykasvien satotason kohoamisesta oli seurauksena, että suokortteen versojen määrä väheni hyvin kuivatulla, salaojitetulla maalla 4—6 vuoden kuluessa alle 0.5 kpl/m² eli niin vähäiseksi, ettei versoista ilmeisesti enää olisi ollut sanottavaa haittaa karjataloudelle. Huonosti salaojitetulla, liian määrällä maalla voimakas lannoitus ei johtanut yhtä hyvään tulokseen, vaan suokortteen versojen väheneminen pysähtyi 0.7—1.1 kpl/m² tasolle. Tehokkaimmaksi suokortteen tukehduttajaksi osoittautui Maatalouden tutkimuskeskuksen viljelyksillä reheväkasvuinen, lyhytikäinen apilaimiteinurmi. Sen sijaan harva, heikkokasvuinen nurmi näytti vaikuttaneen edistävästi suokortteen versontaan. Myös kevätiljoissa todettiin suokortteen versominen erittäin vähäiseksi silloin, kun viljan satotaso oli korkea, mutta voimakkaaksi silloin, kun viljan satotaso oli alhainen.

Näytti siltä, että syysrypsi ja kesanto vaikuttivat suokortteen versomista edistävästi mm. siitä syystä, että maa oli huomattavan osan kasvukautta paljaana, ilman varjostavia viljelykasveja. Kilpailevan kasvuston puuttuminen edisti suokortteen versontaa myös rauta- ja maan- teiden varsilla sekä avo-ojien luiskissa ja pientareilla. Luonnontilaisen maan viljelykseen ottamisen yhteydessä tapahtunut avo-ojitus aiheutti samasta syystä maan suokortteisuuden voimakasta lisääntymistä. Näyttääkin siltä, että salaojitus on katsottava Suomen olosuhteissa suokortteen torjunnan perusedellytykseksi.

