The Effect of Timing and Frequency of Soil Cultivation on Emergence and Depletion of the Soil Seed Bank of Volunteer Grass Seeds and Dicotyledonous Weeds

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ABSTRACT

The effects of timing and frequency of autmun soil cultivation on emergence of volunteer *Poa pratensis* L. and dicotyledonous weeds in the spring were investigated in three field experiments in 1994-1997. Early ploughing increased the emergence of *Poa pratensis* and dicotyledonous weeds in the autumn. In the following spring where the soil cultivation was similar in all plots, the emergence of *Poa pratensis* was reduced in plots where early ploughing was performed in the preceding autumn. This effect was seen in two out of three years. Another experiment investigated the effect of cultivation frequency on emergence and depletion of the soil seed bank of *Poa pratensis* and *Chenopodium album*. Increasing cultivation frequency had a strong positive influence on the emergence of *Chenopodium album* in all three years. There was a small and varying effect of cultivation frequency on emergence of *Poa pratensis*. This indicates that the germination of this species is probably independent of light exposure. The increased emergence of *Chenopodium album* with increased cultivation frequency depleted the soil seed bank of this species, whereas the different cultivations did not influence the seed bank of *Poa pratensis*.

Additional index words: *Poa pratensis*, soil seed bank, dormancy, germination, soil cultivation

INTRODUCTION

When grasses are grown for seed production, a proportion of the seeds will be shed before and during harvest. Some of these seeds remain viable until they are incorporated in the soil when it is cultivated before the next crop is established. Almost all cultivated grasses possess some degree of primary dormancy, and secondary dormancy can be induced if the seeds are exposed to certain environmental conditions (Simpson, 1990). This characteristic enables the grass seeds to survive for a period in the soil.

The longevity in soil of seeds of many different species has been examined, but the few studies on cultivated grasses show a limited longevity in the investigated species (Lewis, 1973; Roberts, 1986). Generally, the longevity of seeds is dependent on soil depth, with increasing longevity with increasing soil depth (Roberts and Feast, 1972). Seeds that are deeply incorporated by a ploughing and left undisturbed can form a persistent seed bank that can last for years (Lewis, 1973; Roberts and Feast, 1973; Chancellor, 1986).

If a new grass seed crop is established in a field containing a seed bank of another grass species or cultivar, there is a big risk of contamination of the new crop with plants from the previous crop. Such contamination is undesirable as it reduces the quality of the product or even makes it unmarketable. It can be very difficult to control one grass species in another but it is almost impossible to control another cultivar in a grass seed crop of the same species and alternative methods are therefore needed. Most of the grass species in question germinate both in spring and autumn, and cultural methods which deplete the upper soil layer for viable seeds therefore should reduce contamination of the new grass seed crop.

This paper presents results of a series of field experiments where the effect of different soil cultivation programmes in the autumn on the emergence of grass seed volunteers in the following spring was investigated. In Denmark the normal soil cultivation practice in autumn for a spring established crop undersown with grass for seed production consists of ploughing in late autumn (October-November). The soil temperature at this time of the year is normally close to 5^{0} C, a temperature where germination ceases and secondary dormancy is induced in many weed species. The objectives were 1: to determine whether earlier soil cultivations at temperatures more favourable for germination could provoke germination of a greater proportion of volunteer grasses (*Poa pratensis*) and broadleaf weeds from the upper soil layer and thereby deplete this layer before the new grass seed crop is undersown the following spring, and 2: to determine whether the frequency of cultivation influenced the emergence of the volunteer grass seeds.

MATERIALS AND METHODS

Two different field experiments were carried out at the Danish Institute of Agricultural Sciences in Flakkebjerg. In the first the effect of different cultivation strategies in the autumn on the emergence of volunteer grasses the following spring was investigated. The experiment was repeated in the same field

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in three consecutive years in the period from autumn 1994 to spring 1997. The soil was contaminated with seeds of *Poa pratensis* one year before the experimental treatments by sowing 30 kg ha^{-1} of *Poa pratensis* in the upper 3-5 cm, followed immediately by a ploughing where the contaminated soil layer was incorporated to a depth of 25 cm. The use of a plough equipped with a skimmer ensured that the majority of the grass seeds were placed in the bottom of the plough layer. Winter barley was then grown in the field according to normal agricultural practice. The winter barley was harvested the following summer, normally in the last part of July, and the straw was removed from the field. The experimental ploughings were made with a three ridged plough equipped with skimmer and immediately followed by a soil compacter. Ploughing depth was 25 cm which ensured that a proportion of the grass seeds which were buried the previous autumn would be placed in the upper soil layer from where they are able to germinate and establish new plants. The harrowings in April were followed by a rolling. The spring soil cultivation was uniform in all treatments and resembled normal practice for a spring established crop.

Table 1. Experimental treatments and approximate timing of different soil cultivations in the three experiments

No.	July	August	September	October	April
1.				Ploughing	2xHarrow
2.			Ploughing	2xHarrow	2xHarrow
3.		Ploughing	2xHarrow	2xHarrow	2xHarrow
4.		Ploughing	6xHarrow	6xHarrow	2xHarrow
5.			Plough+2xHarrow	2xHarrow	
6.		Ploughing	2xHarrow		2xHarrow
7.	Ploughing	2xHarrow	2xHarrow		2xHarrow
8.	Ploughing	6xHarrow	2xHarrow		2xHarrow
9.		Plough+2xHarrow			2xHarrow
10.	Ploughing	2xHarrow			2xHarrow

The second experiment was set up to investigate the effect of cultivation frequency on emergence of *Poa pratensis* and how this depleted the soil seed bank. This involved three trials in the same field from 1996-1998. In the autumn before the experimental treatments, the field was ploughed and the soil was contaminated with seeds of *Poa pratensis* (30 kg ha^{-1}) and *Chenopodium album* (10 kg ha^{-1}) mixed into the upper 4-5 cm. This was done in order to obtain an homogeneous seed bank. Sowing was carried out when the soil temperature was below 5^0 C in order to avoid germination in the autumn.

Experimental harrowings in both experiments were carried out with a traditional seedbed harrow (with a distance between the tines of 10 cm), equipped with a rotavating crumbler. The harrowing depth used was 3-4 cm. The harrow was mounted on a tractor with a wheel width of 2.5 m which enabled the tractor to straddle the plots of 2.5 x 10 m. Driving speed was 6 km h^{-1} (1.7 m s^{-1}). Harrowings in the spring were followed by a rolling. In order to separate the effects of the different soil cultivations, emerged grasses and dicotyledous weeds were normally controlled with a glyphosate treatment (Roundup^R, Monsanto-Searle) one to two days before the experimental harrowings.

Counts of emerged seedlings of grasses and dicotyledonous weeds were completed within 4 x 0.25 m^2 quadrats per replicate. In treatments which included cultivation at more than one time in the autumn, the emergence of volunteer grasses and dicotyledonous weeds was counted just prior to the second and third cultivation. A randomised complete block design with six replicates per treatment was used in all years.

Statistical analysis in the first experiment was by LSD ($P=0.05$). Data from the second set of experiments examining the effect of cultivation intensity were fitted to an exponential function:

$$ES = X - Y * EXP(- Z * \text{No of harrowings}) \qquad (1)$$

in which ES is number of emerged seedlings, X is the asymptotic maximum seedling number at infinite number of harrowings, (X – Y) is the intercept or the number of seedlings emerged at zero harrowings (undisturbed soil), and Z determines the slope of the curve. Data were also fitted to a simple linear regression function

$$F = \frac{(RSS2 - RSS1) / (DF2 - DF1)}{RSS1 / DF1} \qquad (2)$$

An F-test was used to determine whether the model fit was improved significantly by using the non-linear model. RSS and DF are residual sum of squares and degrees of freedom and (1) and (2) refer to the above mentioned models.

RESULTS

Effects of autumn cultivation on autumn emergence

The total number of emerged plants of *Poa pratensis* and dicotyledonous weeds present in the autumn just before the October ploughing declined as autumn progessed and also

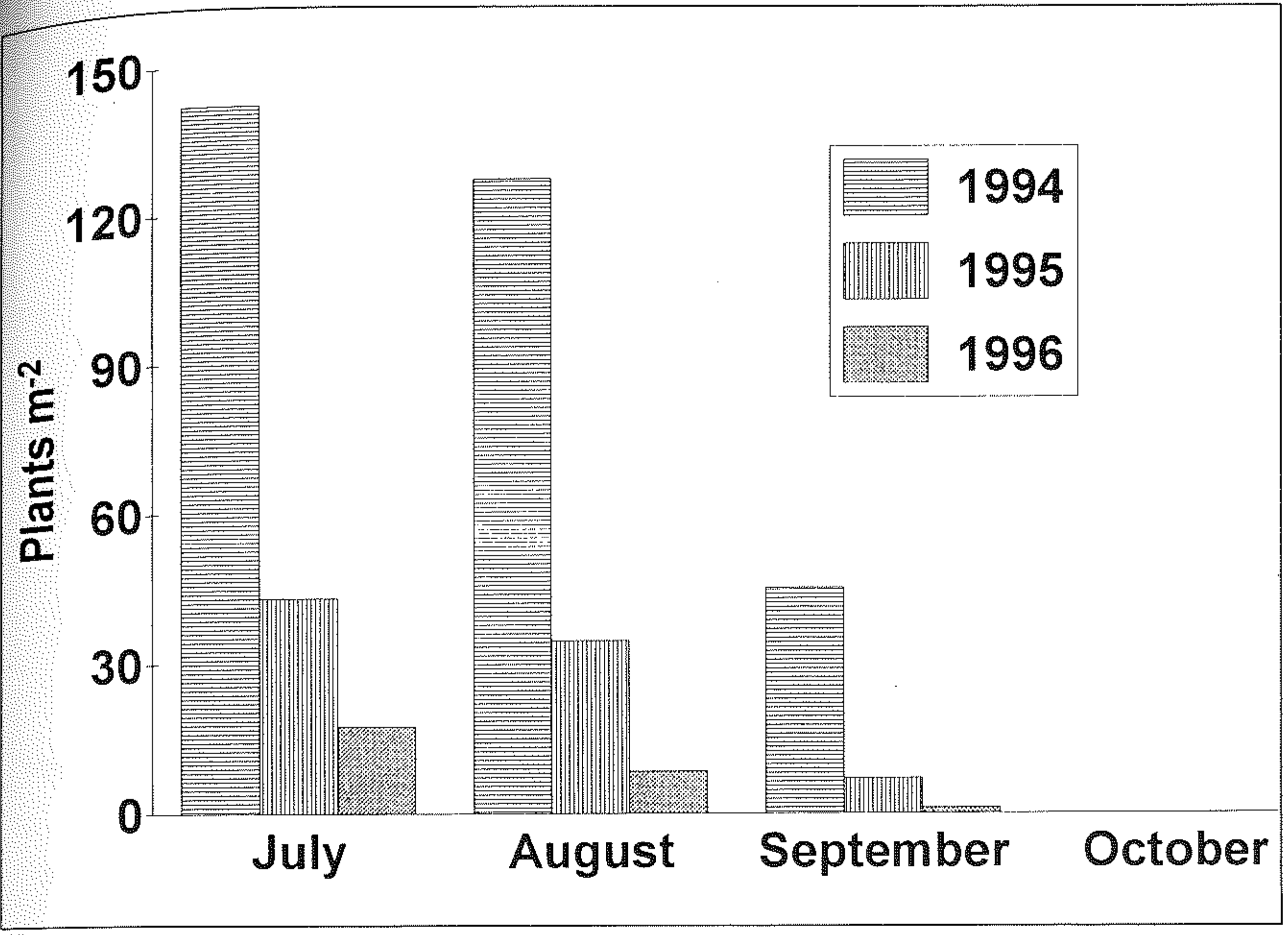

Figure 1. Effect of ploughing time and year on the number of *Poa pratensis* and dicotyledonous weed plants present just before the October ploughing. (Data are pooled for treatments with the same ploughing time: this also applies for Figs. 2 and 3).

Table 2. Parameter estimates with asymptotic standard error in parenthesis and intercept values (1) for the predicted relationship between harrowing frequency in daylight and emergence of *Chenopodium album* plants. I/X denotes the number of plants at zero harrowings as a percentage of the asymptotic maximum at infinite number of harrowings.

Exp (year)	X	Y	Z	I	I/X
1996	501.3 (17.6)	343.5 (37.5)	0.71 (0.18)	157.8	31.5
1997	369.1 (13.5)	294.1 (29.7)	0.79 (0.19)	75.0	20.3
1998	235.0 (9.2)	129.0 (16.4)	0.47 (0.15)	106.0	45.1

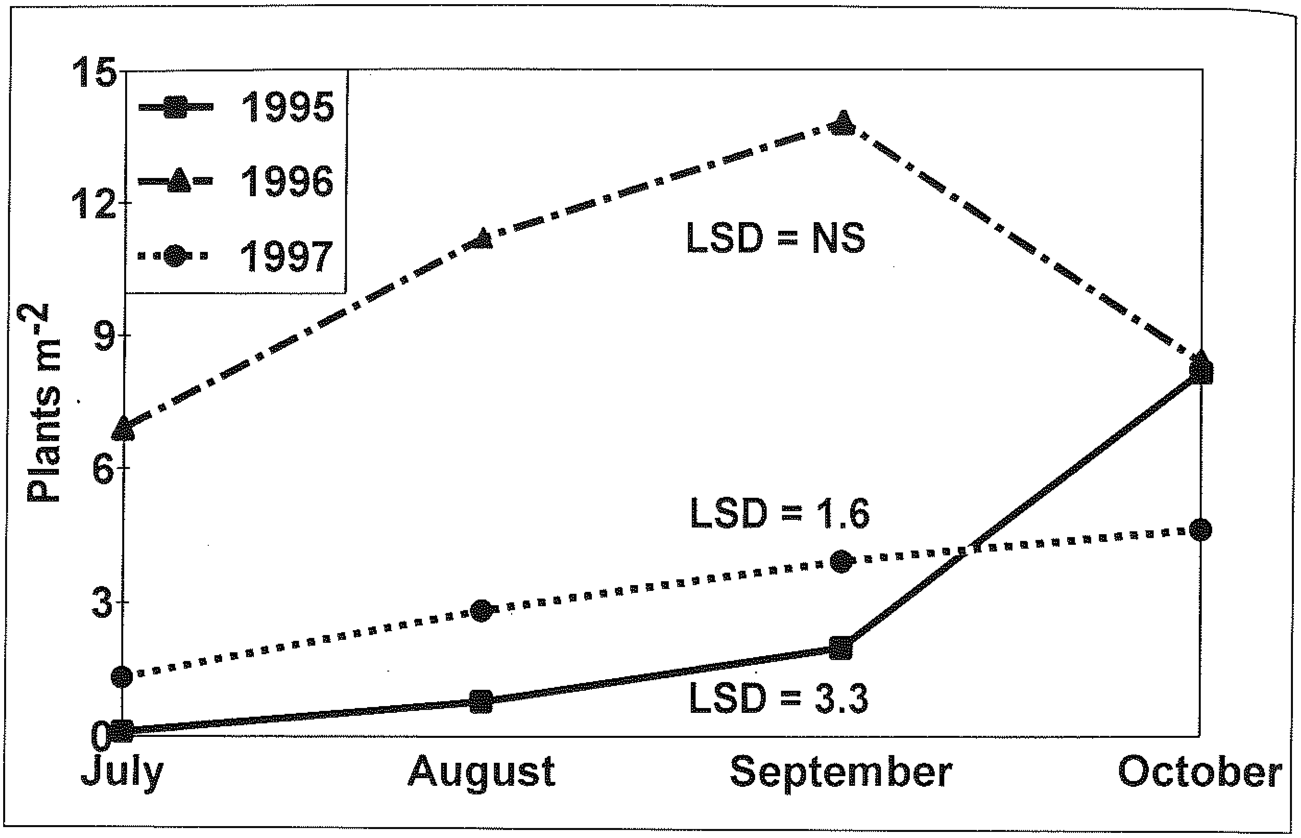

Figure 2. The effect of autumn ploughing time and year on the production of *Poa pratensis* in the following spring.

with year of cultivation. The additional harrowings did not significantly affect the emergence of *Poa pratensis* or dicotyledonous weeds either in the autumn or in the following spring.

There was no effect of cultivation frequency in the treatments where two and six harrowings were compared, for either the number of *Poa pratensis* nor in the number of dicotyledonous weeds. The early ploughing resulted in the largest emergence of *Poa pratensis* and dicotyledonous weeds in the autumn and this number declined the later the ploughing was carried out (Fig. 1). The three years differed considerably in their climatic conditions. In 1994 and 1996 there was a 'normal' autumn rainfall and relative humidity. The autumn 1995 on the other hand deviated from the normal with a very dry and hot autumn until the end of November when the winter suddenly started. The conditions for germination in the autumn this year were rather poor, and this may have affected the number of plants which emerged (Fig. 1).

Effects of autumn cultivation on emergence in the following spring

Ploughing early in the autumn significantly reduced volunteer *Poa pratensis* plant numbers in the following spring in 1995 and 1997 but not 1996 (Fig. 2). In 1995 and 1997 spring emergence was reduced by 73% and 99% in the early ploughed treatment compared to the emergence in the late ploughed treatment. The same tendency was seen for the number of emerged dicotyledonous weeds in these two years (Fig. 3). In the 1995–1996 trial there was no effect of ploughing time on emergence of grass and dicotyledonous weeds in the spring. Although there were some differences in emergence in the autumn it is probable that the germination was low that autumn because the conditions for germination were very unfavourable, with a very dry autumn and an early winter.

Effects of cultivation frequency on emergence and depletion of seed bank

The *Poa pratensis* and *Chenopodium album* populations four to five weeks after the first spring cultivation as a function of increasing cultivation intensity are shown in Fig. 4. For *Chenopodium album*, the figure includes both observed values and the predicted non-linear model, which significantly improved the model fit compared to a linear model. The model parameters are shown in Table 2. For *Poa pratensis* results differed over the three years; there was generally only a small effect of cultivation frequency on plant population and the data were in all three years described satisfactorily by a linear model.

When the emerged plants had been counted the entire experimental area was sprayed with glyphosate and one day later harrowed three times followed by a rolling. Emergence three weeks after this second cultivation was then recorded (Fig. 5). In all years a decreasing number of *Chenopodium album* plants emerged from plots which had been intensively cultivated. This reflects the fact that different cultivation frequencies caused different degrees of depletion of the soil seed bank. The emergence of *Poa pratensis* after the second cultivation constituted only a small percentage of the emergence after the initial cultivation. The same was seen with *Chenopodium album* in two of the three years.

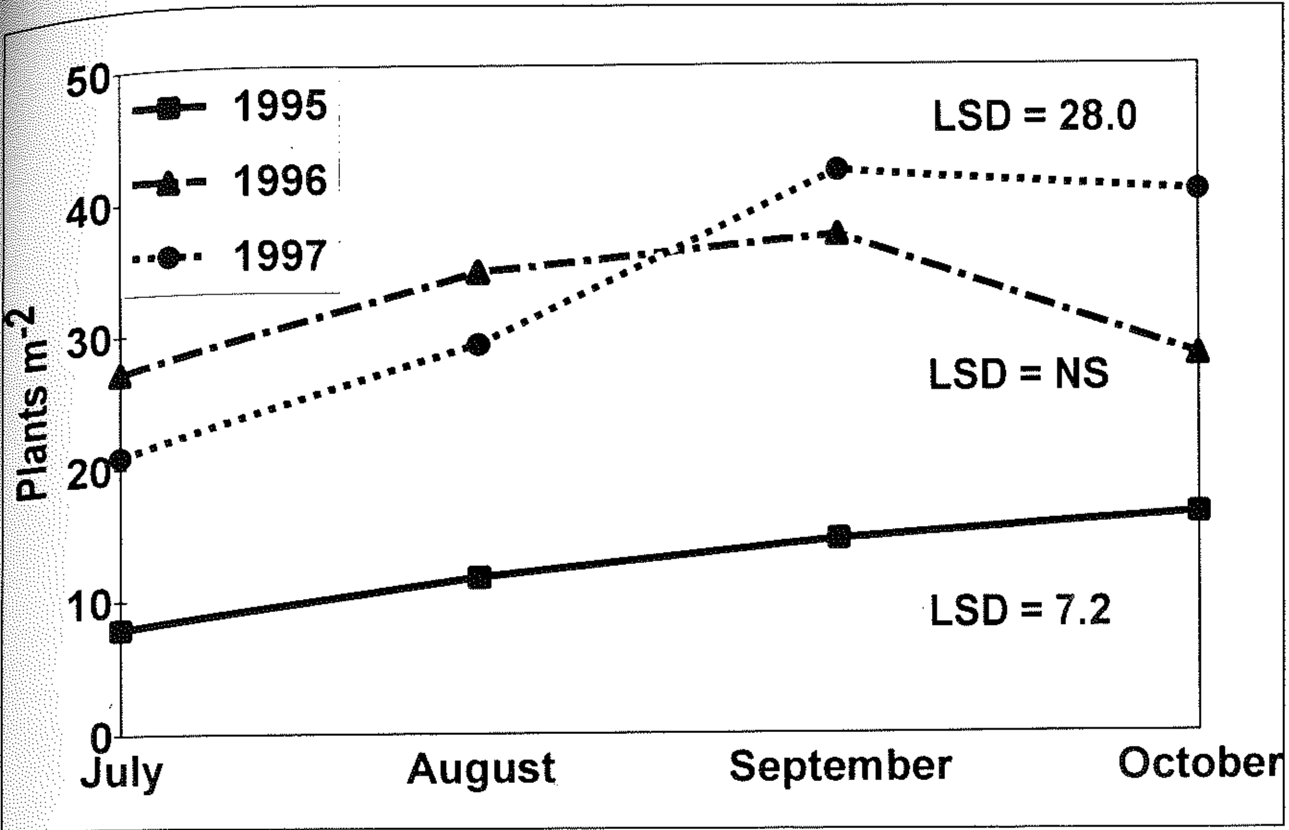

Figure 3. The effect of autumn ploughing time and year on the population of dicotylendenous weeds in the following spring.

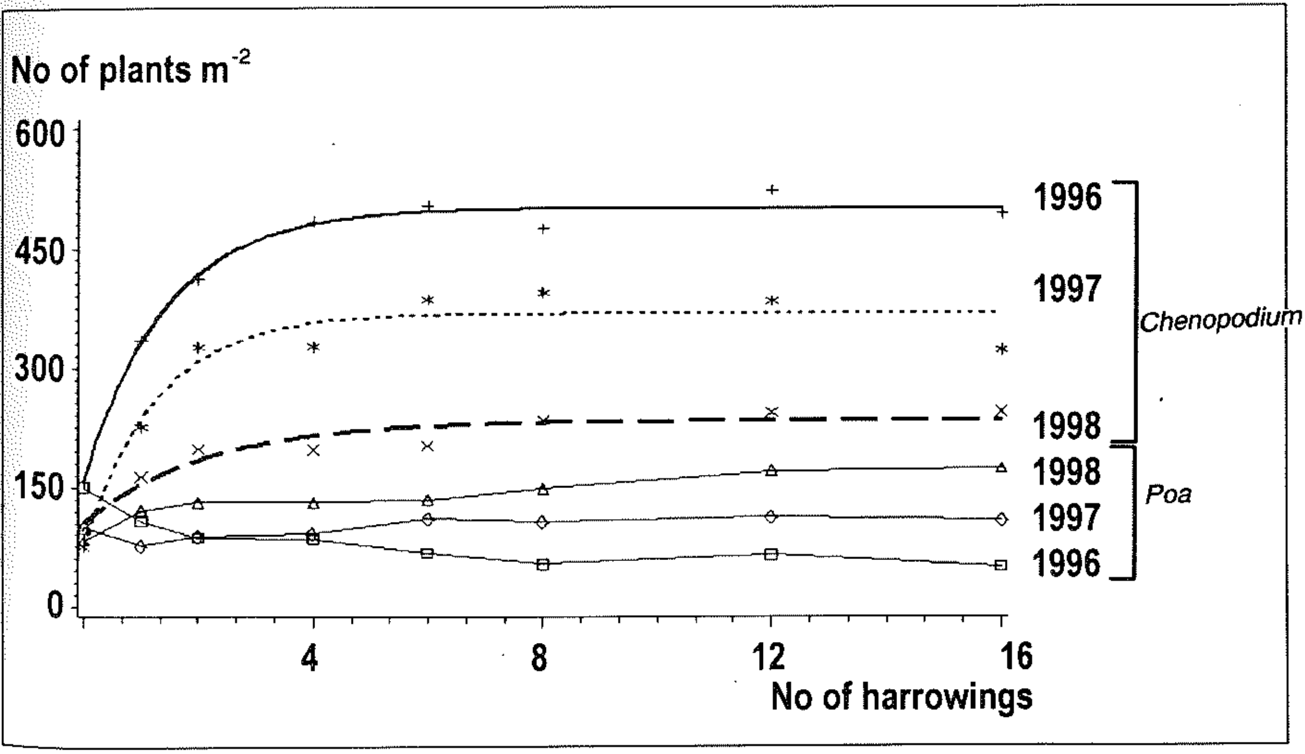

Figure 4. Plant population of *Poa pratensis* and *Chenopodium album* as a function of increasing cultivation frequency. For *Chenopodium album* predicted and observed values (+, * and x) are shown. The observed values for *Poa pratensis* (□, ◊, Δ) are shown with joined lines.

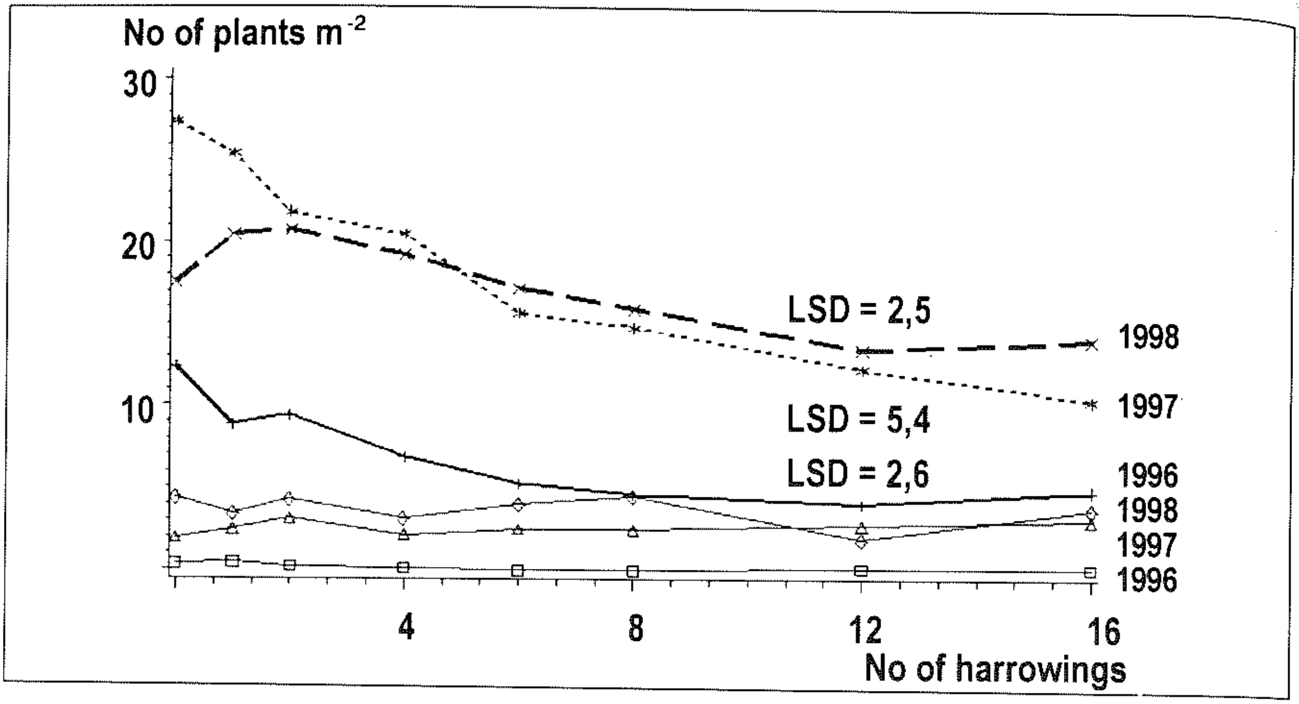

Figure 5. Population of *Poa pratensis* (□, ◊, Δ) and *Chenopodium album* (+, * and x) on an area which was cultivated with increasing frequency. When emergence after these harrowings had stopped, the total area was treated with Roundup and harrowed 3 times followed by rolling. The emergence of weeds was counted three weeks after this treatment.

DISCUSSION

Ploughing is the normal method of cultivation in a traditional cropping system in Denmark. For a spring established crop the ploughing will normally be carried out late in the autumn when the soil temperature is too low to provide conditions for germination of most seeds. This means that remaining seeds from a previous grass seed crop which are brought to the surface by the ploughing will be dormant until the next spring. When the temperature again rises in the spring the next crop has normally been established before the germination of these volunteers. If this crop is undersown with grass for seed production then it will be contaminated with plants from the previous crop, and an unacceptable content of another grass species or cultivar could result.

The preparation of a false (stale) seedbed can be defined as a seedbed prepared several days, weeks, or months prior to sowing or planting a crop. The time interval between the preparation of the false seedbed and drilling/planting should be long enough to allow germination of weed seeds which can be destroyed predrilling/preplanting with flaming, soil cultivation or chemically. The technique has been known for decades and is often recommended in organic farming (Wookey, 1985; Parish, 1987; Ascard, 1990; Stopes and Millington, 1991). The scientific basis for this recommendation is however very limited. Only a few investigations document the effect of a stale seedbed as a tool to reduce the problems with different weeds (Johnson and Mullinix, 1995; Jensen, 1996). In the previous investigations the effect of a false seedbed was seen when the time interval between the false seedbed and the real seedbed was a few weeks. However the new grass seed crop is normally undersown in a spring established crop, such as spring barley, which is sown as early as possible in the spring in order to maintain a high yield. The false seedbed must therefore be prepared in the preceding autumn and the results may deviate from previous investigations as the longer time span more likely will influence the dormancy status of seeds which are dormant in the autumn when the seedbed is prepared. Strict summer annual species do not germinate as a response to soil cultivations in the autumn but most cultivated grasses and among them *Poa pratensis* germinate equally well in autumn and spring.

The effects of a false seedbed can be attributed to the effect of soil cultivation on germination of seeds in the cultivated soil layer. Soil cultivation has in a number of investigations reduced the seed bank of different weed species in the cultivated soil layers, compared to the seed bank in uncultivated soil (Roberts and Dawkins, 1967; Roberts and Potter, 1980; Moss, 1987; Popay, Cox, Ingle and Kerr, 1994). Soil cultivation increases the germination and emergence of weeds and thereby depletes the soil seedbank in the upper soil layer. The investigations mentioned did not include cultivated grasses but this aspect was investigated in the work described in this paper. Though the existing knowledge on longevity of seeds of cultivated grasses in soil is very limited, the results indicate a short longevity in soil compared to many dicotyledonous weed species. Soil cultivation was very effective in reducing the seedbank of species with a short longevity in soil such as *Alopecurus myosuroides* (Froud-Williams, Chancellor and Drennan, 1984). A short longevity is often connected with a less pronounced dormancy or a higher germination under favourable conditions. For this reason one would expect that it should be possible to obtain a reduction in the soil seed bank of volunteer grasses, at least to the same extent as seen with dicotyledonous species after soil cultivations in some of the above investigations.

The decline in the seedbank when the soil is cultivated cannot be attributed to one special factor, as cultivation changes a number of factors which influence dormancy and germination. In recent years however a number of researchers starting with Hartmann and Nezadal (1990) and then followed by others (e.g. Kühbauch, Gerhards and Klümper (1992), Ascard (1994), Scopel, Ballare and Sanchez (1994)) have shown that light during the cultivation process plays a major role in the increased germination in cultivated soil for a number of species. This effect of light was emphasized by the investigation of Jensen (1995) where a close correlation between number of cultivations in daylight and emergence of *Chenopodium album* was found; i.e. an increasing number of seeds will be exposed to light with increasing cultivation intensity of the soil in daylight. In another investigation (Toole and Borthwick, 1971) light was shown to be an important trigger for germination of newly harvested *Poa pratensis* seeds under laboratory conditions. Because of these observations cultivation frequency was included in this investigation. In both experiments there was either no or just a small effect of cultivation frequency on emergence of *Poa pratensis*. From these observations it seems that the germination of *Poa pratensis* seeds occurred independent of light exposure when the seeds were placed near the soil surface by the ploughing. The reason for this was not investigated, but it is known from other investigations that seeds which under some circumstances are strongly light-dependent in their germination response, under some other environmental conditions can have their requirement for light exposure modified (Scopel *et al*, 1991; Derkx and Karssen, 1993) or even can have their need for light substituted by other environmental factors (Baskin and Baskin, 1990; Bouwmeester, 1990; Hilhorst, 1990). A limited requirement for environmental triggers would be a natural germination characteristic for species which have seeds with a short longevity in soil.

In the experiments investigating the effect of a false seedbed in the autumn, the conditions for germination concerning soil moisture and temperature were favourable after the early ploughings in the autumn in 1994 and in 1996. In 1995 on the other hand, there was an extreme drought in the early autumn with a very low soil moisture which was then followed by lower than normal temperatures in the late autumn. Despite the very unfavourable conditions for germination in 1995 there was the same trend in emergence of grass plants in all three years (Fig. 1), where the highest emergence was seen in the early ploughed plots. This effect of soil cultivation in the autumn was reflected in the emergence in the spring in two out of the three years. Although the soil cultivation in the spring was similar in all plots, there was a decreasing emergence of grasses and dicotyledonous plants in plots which had been ploughed early in the autumn (Fig. 2 and 3), except in 1996. Despite the fact that the emergence in the autumn of 1995 followed the same trend as the other years, an overall low emergence in that autumn due to the unfavourable conditions for germination could be the reason for the missing effect of autumn ploughing time in the following spring.

As the climatic conditions in the autumn of 1995 were atypical, it can be concluded that an early ploughing can provoke germination of volunteer grasses of *Poa pratensis* in the autumn and thereby reduce the emergence of *Poa pratensis* plants the following spring. Additional cultivations are of minor importance concerning this species.

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