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Soil & Tillage Research 63 (2001) 75–83

Soil &
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# Evaluation of the establishment of lowland and upland switchgrass (*Panicum virgatum* L.) varieties under different tillage and seedbed conditions in northern Italy

A. Monti[a,*], P. Venturi[b], H.W. Elbersen[c]

[a]*Faculty of Agriculture, Department of Agroenvironmental Science and Technology, University of Bologna,*
*Via Filippo Re 6/8, 40126 Bologna, Italy*
[b]*Faculty of Agriculture, Department of Economics and Agricultural Engineering, University of Bologna,*
*Via Filippo Re 4, 40126 Bologna, Italy*
[c]*ATO-DLO, P.O. Box 17, 6700 AA Wageningen, The Netherlands*

Received 28 March 2000; received in revised form 30 July 2001; accepted 6 August 2001

## Abstract

Information is needed on potential biomass crops for marginal lands in southern Europe. The objective of this study was to investigate switchgrass establishment in four seedbed preparation treatments (sowing, rolling before sowing, rolling before and after sowing and no till) for two varieties (small and large seed types). A $4 \times 2$ split-plot factorial design with four blocks was adopted over a 2 years period. Trials were conducted in Bologna (latitude 44°33′N, longitude 11°21′E, 32 m a.s.l.), in a silt loam soil (Udic Ustochreps fine silty, mixed, mesic). In general, emergence was lower in the autumn trials than in the spring one. Emergence on rolled soil (single and double) was statistically higher than tilled unrolled soil. Cumulative analysis of the two autumn trials including no till showed a significant ($P \leq 0.05$) interaction between treatment and varieties: the large seed variety had a better performance only with no till, particularly in the first year. Overall, if no till was not considered, no significant interactions between variety and tillage treatments were found for final seedling numbers. The statistical analysis on both varieties was therefore combined. Although the double rolled tillage treatment consistently showed a slightly higher average seedling emergence than the single rolled treatment, the final number of emerged seedlings was never significantly different. In all cases, the rolled treatments (single and double) had significantly higher final emergence rates than the treatment with no soil compaction. The average emergence index of unrolled plots was 20% lower than rolled plots. A function was calculated to predict the seedling numbers at the end of emergence based on the seedling numbers at the beginning of emergence. Generally rolling was needed to obtain best switchgrass performances. In northern Italy both varieties had a good emergence when soil conditions were appropriated. © 2001 Elsevier Science B.V. All rights reserved.

*Keywords:* Switchgrass; *Panicum virgatum*; Seedbed preparation; Seedling establishment; Northern Italy

## 1. Introduction

Switchgrass (*Panicum virgatum* L.) is a warm season perennial $C_4$ grass, native to North America where it is a typical species of the tall grass prairie. It occurs mainly west of the Rocky Mountains, from Canada to

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[*] Corresponding author. Tel.: +39-51-249745;
fax: +39-51-2091545.
*E-mail address*: amonti@dns.agrsci.unibo.it (A. Monti).

PII: S0167-1987(01)00238-0

deep into Mexico. The crop is commonly used for feeding livestock and soil conservation. Currently it has being developed as a biomass crop for energy and fibre uses. Applications include electricity and ethanol production (Sanderson et al., 1996; Samson and Omielan, 1992; Turnhollow, 1991) and production of paper pulp and fiber reinforced composite materials (Elbersen et al., 1999; Radiotis et al., 1999; Girouard and Samson, 1998).

Switchgrass tolerates a wide range of climate and soil conditions. It is cold tolerant and can produce good yields (8–20 t DM $\text{ha}^{-1}$) with very low inputs (Christian and Elbersen, 1998) when in full production.

Two ecotypes of switchgrass can be recognised based on morphological characteristics and habitat preferences: lowland ecotypes grow at wetter sites are taller, grow faster and have a more bunched type of growth habit; upland ecotypes grow in drier areas have finer stems and a more decumbent growth habit. Compared to lowland ecotypes they usually have larger seeds and, generally, lower dry biomass yields (Christian and Elbersen, 1998).

In North America much research has been conducted on this species. In Europe, research started only recently (Christian and Elbersen, 1998; De Klerk-Engels and Elbersen, 1999). Results so far indicate that the existing switchgrass varieties are well adapted to southern European conditions. Italy, as all EU countries, is looking for alternative crops for agricultural production on marginal lands that are less suitable for growing traditional crops. A considerable part of these marginal lands is located in sloping areas. In Italy there is a high number of small-size farms in these marginal areas, giving rise to many social problems as agricultural production becomes less profitable and land is often abandoned. The degradation of these agricultural lands can lead to the destruction of biological potential of the soil and even to desertification (Faggi, 1991; Lal, 1990). Erosion can become a major problem. Total soil losses due to erosion range between 0.35 and 59 t $\text{ha}^{-1}$ in the Apennines of Tuscany (Basso and Postiglione, 1994). In erosion-prone areas perennial drought-resistant biomass crops could be an attractive alternative to traditional agriculture (Kort et al., 1998; Vaughan et al., 1989). Switchgrass could be an interesting crop in these sloping areas because it covers the soil year round for up to 15 years before replanting may become necessary. Switchgrass has long been grown specifically for erosion control and many varieties have been selected specifically for this purpose in North America (Hein, 1958; Anonymous, 1979; Alderson and Sharp, 1993).

Seedling establishment is the most critical stage in the development of the crop especially in sloping areas. It is important to use reliable and affordable establishment methods. Many factors can contribute to stand failures, among them are poor seed quality, dormancy, environmental extremes, poor planting methods, weed competition and the particular seedling morphology of these grasses (Elbersen et al., 1998; Sanderson et al., 1996; Tischler and Voight, 1987). Still, among perennial $C_4$ grasses switchgrass is relatively easy to establish. The smooth seeds readily flow through seeding machines and methods have been developed to increase seed germination (Moser and Vogel, 1995). Breeding efforts have been made to increase establishment of switchgrass by changing seedling morphology, decreasing dormancy and increasing seed size (Elbersen et al., 1998; Sanderson et al., 1996; Moser and Vogel, 1995).

Important factors determining establishment success are soil tillage, accurate seed placement, seeding timing. The time of seeding is important to optimally exploit the growing period and to reduce weed problems. For North America many establishment guidelines exist which stress the need for using a firm seedbed in order to get a good stand and also to roll the soil firmly after tillage (Girourard et al., 1999; Teel, 1998; Wolf and Fiske, 1995). Indeed it was observed higher switchgrass seedling emergence rates in soil compacted by tractor tires just after sowing than in non-compacted soil (unpublished data). Compacted soil should improve seed–soil contact and hence reduce emergence time and increase seedling numbers (Radford, 1986). Planting depth is also considered essential, with recommended seeding depths of less than 0.5–1.5 cm (Girourard et al., 1999; Girouard and Samson, 1998; Teel, 1998; Wolf and Fiske, 1995). Use of a 3 cm sowing depth results in an approximate 4-day delay in emergence, which is more evident in clay soil (Venturi et al., 1999). Deeper seed placement will result in poor emergence and a thin stand (Teel, 1998). The North American guidelines also mention the possibility of using no till establishment methods

(Teel, 1998; Sanderson and Wolf, 1995). As yet no guidelines exist for establishing switchgrass in southern Europe.

The use of no till establishment methods, which save energy and speed up operations without reducing establishment success, is interesting especially in sloping areas in the establishment year when the risk of erosion is highest. This is of special importance with biomass crops since production costs are a major factor in determining economic viability.

Switchgrass can only be introduced successfully as a biomass crop in southern Europe if establishment methods are available that can be used on marginal soils and they are reliable and inexpensive. In order to make decisions on the best establishment methods in relation to risk and cost it is necessary to compare the available different seedbed soil preparation methods. The objectives of our study were to (1) evaluate and compare the effect of rolling, double rolling and no rolling tillage methods on switchgrass establishment; (2) compare lowland and upland switchgrass varieties; (3) assess switchgrass establishment in no till seedbed condition.

## 2. Materials and methods

### 2.1. Experimental site

Field tests were conducted at the experimental farm of the University of Bologna, Cadriano (latitude 44°33′N, longitude 11°21′E, 32 m a.s.l.), in a silt loam soil (Udic Ustochreps fine silty, mixed, mesic (Soil Taxonomy); Haplic Calcisol (FAO)), sub-alkaline (pH 6.9), with high potassium and average phosphorus and nitrogen contents, during three periods (autumn 1998, spring 1999 and autumn 1999). Mean annual temperature of the experimental site is 13°C. Corn (*Zea mays* L.) was the previous crop in each of the three trials. Soil characteristics are reported in Table 1. Weather conditions were measured at the meteorological station of the farm and are shown in Fig. 1.

### 2.2. Switchgrass varieties

Experiments were conducted comparing two different switchgrass varieties: Cave-in-Rock (CIR) and Alamo (autumn 1998) or Kanlow (spring and autumn

Table 1
Main chemical and physical properties of soil taken from the experimental site located in Cadriano, Bologna, Italy

| Parameter | Method | Value |
|---|---|---|
| Sand (g kg$^{-1}$) | Bojoucos | 340 |
| Silt (g kg$^{-1}$) | Bojoucos | 360 |
| Clay (g kg$^{-1}$) | Bojoucos | 300 |
| pH ($H_2O$) | | 6.9 |
| CSC (meq 100 g$^{-1}$) | | 45.6 |
| $CaCO_3$ total (g kg$^{-1}$) | Gasvol. | <5 |
| $CaCO_3$ active (g kg$^{-1}$) | Droineau-Gehu | <5 |
| Organic matter (g kg$^{-1}$) | Walkey-Black | 15 |
| N total (g kg$^{-1}$) | Kjeldahl | 13 |
| P ass. (μg g$^{-1}$) | Olsen | 28 |
| K exch. (μg g$^{-1}$) | $BaCl_2$ + tea | 174 |
| Ca exch. (mg g$^{-1}$) | $BaCl_2$ + tea | 4654 |

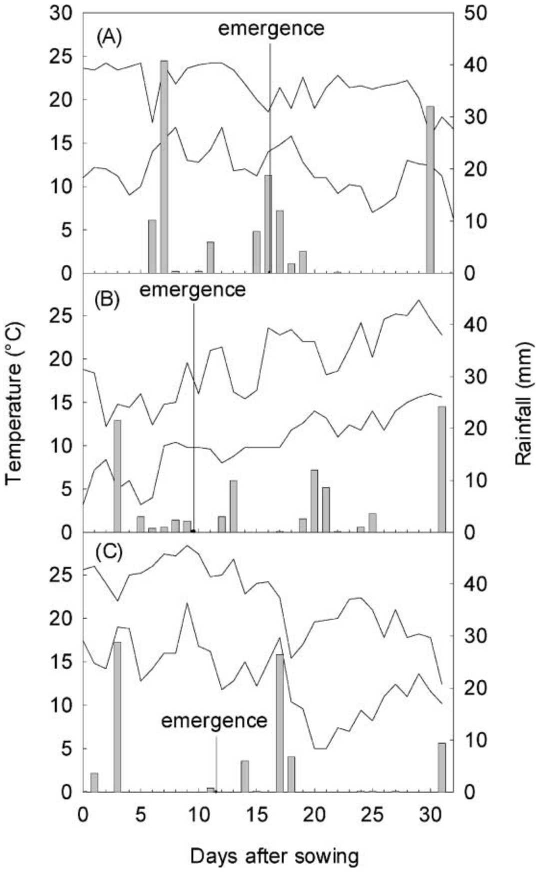

Fig. 1. Meteorological data of the experimental site from the days after sowing in autumn 1998 (A), spring 1999 (B) and autumn 1999 (C). Upper and lower lines indicate daily maximum and minimum temperature, respectively; bars indicate the daily rainfall.

Table 2
Information on seed used for the three field trials (autumn 1998 and spring and autumn 1999)

| Year | Variety | Ecotype | Seed weight (mg $100^{-1}$) | Seed germination (%) | Seed density ($\text{nm}^{-2}$) | PLS density ($\text{nm}^{-2}$)[a] |
|---|---|---|---|---|---|---|
| 1998 | CIR | Upland[b] | 130 | 61 | 572 | 346 |
| | Alamo | Lowland | 82 | 68 | 1030 | 695 |
| 1999 | CIR | Upland[b] | 130 | 74 | 572 | 422 |
| | Kanlow | Lowland | 85 | 58 | 1030 | 576 |

[a] PLS density is obtained by multiplying PLS (purity by seed germination rate) by seed number per square meter. Purity and germination were calculated after 28 days.

[b] CIR is generally considered an intermediate between upland and lowland.

1999). CIR is generally considered an intermediate lowland/upland ecotype, it has relatively larger seeds than Alamo or Kanlow, both lowland ecotypes. Information on seed weight and germination is given in Table 2.

Germination rates were determined according to a slightly adapted International Seed Testing Association (ISTA, 1993) method for *P. virgatum* L. In short: seed mass and germination of each seed lot was measured on four sub-samples of 100 seeds (Table 2). Seeds were placed on a moist filter in a Petri dish (TP), which was placed in an incubator for 12 h alternating periods at 15 and 20°C, with light during the 20°C period. Total germination after 28 days was used to calculate pure live seed (PLS) (Moser and Vogel, 1995).

### 2.3. Experimental design and treatment application

Trials were conducted from 16 September to 11 November 1998, from 12 April to 17 May 1999, and from 20 September to 20 October 1999.

The experiment design was a 4 × 2 factorial with a strip-plot in four blocks. Main plot factors consisted in four seedbed preparation methods (see below). Each main plot was split into two randomised sub-plots with two ecotypes (CIR: small seed; Alamo or Kanlow: large seed). Each plot measured 3 × 25 m with 15 cm row spacing distance (six rows of each ecotypes) and with 2 cm sowing depth.

Four seedbed preparation methods were compared:

1. S (ploughing–cultivating–sowing): the soil was ploughed to a 35 cm depth and cultivated to a 10 cm depth before sowing;
2. R–S (ploughing–cultivating–rolling–sowing): rolling before sowing was added to the above mentioned steps;
3. R–S–R (ploughing–cultivating–rolling–sowing–rolling): soil was rolled again after the above mentioned steps;
4. No till: seed sown directly into no tilled soil.

For the main soil treatment a Rabe Week disc-plough pulled by a tractor (Fiat 300, 75 kW) was used. Cultivation was performed with a 300 cm wide Howard-type rotary cultivator. Rolling was done with a 270 cm wide roll of 250 kg, applying a pressure of around 1.4 MPa. For the last two operations a Fiat tractor of 60 kW was used. For all treatments sowing was carried out with a Vignoli precision mechanical drill. Discs were specifically built for switchgrass seeds and are characterised by 4 × 2 mm oval shaped holes. Seeds were placed at approximately 2 cm depth.

No till data are not available for the second trial (spring 1999), since the residues in the soil did not allow a completely covered seed.

### 2.4. Plant and soil measurements

Seed density was calculated multiplying the number of seeds by PLS (PLS density; Table 2). PLS densities were multiplied using a correction factor (0.49 in the first trial and 0.71 in the second and third trials) to compensate for the different density between small and large seeds.

Since the 1998 and 1999 trials had a different predicted PLS density, an emergence index (EI), obtained using the ratio of real and predicted (PLS $\text{m}^{-2}$ calculated in Table 2) seedling number, was used to compare number of seedlings of different trials. Seedling numbers were plotted against growing degree days (GDD) calculated considering 11°C degrees as the base temperature (Hsu and Nelson, 1986).

The number of emerged seedlings was counted every other day beginning at emergence of the first seedlings. A seedling was considered emerged when the coleoptile was visible on the soil surface. In every plot two random of 1 m long lengths were marked as sampling areas.

A soil cone penetrometer (ASAE, 1999) was used to measure average resistance at 0–10 and 10–20 cm soil depth. Ten soil resistance measurements for each depth were recorded in every plot on the first emergence day. At the same time the soil moisture was determined by TDR method (vol.%).

### 2.5. Statistical methods

Analysis of variance was carried out combining autumn and spring trials without considering no till treatment (not available in spring trial). Four treatments were compared combining autumn trials. Separation of means was done according to Tukey's test $(P \leq 0.05)$.

## 3. Results and discussions

### 3.1. Plant emergence and GDD

The emergence over GDD for the two switchgrass varieties during three experimental runs are shown in Fig. 2(A)–(C). The average final number of emerged seedlings varied between 79 seedlings m$^{-2}$ for the autumn experiments and 204 seedlings m$^{-2}$ for the spring experiment. Since the same seed and seeding rate was used for spring and autumn 1999 experiments (Table 2), the seed conditions prior to emergence could explain the differences. It is known that cold and wet conditions can break switchgrass seed dormancy (Zhang and Maun, 1989; Wolf and Fiske, 1995). The higher seedling emergence in the spring experiment could, therefore, be explained by the lower night temperatures in spring (Fig. 1). In the days before emergence in spring 1999 night temperatures fell below 5°C, while in autumn 1998 and 1999 they were just below 10 and 15°C, respectively.

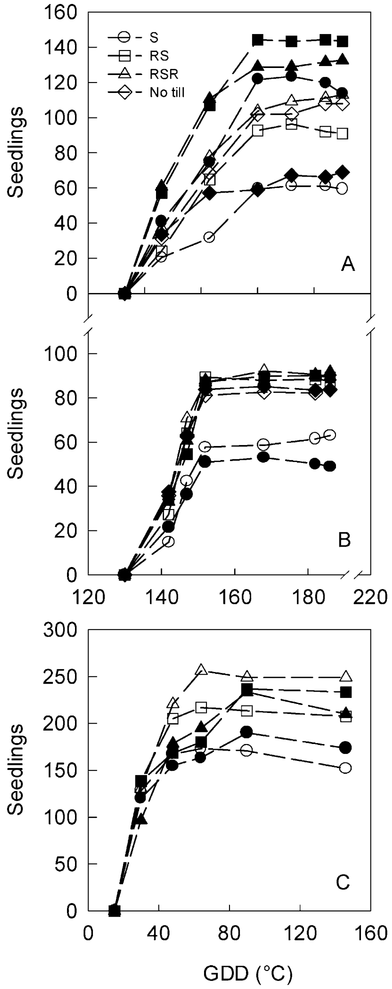

Fig. 2. Seedling numbers of small (filled symbols) and large (blank symbols) seeds over the GDD in different seedbed situations (R, RS, RSR and no till, see methods) in autumn 1998 and 1999 (A and B) and spring 1999 (C).

### 3.2. Plant emergence and soil resistance

Higher soil resistance in the 0–20 cm soil layer in autumn 1999 compared to spring 1999, as shown in Table 3, could also have contributed to the higher spring emergence. Soil resistance was strongly correlated with emergence mainly when the soil resistance was lower than 2 MPa. Considering the best fitted curve (Fig. 3), the EI from 1 to 2 MPa changed from 0.54 to 0.30. Since no interactions were found between year and soil tillage or depth, statistical analysis for soil resistance was combined for the years (Table 3).

Table 3
Soil resistance (MPa) at different seedbed preparations (S, RS and RSR) and soil depth (0–10 and 10–20 cm)[a]

| Treatment | Soil depth | | Season | | |
|---|---|---|---|---|---|
| | 0–10 cm | 10–20 cm | Spring | Autumn | Mean |
| S | 1.41 | 1.95 | 1.11 | 2.24 | 1.67 ab |
| RS | 1.21 | 1.94 | 1.15 | 2.01 | 1.58 b |
| RSR | 1.54 | 2.32 | 1.22 | 2.64 | 1.93 a |
| Mean | 1.38 b | 2.07 a | 1.16 b | 2.29 a | |

[a] Each value is the average of 10 measurements ($n = 10$). Letters in the last column signify differences among seedbed preparations; letters in the last row signify differences between soil depths or seasons ($P \leq 0.05$, Tukey's test). No interactions were found between factors.

Soil resistance was influenced by tillage and soil depth. Except for the no till treatment that was not included in the spring trial, the highest values were found in the double rolled tillage treatment (RSR) and in the deeper soil layer.

### 3.3. No till results

Overall, if no till was excluded, no significant interactions between variety and tillage treatments were found for final seedling numbers. The statistical analysis for both varieties was therefore combined (Table 4). Although the RSR treatment consistently showed a slightly higher average seedling emergence than the single rolled (RS) treatment the final number of emerged seedlings was never significantly different (Table 4). In all cases the rolled treatments (RS and RSR) had significantly higher final emergence rates than the treatment with no soil compaction (S). The average EI of unrolled plots (S) was 20% lower than rolled plots (single and double rolled).

The no till treatment was only included in the autumn 1998 and 1999 trials (Fig. 2). Since the interaction between tillage and variety was statistically significant, seedling numbers of the two varieties are given separately in Table 4. The large seed variety had a better performance only in the no till treatment, while the small seed variety had a higher final seedling numbers in every other situation (Table 3). In autumn 1998, the seedling number of the small seed variety was 40% lower than the large seed variety in the no till treatment. This was not so clear in autumn 1999 when the two varieties had similar behaviour. To verify if the different seedbed preparations affected the morphology of the two varieties, the primary root length, number of adventitious roots and mesocotyl length were measured and evaluated in the no till and double rolled treatments. The treatment never

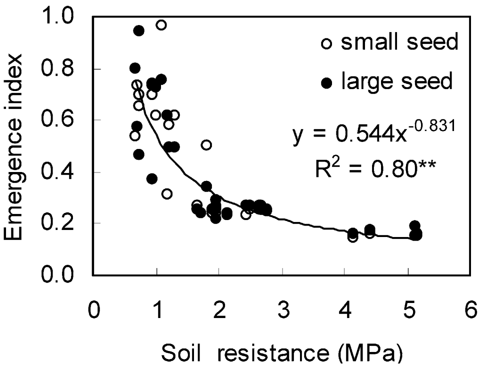

Fig. 3. Correlation between soil resistance at 0–20 cm depth and emergence expressed as EI.

Table 4
EI in different seedbed preparations (S, RS, RSR and no till)[a]

| Treatment | A | | A + S |
|---|---|---|---|
| | Small seed | Large seed | |
| S | 0.48 bc | 0.41 c | 0.56 b |
| RS | 0.61 a | 0.50 bc | 0.69 a |
| RSR | 0.59 ab | 0.57 ab | 0.72 a |
| No till | 0.48 bc | 0.55 ab | – |

[a] Combined data of autumn trials (A) including no till treatment, and autumn and spring trials (A + S) without considering no till treatment (not present in spring trial). Mean separation for $P \leq 0.05$ (Tukey's test). Because of the interaction between tillage and seed size in the case (A), both varieties are shown in column A.

Table 5
Mesocotyl and primary root lengths, and adventitious root numbers of small and large varieties in autumn trials

| Variety | Mesocotyl length (mm) | Primary root length (mm) | Adventitious root number (*n*) |
|---|---|---|---|
| Small seed | 8.9 ± 3.1 | 29.1 ± 6.8 | 7.8 ± 0.8 |
| Large seed | 11.3 ± 4.5 | 40.7 ± 6.9 | 9.9 ± 1.1 |
|  | n.s. | ** | ** |

** Significance for error probability of 1%.

resulted as being significant and no interaction between variety and tillage was found (Table 5). The fewer emerged seedlings of the small seed variety in the no till treatment can therefore be attributed to causes other than physical obstacles of the soil that would act on the morphological development of the seedlings. Varieties differed significantly for primary roots (40% more for the large seed variety) and number of adventitious roots, but not for mesocotyl length (Table 5).

### *3.4. Relative emergence rate*

Independently of year, treatment or variety, emergence was always completed within about 8–10 days from the appearance of the first seedlings. This can be easily seen by analysing the daily increase in emerged seedlings compared to the total seedling number that for simplicity's sake will be indicated as relative emergence rate (RER). In all years and for both varieties the length of the emergence phase was unrelated to the final seedling number (Fig. 4). The RER can, therefore, be expressed with a good approximation ($R^2 = 0.80$, $P \leq 0.01$) as a function of the number of days from the start of emergence (DAE) as

$$\mathrm{RER} = 0.517\exp(-0.470\,\mathrm{DAE}) \tag{1}$$

The RER being expressed as

$$\mathrm{RER} = \left[\frac{s_2 - s_1}{t_2 - t_1}\right]\frac{1}{s_2} \tag{2}$$

where $s_2$ and $s_1$ represent the number of seedlings emerged at time $t_2$ and $t_1$, respectively, combining Eqs. (1) and (2) and knowing how many seedlings emerged on the first day of emergence, it is possible to iteratively estimate the final number of seedlings at the end of emergence ($s_{\mathrm{fin}}$)

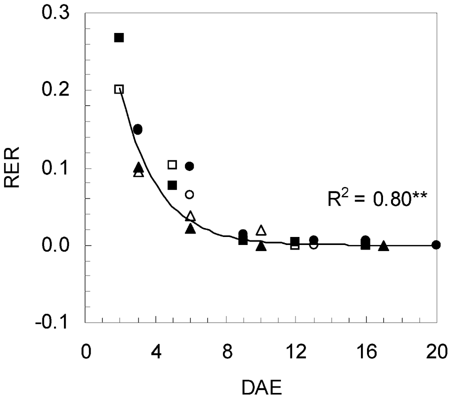

Fig. 4. RER over days after emergence (DAE). (●) autumn 1998, (▲) spring 1999 and (■) autumn 1999. Filled and blank symbols represent, respectively, large and small seed varieties.

$$s_{\mathrm{fin}} = \frac{s_i}{1 - \mathrm{RER}_i} \tag{3}$$

where $s_i$ indicates the number of seedlings at day $i$ which corresponds to a determined $\mathrm{RER}_i$ obtained from Eq. (1). This information could prove useful in deciding whether or not to re-sow on the basis of a set minimum density threshold. Taking as an example two cases in which the initial number of seedlings per square meter were equal to 20 and 50 ($s_1$), on the basis of Eqs. (1) and (3) it can be estimated that there will be approximately 52 and 131 seedlings $\mathrm{m}^{-2}$, respectively, at the end of emergence.

## 4. Conclusions

The number of seedlings emerged at the end of emergence was clearly lower in the autumn trials than in the spring one. The higher soil resistance in autumn compared to spring (1.16 vs. 2.29 MPa) could have contributed towards impeding emergence, as a good correlation between soil resistance and seedling numbers was found.

Compared to the single rolling, the double rolling gave better results, but not in a significant way. Rolled treatments (single and double) showed higher emergence than the unrolled soil: on average the EI in the unrolled plots was 20% lower than in the rolled ones.

Lowland and upland varieties did not differ except for no till situation where upland (large seed) variety showed higher emergence. Overall the EI was only slightly lower in no till situation compared to other treatments.

Independently of year, treatment and variety, emergence was completed in 8–10 days. A simple empirical prediction equation was obtained of the number of seedlings at the end of emergence. This equation was set up on the data obtained in this research and therefore further verifications are necessary with data obtained in different situations. Nevertheless, if reliable, it could prove useful in deciding whether or not to re-sow. Further trials will also be necessary to evaluate the possibility of using a roller and no till seed drill on sloping soils subject to high erosion (Wischmeier and Smith, 1978).

## Acknowledgements

Seed for the experiments was provided by Mr. J. Englert of the USDA, National Plant Materials Centre in Beltsville (Maryland) and Sharp Bros. Seed Co. Healy (Kansas).

H.W. Elbersen wishes to acknowledge the financial support by the Commission of the European Communities. Agriculture and Fisheries (FAIR) program, CT97-3701. This publications does not necessary reflect commission view and in no way anticipates its future policy in the area.

We would like to express our gratitude to S. Vecchi and R. Gobbo for field assistance, and Prof. G. Venturi for sharp comments.

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