CULTURAL METHODS FOR DEHYDRATING ONION PRODUCTION IN QUEBEC, WITH PARTICULAR REFERENCE TO THE FLUID DRILLING TECHNIQUE

by

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Fluid drilling of dehydrating onions

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ABSTRACT

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CULTURAL METHODS FOR DEHYDRATING ONION PRODUCTION IN QUEBEC, WITH PARTICULAR REFERENCE TO THE FLUID DRILLING TECHNIQUE

Field experiments were conducted on organic soil to determine optimal cultivars and cultural methods for the production of a dehydrating onion.

Among the 12 cultivars tested, Dehydrator-14 and Southport White Globe proved most suited. Fluid drilling hastened emergence and increased bulb size but decreased final survival and yields compared to dry seeding. Seeding one week after the soil could be worked appeared most beneficial. A sowing rate of 35 seeds m^{-1} produced the optimal bulb size and yield.

Laponite gels did not appear adequate under present field conditions. Agrigel and Water-Lock J550 were the best gels. Incorporation of gel additives (endomycorrhiza, growth regulators, fertilizers and fungicides) gave positive results. Cytex (0.25 to 5%) had no significant effect. Pro-Gro proved efficient in improving plant stand and yield in a smut infested field. While incorporation rates of Pro-Gro from 0.1 to the standard (0.16 g l^{-1}) had no deleterious effect on early growth, rates from 5 to 10 times were phytotoxic.

RESUME

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METHODES DE CULTURE POUR LA PRODUCTION D'OIGNON A DESHYDRATER AU QUEBEC, AVEC EMPHASE SUR LA TECHNIQUE DE SEMIS EN GEL

Des expériences ont été entreprises sur sol organique en vue de déterminer les meilleurs cultivars et méthodes de culture pour la production d'oignon à déshydrater.

Dehydrator-14 et Southport White Globe furent les cultivars les plus adéquats parmi les 12 cultivars testés. L'ensemencement en gel a permis une émergence plus rapide et l'obtention de bulbes plus gros que le semis de graines sèches. Par contre, le taux de survie et les rendements ont été diminués. Semer une semaine après que la terre puisse être labourée a semblé le plus bénéfique. Un taux de semis de 35 graines m^{-1} a produit un optimum de rendement et de grosseur de bulbes.

Les gels Laponite n'ont pas été adéquats dans les conditions de terrain existantes, tandis qu'Agrigel et Water-Lock J550 furent les meilleurs gels. L'incorporation d'additifs au gel (endomycorrhizes, régulateurs de croissance, fertilisants et fongicides) a donné des résultats positifs. Cytex (0.25 à 5%) n'a eu aucun effet significatif. Pro-Gro fut efficace pour améliorer le taux de survie et le rendement dans un champ infesté de charbon de l'oignon. Tandis que des taux de concentrations variant entre 0.1 et la concentration standard (0.16 g l^{-1}) de Pro-Gro n'ont eu aucun effet sur la croissance des jeunes plantules, des taux de 5 à 10 fois plus élevés furent phytotoxiques.

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LIST OF ABBREVIATIONS

AGRIG: Agrigel
BE10: cv. Bejo 10
BE11: cv. Bejo 11
BEJO: cv. Bejo 10 (in 1983)
CONDS: dry seeded control
CONFD: fluid drilled control
COV: covered
COVER: soil cover treatment
CREO: cv. Creoso
CY: cultivar-year combinations
DEHY: cv. Dehydrator-14
DEH82: cv. Dehydrator-14 in 1982
DEH83: cv. Dehydrator-14 in 1983
DS: dry seeding
DSCON: dry seeded control
FD: fluid drilling
FDCON: fluid drilled control
FDCYK: fluid drilling with cytokinin (liquid seaweed)
FDFER: fluid drilling with fertilizers
FDMYC: fluid drilling with mycorrhiza
FDPRO: fluid drilling with Pro-Gro
FUNGSEED: fungicide-seeding method combinations
GRBU: cv. Green Bunching
HYSO: cv. Hysol
LAP445: Laponite 445
LAP508: Laponite 508
LIQUA: Liquagel
LSD: Least significant difference
METHOD: sowing method
ns: non significant
OE97: cv. Olhsens Enke 2497
OE98: cv. Ohlsens Enke 2498
PRIM: cv. Primero
PRODS: dry seeding with Pro-Gro
PROFD: fluid drilling with Pro-Gro
ROVDS: dry seeding with Rovral
ROVFD: fluid drilling with Rovral
SEED: Seeding method
SWG: cv. Southport White Globe
SWG82: cv. Southport White Globe in 1982
SWG83: cv. Southport White Globe in 1983
UNC: uncovered
VWHI: cv. Vista White
WKEE: cv. White Keeper
WLB100: Water-Lock B100
WLB200: Water-Lock B200
WLJ550: Water-Lock J550

I. INTRODUCTION

A major part of the 30,000 tons of onions produced annually in Quebec is grown on the organic muck soils of the counties of Chateauguay and Napierville where 180 and 595 ha, respectively, were harvested in 1982 (Statistics Canada 1983). The province of Quebec is 90% self-sufficient in fresh market onions. However, the situation is different for dehydrating onions. As reported in a 1980 census (MAPAQ 1980), the dehydrating onion production was only 5.8% of the total Quebec production. Accordingly, only a small proportion of the 1500 tons of dehydrated onions used annually in the province is thus produced locally.

The lack of expertise, proper equipment and financial support has impeded the development of the dehydration industry in Quebec. Furthermore, the uses and advantages of the dried onion over the fresh, canned or frozen product are not well known by industries and consumers. In fact, the dehydrated onion is considered to be the closest in taste to fresh onion with the additional advantages that it can be stored longer without losing texture, colour, flavour or food value, and it requires a small area for storage. Another reason for the limited production is the requirement of 7 to 17 kg fresh onions for every kg of dehydrated material. Therefore, tremendous quantities (minimum 20,000 t of onions per year) are required to supply a dehydration industry in order to make it profitable (Woods Gordon 1982). Unfortunately, the regularity of supply of raw material is the main problem in Quebec where the harvest period is restricted and climatic constraints important.

Despite the difficulties encountered there is place for a dehydration industry in Quebec to satisfy the growing demand and to develop the market to compete with American products. Moreover, as this culture has only recently been introduced into Quebec, many cultural and managerial aspects remain to be established. The varieties presently produced, White Creole and Southport White Globe, are not performing satisfactorily in our climate (Woods Gordon 1982). Research efforts thus need to be concentrated on finding high yielding cultivars which present the proper characteristics, prolonging the growing season by appropriate technological methods and developing new openings for the product. The present project was undertaken to screen potential cultivars and establish a growing system suitable for white onion production in the province of Quebec.

II. REVIEW OF LITERATURE

This literature review has been designed to present details concerning the white onion crop and the managerial/cultural techniques that influence its growth and development.

2.1 Characteristics of the dehydrating onion

The onion, Allium cepa L., believed to originate from the Middle East, was first described by Linnaeus in 1753 and has been in cultivation for over 5,000 years (Jones and Mann 1963). This crop, belonging to the genus Allium, has been recognized as a member of the Alliaceae segregate family by Cronquist (1981) and of the Allioidae sub-family by Hickey and King (1981). Both units are in the broad family of the Liliaceae. Among the some 600 species Allium cepa has been the most widely cultivated.

The onion bulb is of prime importance as it represents the economical part of the plant. It consists of a short underground stem or pseudostem (Lercari 1982) with fleshy scale leaves which envelop the terminal bud (Rabinowitch 1979). Considering botanical, physiological and chemical characteristics, the white dehydrating onion resembles all other dry bulb onions, but it differs somewhat in its uses and certain chemical components.

The demand for onion products and particularly for dehydrated products has been increasing (Jones and Mann 1963; Yamaguchi, Paulson, Kinsella and Bernhard 1975; Woods Gordon 1982). Dehydrated onions are sold in various forms: chopped, sliced, in cubes, granulated, ground or powdered and are used for seasoning, in canned food products and salads (MAPAQ 1980). Onions for dehydration should be high in pungency and should not lose their white colour or develop a bitter flavour on drying. They should have small necks and an elongated shape, be free of diseases and mechanical injury, and above all, have a high content in total solids (Jones and Mann 1963; Woods Gordon 1982). White cultivars are used almost exclusively as they genetically maintain a higher content of soluble solids than other types.

Mann and Hoyle (1945) noted that onion cultivars characterized by small bulbs had higher dry matter contents than their large bulb counterparts. McCullum (1968) as well as Nieuwhof, DeBruyn and Garretsen (1973) confirmed this negative correlation between bulb size and dry matter among cultivars. The dry matter content is genetically linked to cultivar type. Indeed, McCullum (1968) found heritabilities of between 70 and 80%. Despite this heritability, environmental and experimental factors have been shown to modify the accumulation of dry matter and the colour of any given cultivar (Brewster, Hardwick and Hardaker 1975; Steer 1982; Yamaguchi _et al_. 1975). In turn, dry matter content affected the sugar content and the pungency (Brewster 1977; Lercari 1981 & 1982; Yamaguchi _et al_. 1975).

2.2 Culture of the crop

Statistics on specific groups of onions (e.g. colour, market usage) are extremely difficult to obtain and data for bulb onions encompasses all subunits.

World production of bulb onions was 22,397,000 t in 1982 (FAO 1983), making this crop the third most important vegetable following tomatoes and cabbages, in terms of annual tonnage. While Asia and Europe were the biggest producers, North America was ranked third along with the USSR (Table 1). Despite the relatively small area harvested (67,000 ha), North America had a yield of 31 t ha^{-1}, the highest in the world. In Canada, approximately one third of the onions were produced in Quebec with average yields of 35.7 t ha^{-1} in 1982 and 28.4 t ha^{-1} in 1983 (Statistics Canada 1983). Bulb onion yields between 56 to 68 t ha^{-1} have been reported on productive organic soils in Quebec (Jasmin, Hamilton, Millette, Hogue and Bernier, 1977).

TABLE 1. Area, production and yield of dry onions in the world, by continent, and in Canada (1982)[1]

	Harvested area (1000 ha)	Production (1000 t)	Yield (t ha $^{-1}$)
World (total)	1 677	22 397	13,4
Asia	926	10 293	11,1
Europe	237	4 394	18,5
USSR	185	2 100	11.4
Africa	138	1 725	12,5
South America	117	1 603	13,8
North America	67	2 090	31,0
United States	50	1 875	37,3
Canada	4	132	34,9
Ontario[2]	2	79	34,9
Quebec[2]	1	36	35,7
Oceania	7	191	27,1

[1]. from FAO (1983)
[2]. from Statistics Canada (1983)

2.2.1 Adaptation of cultivars

For successful onion production, the first step is to select varieties that will grow, bulb and mature satisfactorily under the temperatures, daylengths and other environmental factors of the area considered. Accordingly, onion cultivars have been classified by daylength requirement as well as by market type, and shape (Voss 1979). Among environmental factors affecting the development of the onion plant, photoperiod and temperature are the most important. All cultivars and hybrids are technically long-day plants since bulbs form more readily as daylength increases. However, the minimum critical photoperiod varies with cultivar adaptation. Whereas, a short-day cultivar requires 12 to 14 hours to initiate bulbing, a long-day cultivar will need 14 to 16 hours and an intermediate one, 14 hours (Voss 1979).

Jones and Mann (1963) demonstrated that bulbing was determined by an interaction between daylength and temperature which primarily determined limits of adaptation. In temperate zones, once the critical daylength was reached and bulbing initiated, the onion growth rate depended on temperature (Brewster 1977). Thus, other factors being equal, onions bulbed more rapidly under warm rather than cool temperatures, the optimal being 21-27°C. Temperature also played an important role in determining the maturity date as the onset of neck fall occurred earliest at 25-30°C (Brewster 1977). Above optimal temperatures, bulbs matured earlier and consequently yields were reduced. Whereas at below optimum temperatures, maturity was usually delayed and problems with field curing and storage quality were encountered.

Plant size and fertilizer regime also influenced bulb development and maturity (Brewster 1977). Smaller bulbs resulting from denser plantings matured earlier than onions spaced for the production of large bulbs (Jones and Mann 1963). Fertilization, mainly nitrogen nutrition, influenced bulbing. Deficiencies in nitrogen supply promoted bulb initiation, whereas, excess nitrogen delayed initiation (Jones and Mann 1963).

For the dehydrator type of onion, the optimal bulb shape was found to be elongated or torpedo like as this reduced processing losses. Bulb shape was shown to be determined by the cultivar type but modified by environmental and cultural factors which lead to intermediate values (Plate 1). For instance, Voss (1979) reported that globe shaped varieties tended to elongate under higher than normal temperatures. Similarly, Rabinovitch (1979) attributed the occurrence of multihearted and double bulbs mainly to genetic background of the plant but also implicated factors such as fertilizer regime, depth of planting and crop spacing.

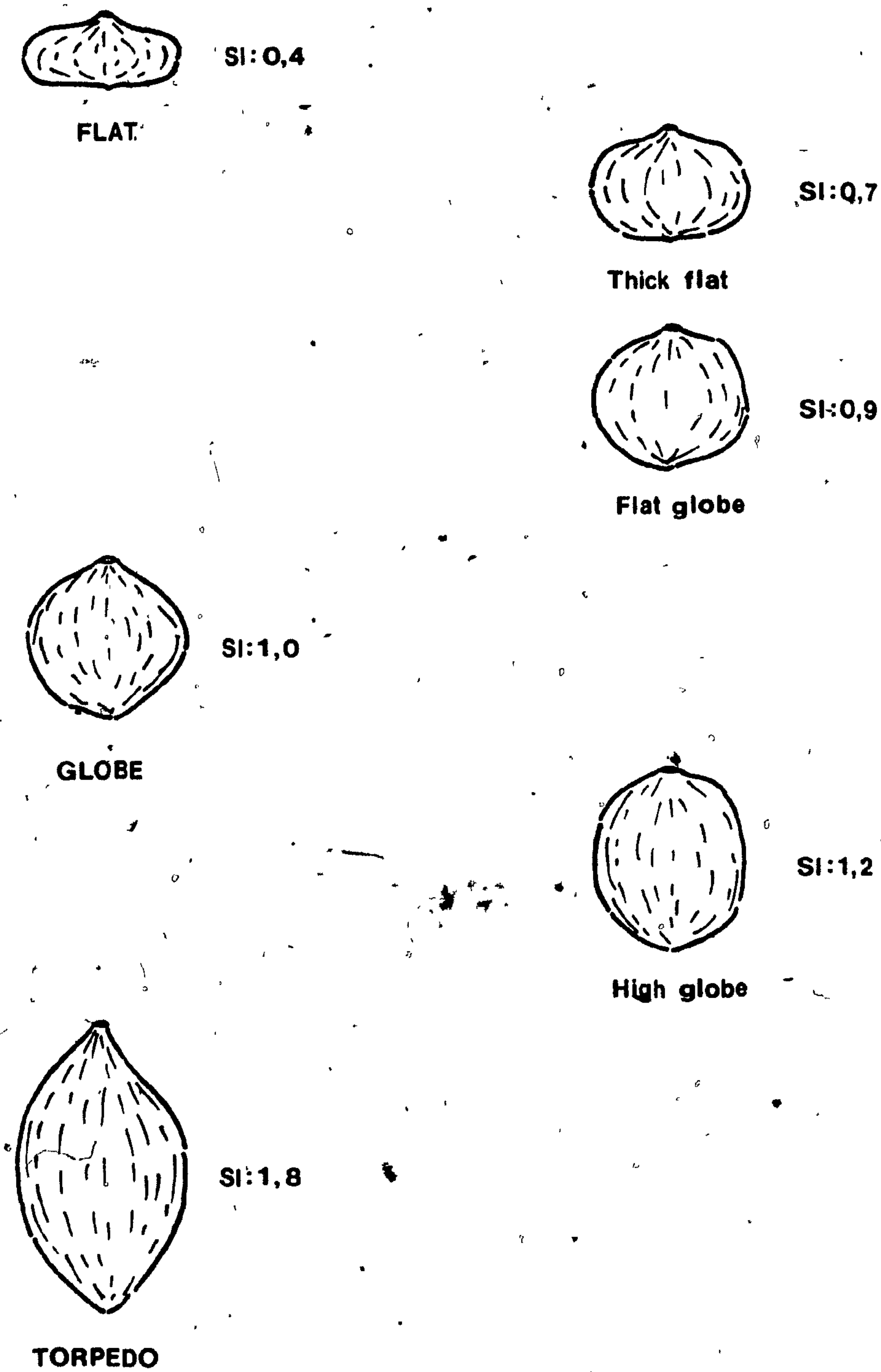


PLATE 1. Bulb shapes and shape indices: SI (height/diameter) (adaptated from Voss 1979).

2.2.2 Sowing time

In order for onions to be at the optimum physiological age for daylength-mediated bulb induction, the seeds have to be sown early in the spring (Brewster 1977), as soon as the soil can be worked properly. Tiessen, Nonnecke and Valk (1970) reported that the earlier the seeds were sown within two weeks after the soil became workable, the larger the yield for both early and late cultivars. On organic soil, onions have even been seeded before the frost was completely out of the ground. Brewster (1977) reported that an early sowing or an early establishment leading to an increase in full canopy duration appeared to be the basic requirement for higher yields. However, early sowing did not produce consistent yield improvements. Indeed, Hoyle, Brown and Yamaguchi (1972) found wide variations in bulb size and hence marketable quantity with early seeding.

Although an early sowing is ideal for higher yields, cold soil conditions during the early stages of growth has not only delayed emergence but also delayed plant development and resulted in greater susceptibility to pathogens and bolting (Tiessen et al. 1970; Wagenvoort and Bierhuizen 1977). A long, cool spring has usually been accompanied by a high percentage of bolting and to avoid this, Jones and Mann (1963) suggested that particularly susceptible cultivars should be planted later. However, the planting delay had to be reasonably short in order to allow enough leaf growth before bulbing. Therefore, for each district and each cultivar, there was a best sowing time in order to maximize production while minimizing bolting. When sowing was done in cool damp weather, onion smut infection was increased due to the delay in plant emergence and the consequent increase in the period of susceptibility (Chupp and Sherf 1960). On the other hand, warm and dry weather permitted the onion to germinate rapidly and avoid the disease.

Onion seeds germinated in soils with moisture levels ranging from slightly above the permanent wilting point to field capacity (Lorenz and Maynard 1980). An adequate moisture was shown to be particularly important for quick growth soon after emergence to achieve maximum leaf cover before the onset of bulbing (Brewster 1977). Therefore, muck soils have been found to be ideal for onion production due to the high waterholding capacity (Tiessen et al. 1970; MAPAQ 1982). The sowing depth normally used has been 0.5 to 2.5 cm and when sowing was done late in the spring, 3 to 4 cm (Tiessen et al. 1970).

2.2.3 Density of sowing

Crop spacing has been one of the major cultural factors under the grower's control and it has played an important role in ensuring that the required size of produce was obtained at the right time and with the maximum profit. This was particularly true for the onion crop for which the ripened bulb is the entire plant and represents the marketable product. Bleasdale (1982) demonstrated that the yield of the onion crop increased with increasing population until a certain density was reached and then a further increase in population slowly depressed the yield which eventually became independent of density. Total yield was not necessary associated with marketable yield. Bleasdale (1966) found that at the maximum ceiling yield, bulbs averaged 32 mm in diameter and were thus slightly too large for pickling and required too much peeling to be practical for processing. Bleasdale (1966) and Frappell (1973) reported that a plant density of

70 plant m^{-2} was optimal for maximum yields of bulbs over 45-50 mm in diameter, but was accompanied by a loss of 20% over the total potential yield. Consequently, large bulbs as required by the processing market, could only be obtained at the expense of some loss in total yield.

The Quebec government (MAPAQ 1982) recommended sowing onion seeds in rows 40 cm apart at a rate of 40 to 50 plants m^{-1}, equivalent to a density of 100 and 125 plants m^{-2}, respectively. Bleasdale (1973) reported that under normal field conditions in temperate regions, individual bulb size at densities greater than 70 plants m^{-2} was not limited because ceiling yields were achieved but because the length of the growing season was restricted. Furthermore, he stated that bulbs planted at high density did not have time to achieve an acceptable size due to the slower rate of bulb enlargement engendered by increased competition. However, the more intense shading in high-density plantings tended to change the growth pattern at the end of the season and resulted in more rapid maturity than low density plantings (Frappell 1973; Brewster 1977). Jones and Mann (1963) reported that maturity was hastened by as much as 3 to 4 weeks when plants were densely planted in the row for set production than when widely spaced for the production of large bulbs.

Regularly spaced onions suffered equally from competition but if the competition was irregular the plants became more uneven in size. On the other hand, Brewster and Salter (1980) found no advantage in terms of yield or uniformity of bulb size from having plants spaced regularly rather than randomized within the row, when the crop was grown on sandy loam soil.

Two other factors contributed to the variation in bulb size: the spread in time to emergence and the percentage of emergence in the field. Bleasdale (1973) stated that equal plant spacing provided equality of opportunity for the plant to use resources, but the extent to which this opportunity was grasped depended upon the time of emergence of a seed in relation to its neighbours. A seed that emerged earlier gave a bulb larger in relation to its weaker or later emerging neighbours because it utilized the space that was allocated to the other plants in addition to its own. A situation where a great proportion of large bulbs (diameter above 60 mm) were obtained can be explained by the lesser competition resulting from a greater variation in emergence time or in low seedling emergence. A poor plant stand, due to a small fraction of the seeds being viable or to unfavourable environmental factors, caused an irregular pattern of arrangement in the row even when a precision drill was used.

2.2.4 Sowing methods

Field emergence of most crops is lower than laboratory germination tests, particularly for fragile seedlings like onions, due in part to unfavourable edaphic conditions at sowing and to the presence of pathogens in the soil at any sowing date. Some of the adverse effects could be avoided by the use of transplants or by establishing more plants than required by conventional methods and then thinning to the desired stand, but these methods proved impracticable and uneconomic for onions (Currah, Gray and Thomas, 1974). Precision seeding counts among the techniques available and suitable for the onion crop. It is one technique that produces an optimal plant spacing with low seeding rates (Bufton 1978). This optimum seeding tends to minimize the competition for light, moisture and nutrients, and thus improve growth and increase yields with more uniform size and shape of onions at harvest. However, to achieve complete success with precision seeding, a number of other managerial procedures must be employed (Lorenz and Maynard 1980; OMAF 1983). Due to its angular shape, the onion seed needs to be coated with a water absorbing material to provide a round uniform shape. Moreover, since no extra seeds are being sown to account for seed losses, precautions must be taken to obtain emergence and plant survival as close to 100% as possible. Thus, applications of herbicides and pesticides have to be well scheduled and efficient. In addition, higher quality and more expensive seed (hybrids) may be required.

Results with precision seeding research in Ontario indicated that higher yields of better quality vegetables were possible regardless of when the crop had been sown (OMAF 1983). Despite the many advantages attributed to precision sowing, the crop did not establish itself any earlier than by conventional means. Earliness was a critical factor in onion production for two reasons. Firstly, a low relative growth rate, a shallow root system of comparatively low density and short upright leaves resulted in a slow establishment and a high susceptibility to weed competition and diseases, especially in the early stages of growth (Brewster 1977). Moreover, as the onion required 90 (early varieties) to 150 days (late varieties) from seeding to maturity, a main concern was to accelerate field emergence and establishment. Sowing pregerminated seeds have advanced the emergence of spring sown onions by many days, and thus extended the growing season (Currah 1975).

Sowing imbibed or pregerminated seeds, as a part of the fluid drilling system was reported to help in reducing emergence problems caused by complex seed/soil interactions which made plant stand difficult to predict (Taylor 1977).

2.3 Fluid drilling of onions

The fluid drilling technique has been well documented and in 1981, Gray produced an extensive review of this subject. Therefore, only aspects specific to onions will be mentioned in this review.

Onions have normally been germinated at temperatures between 18-22°C for 3 to 3 1/2 days (Gray 1981; Finch-Savage and Cox 1983). Occasionally, temperatures as high as 28°C have been successfully used (Lipe and Skinner 1979). The optimal radicle length for seeding varied from 2 (Gray 1981) to 4 mm (Finch-Savage and Cox 1983). In order to standardize germination and radicle length, onions seeds have been primed (Heydecker, Higgins and Turner 1975), or submitted to other physiological or chemical treatments. Heydecker and Coolbear (1977) and Khan (1977) have extensively reviewed this subject.

Seed separation into viable and non viable components has been carried out with onions using a 42% sucrose solution (Taylor, Motes and Price 1978). This method was able to remove 95% of the non germinated material thereby greatly improving changes for precision seeding. Storage of pregerminated onion seeds at low temperatures (1°C) for periods of up to 9 days has been successful (Brocklehurst, Dearman and Finch-Savage 1980). Longer storage was found to both reduce viability and increase radicle length beyond the optimum. Long radicles have been not only easily damaged during the gel mixing and seeding procedures (Finch-Savage 1981), but also injured more by low soil temperatures (≤0°C) than either seeds with shorter radicles (Irwin and Price 1983) or dry seeds (Steckel and Gray 1980).

Many materials have been used for suspending and sowing the pregerminated seeds, but not all gels are suitable as they must exhibit specific characteristics (Darby 1980). Approximately 20 gels have been marketed and can be made of synthetic or natural materials (e.g. silicates, acrylates, acrylamides or starches); (Price, personal communication). Their efficiency varies with the crop type, cultural conditions and the type and rate of additive mixed with the gel (Gray 1981; Ghate 1982; Orzolek 1982a&b; Ghate and Phatak 1983; Pill and Watts 1983).

Recent findings indicated that further benefits of fluid drilling were associated with the use of a carrier gel as a means of introducing nutrients, growth regulators and pesticides close to the seeds (Gray 1981). Such technique could produce an ideal nutritive, disease and weed free microenvironment for the developing plants by modifying the soil around the seeds or even replacing it for a period up to several weeks (Currah 1978b; Hiron and Balls 1978; Salter 1978). At this time, most work with gel additives has been directed toward the incorporation of nutrients. The accurate placement of fertilizer through gel addition of phosphates enhanced seedling growth of onions. The best nutrient combination obtained for the onion was 17 g l^{-1} ammonium phosphate ($(NH_4)_2HPO_3$) and 30 g l^{-1} potassium phosphate ($K_3PO_4.H_2O$) (Finch-Savage and Cox 1983). This treatment resulted in an earlier and better growth, with a final increase in plant dry weight of 50% over the dry seeds and 20% over the gel alone after 91 days.

Interest has also been shown in the possible use of hormones as gel additives. Although no specific report was found on the application of hormones into the gel for fluid drilled onions, exogenous applications of cytokinins have been used successfully to reverse the advancement of leaf blade senescence caused by abscissic acid and maleic hydrazide (Brewster 1977). One zeatin-containing substance has been used with the fluid drilling system. In fact, Gray and Bryan (1978) investigated the effect of an incorporation of 1.3% Cytex in the gel and obtained an improvement in growth of celery seedlings. These advantages were reached with considerably lower rates of the product than that required for traditional spraying techniques to obtain equivalent results. Similar experiments showed increased plant stand and yield of cucumbers when 2% Cytex was added to the gel compared to the gel alone (Orzolek, personal communication). In general, higher percentage emergence and yields were obtained when the growth regulator was added to the gel than when it was used as seed soaks prior to gel seeding. Ohep Gruny (1981) obtained a stimulation of tomato seedling emergence in greenhouse conditions with 1% Cytex in the gel, but the same conclusions were not reached under field conditions. He attributed this difference to a shorter period of availability of the product which was probably leached in the early stages of field growth.

With onions, fungicidal chemicals have been the main type of gel additives. White rot in salad onions has been effectively controlled by incorporating Iprodione (3-(3,5-dichlorophenyl)-N-isopropyl-2, 4-dioxoimidazolidine-1-carboxamide) in the gel, as 0.25 times the dose used for traditional dry seed coating controlled the disease as effectively as the dry seed treatment at 125 g a.i. kg^{-1} (Entwistle 1979). On the other hand, 1 to 4 times the standard rate proved phytotoxic (Entwistle and Munasinghe 1981).

Recent attempts on the incorporation of insecticides, nematicides and herbicides into the gel have also shown possibilities for improving the growing environment around pepper and carrot seedlings (Ghate and Phatak 1983; Thompson and Jones 1983).

Gray (1981) stated that fluid drilling could be of great benefit for a crop like onion noted for its poor emergence and slow seedling growth. Improvement of percentage emergence and early growth rate have been obtained using fluid drilling (Darby 1980; Finch-Savage 1981). Gel seeded onions gave up to 15 days earlier field emergence compared to dry seeds. This earliness resulted in increased bulb weight brought about by the extension of the growing season. Yield increases of up to 25% were attained by this technique (Salter 1978). Lipe and Skinner (1979) showed that pregerminated seeds sown in a plug-mix gave 10 to 12 days earlier maturity and 37.5% bulb diameter increase at harvest, resulting in significant yield improvement for marketable onions (>50 mm diameter).

The results of the fluid seeding technique have not always been positive. Large bulbs obtained with fluid drilling have been due in many instances to reduced competition resulting from lower plant stands for pregerminated compared to dry seeds (Currah 1976; Lipe and Skinner 1979). Hiron and Balls (1978) reported that the emergence percentage often resulted from very early sowings. Finch-Savage (1984) suggested that the two main reasons for variation in response of the onion crop to fluid drilling drilling were the low proportion of seeds germinated at sowing time (i.e. 8%, Brocklehurst et al. 1980; 20-30%, Lipe and Skinner 1979; 19%, Finch-Savage 1984) and a low soil moisture content following sowing. In his study, Finch-Savage (1984) showed that seedlings with radicles up to 6 mm in length emerged in advance of those from seeds with radicles less than 2 mm, but the use of seeds with longer radicles also increased the spread of emergence and decreased percentage emergence. Differences in response to fluid drilling most likely reflected disparity in environmental and cultural conditions in the trials. Indeed, benefits of fluid drilling had also varied with the cultivar and even with seed lot, for any given crop (Gray 1981). Moreover, variations in response could have resulted from conditions prevailing during each step of the technique. It is thus important to adapt the method to obtain the full potential of fluid drilling.

In the current thesis, the subjects of experimentation were as follows: cultivar evaluation, time of sowing, density of sowing and fluid drilling of white onions used for dehydration. The fluid drilling technique was compared to dry seeding methods and was assessed as a means of incorporating additives (e.g. endomycorrhiza, cytokinins, fertilizers and fungicides) to improve early seedling establishment and growth, and to control diseases. Various gel types were also tested.

III. GENERAL MATERIALS AND METHODS

Materials and methods described in this chapter were employed in more than one experiment. Specific materials and methods have been presented within each experimental section.

3.1 Field experiments

3.1.1 Seed preparation and germination

Unless otherwise indicated, onion cultivar Southport White Globe was used as the experimental material. Seeds were counted using an Electronic seed counter (Audiotronics) and groups of 225 seeds placed in individual envelopes. Each envelope corresponded to a 5 meter row with a sowing rate of 45 seeds m^{-1}. Seeds sown dry were treated with Pro-Gro (carbathiin/thiram) systemic fungicide at a rate of 25 g kg^{-1} of seeds, following the recommendations of Crête and Tartier (1973).

Each sample of 225 seeds destined to be fluid drilled was put into a 0.5 mm nylon mesh bag to aid in sowing and emergence counts. Bags were placed in 25 l of water in a Magni Whirl waterbath (Blue M Electric Company). The temperature was maintained at 19-20°C during the germination period by a dual microtrol electrical control switch. Air was provided by a laboratory air nozzle attached to a brass valve junction which forced the air into five 50cm inert tygon tubes of 4.8 mm interior diameter (1.6 mm wall thickness). The initial air pressure was 1.3 kg cm^{-3}. After 24 hours, the water was drained and replaced with water at the same temperature to leach out possible inhibitors. Seeds were checked twice daily for radicle emergence. After 3 days most seeds had produced radicles of between 2 to 5 mm length.

As the weather was particularly wet and cold in 1983, pregerminated seeds for the three first sowing dates (May 13, 14 and 19) had to be stored for 2 to 4 days. An electrical coolant was put directly in the waterbath to lower the temperature to 1°C during the cold storage as suggested by Brocklehurst et al. (1980).

3.1.2 Gel preparation

Unless otherwise specified, Laponite 508 (magnesium silicate) was used as the gel material following the recommendations of Darby (1980). Gel powder was weighed on a Mettler PL 1200 top loading electronic balance and mixed with tap water (pH 6.5) using a Waring blender (model 50116) at 23,000 r.p.m. Gel powder was incorporated at a rate of 15 g l^{-1} to obtain flow and seed suspension properties suitable for sowing (Ghate 1982).

Once the gel has been prepared, pregerminated seeds were washed from the nylon bags and recuperated in a small plastic strainer. Each seed sample was mixed with 150 ml of gel in a beaker and this mixture was then poured in a 1 liter plastic bag. One bag was used to sow each 5 m row. The resulting gel extrusion rate of 30 ml m^{-1} was equivalent to that recommended by Fluid Drilling Ltd.(Anonymous 1980).

3.1.3 Sowing methods

Details of the sowing dates for individual experiments are presented in Table 2. In all experiments seeds were sown at a depth of 2 cm. Each treatment consisted of a plot of four 5 meter rows spaced 45 cm apart and replicated 4 times. The outer two rows and 0.5 m at each end of the two inner rows served as guard plants. Dry seeds were sown using a 4-row automatic seeder equipped with a V-shaped leather belt to permit a precise seeding rate of 45 seeds.m^{-1}. For fluid drilling, the plastic bag containing the gel and seeds was cut and the mixture extruded to give a rate similar to that for dry seeds.

TABLE 2. Sowing and harvesting dates for onion field trials conducted during 1982 and 1983 at Ste-Clotilde, Quebec.

EXPERIMENT	YEAR	SOWING DATE	HARVESTING DATE
4.1 Cultivar evaluation	1982	May 6	Sept. 13 & 20
	1983	May 14	Aug. 26 & Sept. 13
4.2 Density of sowing	1982	May 3	Sept. 13 & 20
	1983	May 19	Sept. 13
4.3 Sowing dates	1982	April 29,May 6 May 13	Sept. 20 Oct. 6
	1983	May 13,19 & 25	Sept. 13
4.4 Gel types	1983	May 19	Sept.13
4.5 Gel additives			
4.5.1 Gel additives	1982	May 6	Sept. 13 & 20
4.5.2 Field trials 1983			
4.5.2.1 Cytokinins	1983	May 19	Sept. 13
4.5.2.2 Fungicides	1983	May 19	Sept. 13

3.1.4 Cultural and managerial techniques

All field experiments were conducted at the Ste-Clotilde substation of Agriculture Canada, St-Jean-sur-Richelieu (45°10' latitude, 73°41' longitude), 40 km Southwest of Montreal. The area has an organic humic mesisol profile, 1.5 to 2.5 meters deep with a pH of 5.9-6.1. The growing season in this area was 137-152 days (Dubé, Chevrette and Lamb, 1982). Temperature, precipitation and daylength values were recorded weekly (April to October) and were presented in Table 3. In 1982, the weather pattern was very variable. The spring was warm and relatively dry, the mid-summer was rather cool and wet, while the fall was warm and dry. The 1983 season was characterized by a cool and very wet early spring, a hot and dry summer and a relatively warm and wet fall.

Each year, a 10-5-10 granular fertilizer (Cyanamid Canada) was broadcasted with an Easy-flow rotary broadcaster (Massey-Ferguson) at a rate of 1120 kg ha^{-1} and incorporated into the top 10 cm of soil using a disc harrow. Throughout the season, a regular spray program was undertaken following Quebec government recommendations (Table 4; MAPAQ 1982). No supplementary irrigation was applied, and tile drainage was in place to eliminate excessive rain water.

At maturity, onions were lifted by hand and left in the field to cure for a period of 1 to 2 weeks, until the tops were dry. Late maturing plots were pulled on September 9 (1982) or 8 (1983) to ensure at least a minimum curing before the first frost. At harvest, the dry tops were discarded using an Ezee Flow mechanical cutter equipped with rotary blades. Harvesting dates for each experiment are listed in Table 2.

TABLE 3. Meteorological data for the summers of 1982 and 1983 in Ste-Clotilde, Quebec.

		Mean air temp. (°C)				Precipitation		Daylength
		Max.		Min.		(mm)		(hours & min.)
Month	Days	1982	1983	1982	1983	1982	1983	mean
April	1- 7	1,3	6,6	-7,1	-0,6	20,0	25,0	12h59
	8-14	6,9	8,5	-2,3	0,8	10,0	30,6	13h22
	15-21	13,6	5,4	2,5	0,2	14,2	53,2	13h41
	22-28	14,9	12,2	4,4	2,0	1,8	40,4	14h00
May	29- 5	18,6	16,2	2,7	8,4	0,0	29,2	14h20
	6-12	20,5	11,9	8,1	3,6	11,8	47,4	14h40
	13-19	20,2	16,6	7,1	3,7	14,0	14,8	14h57
	20-26	18,9	19,4	8,7	9,1	21,2	41,8	15h14
June	27- 2	25,8	17,0	14,9	8,5	17,0	36,6	15h24
	3- 9	21,0	19,5	8,4	7,1	3,4	13,7	15h33
	10-16	22,9	29,1	11,0	15,5	14,0	0,0	15h38
	17-23	20,4	29,9	11,3	15,6	73,4	0,4	15h40
	24-30	21,6	23,3	11,6	11,4	11,6	19,4	15h39
July	1- 7	24,7	27,1	9,5	16,8	14,8	18,4	15h35
	8-14	27,4	26,0	15,4	14,3	0,6	15,9	15h27
	15-2	29,3	27,1	16,3	16,4	11,4	28,8	15h17
	22-28	26,1	27,6	14,3	15,1	25,4	1,8	15h05
August	29- 4	23,7	27,5	12,4	18,0	91,4	27,4	14h45
	5-11	25,1	25,9	14,7	14,1	26,3	57,6	14h28
	12-18	24,1	25,6	13,6	11,9	20,8	3,0	14h07
	19-25	20,6	24,3	11,4	12,9	72,8	3,0	13h48
September	26- 1	20,4	26,0	8,1	14,8	48,8	26,6	13h29
	2- 8	19,1	28,2	9,0	15,9	7,2	9,8	13h10
	9-15	25,1	22,5	12,9	10,8	21,8	1,2	12h49
	16-22	17,1	22,8	6,9	11,4	3,2	67,8	12h22
	23-29	17,6	18,0	10,0	4,7	27,2	0,4	11h59
October	30- 6	18,6	20,1	5,4	8,9	6,8	38,4	11h35
	7-13	12,8	15,1	5,5	5,0	18,6	18,2	11h13
	14-20	12,8	10,8	3,9	2,7	7,2	0,4	10h49
	21-27	10,1	8,7	-1,4	-1,6	0,0	19,0	10h31
	28-31	17,8	10,3	5,9	0,1	1,2	4,4	10h16

TABLE 4. Spray program for onion field experiments 1982 and 1983

Type of treatment Trade name (common name)	Rate of application	Number and time of applications	
Herbicide			
Randox-E (allidochlor)	11 l ha^{-1}	1	0-6 days after sowing
CIPC (chlorpropham)	11 l ha^{-1}	1	idem
Granular Randox (allidochlor)	33.6 kg ha^{-1}	1	1982:July 14 1983:not used
Fungicide			
Dithane M-45 (mancozeb)	2.8 kg ha^{-1}	8	1982:June 28 to Aug.24 1983:July 5 to Aug.24
Insecticide			
Diazinon 500-E (diazinon)	2.8 kg ha^{-1}	3	1982:May 27,June 3 &10 1983:June 7,15 &22
Lorsban (chloropyrifos)	1.1 l ha^{-1}	1	1982:May 26 1983:June 9

At harvest, measurements were taken on the full length (5 m) of each of the 2 middle rows. Data were taken on total bulb weight and number. Mean bulb weight was calculated and fresh weight transformed to be expressed as a yield, in tons ha^{-1}.

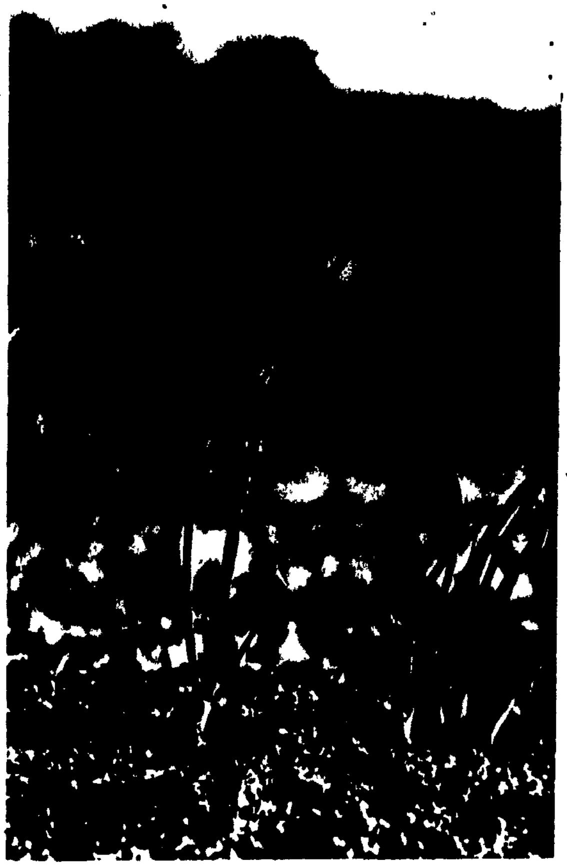
From each plot harvested, a sample of 5 bulbs was taken (20 bulbs per treatment) and used to measure height and diameter, and to calculate the shape index (height/diameter) of the onions. To determine dry matter content, the bulb was quartered and one quarter section was used. The quarters were cut longitudinally to take into account the gradient in dry matter existing from top to bottom and from outside to inside of the bulbs (Foskett and Peterson 1950). After peeling the outer dry scale, the samples were chopped into 5 to 10 mm size pieces and weighed by plot. The material was put in 1.3 kg brown paper bags cut at half height to provide an easy to handle container, and placed in a hot air cabinet drier (Crestweld) at 65°C for 48 hours (Orzolek 1982a) until the samples were dry but not brown. Dried material was then weighed and the percentage of dry matter calculated. This value was multiplied by the total fresh yield computed previously to obtain total dry yield in terms of tons ha^{-1}.

0. Dry seed
1. Germinated seed
2. Loop stage (field emergence)
3. Flag stage (cotyledon)
4. First leaf
5. Fall of the cotyledon (2nd & 3rd leaves)
6. Leek stage (4th leaf)
7. Fall of the first leaf (5th,6th & 7th leaves)
8. Bulb formation (leaves 8 to 10)
9. Bulb growth (visible bulbing)
10. Neck fall (loss of turgidity)
11. Bulb ripeness (dried leaves, closed neck)

2. Loop stage

PLATE 2. Onion growth stages
(adapted from Rey *et al.* 197?)

3. Flag stage



6. Leek stage

10. Neck fall

PLATE 2. (Continued)

3.1.6 Statistical analysis

An analysis of variance using the Statistical Analysis System (SAS) offered by McGill University was conducted for each experiment. The experimental designs and appropriate statistical tests employed have been mentioned within individual experimental sections. The analyses of variance are presented in Appendix tables A.1 to A.7 and A.9 to A.13.

In all experiments, percentage data (% maturity, % survival, % bulb dry matter) were analysed using both percent data and data transformed by arcsine square root to obtain a normal distribution of the data (Little and Hills 1975; Puri and Mullen 1980). Transformations did not alter results of the statistical analyses, thus only percent data have been used in the results and Appendix tables. Linear correlations between the variables were performed to determine the relationships among the observed treatment effects.

3.2 Growth cabinet experiments

3.2.1 Methods and experimental conditions

For all growth cabinet experiments, fertilized organic soil from Ste-Clotilde was collected next to the experimental site and was pasturized (1 hour at 80°C) one week prior use. Soil was placed in 19 X 14 X 7 cm peat flats to a 5 cm depth. Fifty cm of row (either 5 X 10 cm transversal rows or 4 X 12.5 cm longitudinal rows) were formed on the soil surface of each flat. Fifteen ml of Laponite 508 gel (section 3.1.2) was extruded along each row, resulting in an extrusion rate equivalent to that used for the field trials (30 ml m^{-1}).

Seeds were pregerminated as described in section 3.1.1 and when they had 2-3 mm radicle were placed singly with tweezers into the gels. The control treatment consisted of pregerminated seeds placed directly in the rows. All seeds were covered with 1 cm of soil before the flats were put in the growth chambers.

During the experiments, the temperature of the growth chambers (Conviron E-15) was held at 20°C during the day and 15°C at night. The day temperature was coupled with 15 hours of a combination of fluorescent (cool-white) and incandescent light which provided a light intensity of 280 umol $s^{-1}m^{-2}$.

3.2.2 Measurements

Preliminary experiments on the effects of gel types and additives on seedling emergence and growth were conducted under controlled environmental conditions. Due to the nature of the system, it was possible to obtain more detailed data on emergence patterns than from the field trials. Daily emergence counts were used to produce emergence curves according to methods outlined by Goodchild and Walker (1971). Mean emergence time was calculated for each treatment using Orchard's (1977) formula:

$$\bar{X} = \frac{\sum (Nx \cdot X)}{\sum Nx}$$

where $\bar{X}$ is the mean emergence time for a treatment

Nx is the number of seedlings emerging on day x, and

X is the number of days from sowing, at each recording date.

Forty-one or 49 days after seeding depending on the experiment, results were taken on total fresh weight and percentage survival. Mean plant weight was also calculated.

3.2.3 Statistical analysis

The experimental designs and tests done are specified within each experiment. Analyses of variance were performed on the data for all experiments, and are presented in Appendix tables A.8, and A.14 to A.18. All percentage data (emergence % and survival %) were analysed using both percent data and data transformed by arcsine square root. Transformations did not alter the statistical analyses, thus only percent data have been used in the results and Appendix tables.

IV. EXPERIMENTAL WORK

4.1 CULTIVAR EVALUATION - Field trials 1982 & 1983

4.1.1 Introduction

The main characteristics for good dehydrating onions are high dry matter content (Voss 1979), white colour, and large bulb with an elongated shape to facilitate and optimize the processing (Woods Gordon 1982). It is also essential to find cultivars that can yield satisfactorily within the relatively short growing season (Dubé *et al.* 1982) and long daylength (Thomas 1983) experienced in Quebec. In 1982 and 1983, cultivars from U.S.A. and Europe were compared with the standard Southport White Globe and other cultivars grown in Quebec, to determine firstly their suitability for producing onions for dehydration in the Ste-Clotilde organic soil area and secondly their response to the fluid drilling technique.

4.1.2 Materials and methods

Onion seeds were obtained from a number of sources (Table 5). Eight cultivars were tested in 1982 and 9 in 1983. Only five of those cultivars were used both years as poor performers were removed and replaced after the first year.

Seeds used for dry seeding were counted and prepared as described in section 3.1.1. Seeds for fluid drilling were germinated in a water bath at 19-20°C for 3 1/2 days and were stored in cold aerated water for 3 days in 1983. During the storage period, growth continued with the result that some radicles were longer than the 2-5 mm optimum length. Laboratory viability tests were conducted on 4 samples of 100 seeds for each cultivar (Table 5). Gel was prepared following procedures outlined in section 3.1.2.

Sowing was done on May 6 in 1982, and on May 14 in 1983. Standard cultural and managerial procedures were followed (section 3.1.4). Observations of plot maturity (85% neck fall) began on August 23 in 1982. In 1983, two cultivars, Creoso and Primero reached neck fall stage August 9 and the remainder August 24, 1983. The onions were pulled from August 26 to September 9 in 1982; and from August 10 to 17 for Creoso and Primero cultivars, and August 31 to September 8 for the other cultivars in 1983. In 1982, harvesting was carried out between 130-137 days after seeding. In 1983, harvesting was in two distinct periods at: 104 days and 122 days for Creoso/Primero and all other cultivars, respectively.

TABLE 5. Source and percentage viability of onion cultivars used in 1982 and 1983 field trials.

CULTIVAR	SOURCE		VIABILITY (%)	
	Seed company	Location	1982	1983
Bejo 10[1]	Bejo Zaden	Holland	90%	95%
Bejo 11[1]	Bejo Zaden	Holland	90%	---
Creoso[1]	Dessert	California	---[3]	87%
Dehydrator-14[1]	Dessert	California	---	90%
Green Bunching[2]	Perron	Quebec	85%	81%
Hysol[2]	Sluis & Groot	Holland	70%	50%
Ohlhens Enke-2497[1]	Ohlsens Enke	Denmark	90%	---
Ohlsens Enke-2498[1]	Ohlsens Enke	Denmark	90%	---
Primero[2]	Dessert	California	---	85%
Southport White Globe[2]	Perron	Quebec	85%	81%
Vista White[1]	Moran	California	80%	75%
White Keeper[1]	Perron	Quebec	---	92%

1. Hybrid
2. Standard cultivar
3. not used in the trial

In both years, time to emergence and to maturity, plant stand at harvest, mean bulb weight, bulb shape index, fresh and dry yield, and bulb dry matter content were measured and statistically analysed.

In 1982, the cultivar trial was set up as two separate experiments, one for each sowing method (fluid drilling and dry seeding). In each experiment, the 8 cultivar treatments were arranged in a randomized complete block design and replicated 4 times. Analyses of variance were performed on the data within each experiment (Tables A.1 & A.2). Means were compared and cultivars ranked using the Least Significant Difference (LSD); (Little and Hills 1975). Since the 2 sowing methods were tested in separate experiments, no statistical tests could be used to compare the effect of sowing method. Hence only non statistical comparisons were done.

The 9 cultivars and the 2 sowing methods were compared within a single experiment in the 1983 trial using a completely randomized design, arranged as a 9X2 factorial with 4 replications. Depending on the results of the analyses of variance, three different statistical tests were performed on the 1983 data (Table A.3). Firstly, when there was a significant interaction between cultivar and sowing method, simple effects were examined and an LSD test was used at the 0.05 level of significance for comparisons among the 18 treatment combination means. Secondly, when differences among cultivars and seeding types were both significant, the LSD (0.05) was applied on treatment combinations. Finally, in cases where the sowing method had no significant effect on the variable measured, the LSD (0.05) was calculated on the averaged values of fluid drilled and dry seeded treatments for each cultivar.

4.1.3 Results for 1982

Time to emergence

There was no significant difference in time to emergence among cultivars for either fluid drilling or dry seeding experiments (Tables A.1 & A.2). Nevertheless, there was a tendency for Green Bunching, Southport White Globe and Bejo 10 cultivars to emerge earlier in both experiments, and for the Ohlsens Enke series to emerge later than other cultivars (Table 6). Although statistical comparisons cannot be made between the two experiments, the data show that seedlings from fluid drilled plots emerged 2.8 to 5.8 days earlier than their dry seeded counterparts. The greatest advantage in time to emergence from the fluid drilling technique was noted for Bejo cultivars.

Time to maturity

Considering both fluid drilling and dry seeding experiments, cultivars Green Bunching and Hysol reached maturity significantly earlier than all other cultivars with Ohlsens Enke-2497 being the slowest to mature (Figure 1a). Ranking among cultivars was similar for the two sowing types, but the dry seeded plots matured faster than fluid drilled ones with the exception of Green Bunching which matured a day earlier when fluid drilled. The average time to maturity was 122.4 and 120.7 days for fluid drilled and dry seeded treatments, respectively.

TABLE 6. Effect of fluid drilling and dry seeding on time to emergence of 8 onion cultivars in a 1982 field trial.

Cultivar	Time to emergence (days from sowing)	
	Fluid Drilling	Dry Seeding
Bejo 10	8.0	13.0
Bejo 11	8.5	14.3
Green Bunching	7.8	12.5
Hysol	8.8	13.3
Ohlsens Enke-2497	10.0	12.8
Ohlsens Enke-2498	9.3	14.0
Southport White Globe	8.3	12.0
Vista White	9.0	13.8
LSD (0.05)	ns	ns

ns: non significant

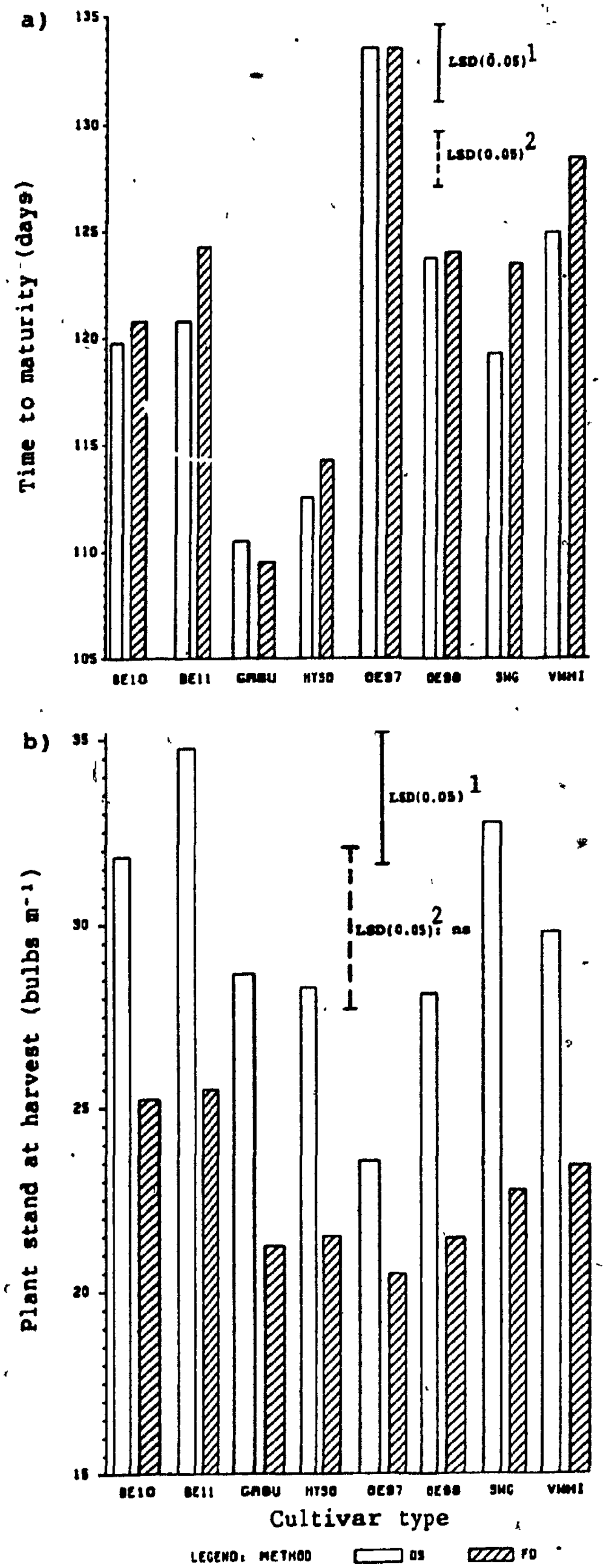


FIGURE 1. Response of cultivars in terms of a) time to maturity and b) plant stand at harvest to fluid drilling and dry seeding methods in a 1982 field trial.
1. LSD values for DS treatments   2. LSD values for FD treatments

Plant stand at harvest

When dry seeded, Bejo 10, Bejo 11 and Southport White Globe cultivars had a significantly higher plant stand at harvest than other cultivars. Ohlsens Enke-2497 had the lowest plant stand of all cultivars (Figure 1b). Similar trends were noted for the fluid drill experiment, although differences between cultivars were not significant (Table A.1). More bulbs were harvested from dry seeded plots (mean of 29.7 bulbs m^{-1}: 66.0% survival) than fluid drilled ones (mean of 22.7 bulbs m^{-1}: 50.4% survival) for all cultivars (Figure 1b).

Bulb shape index

Bulb shape index (height/diameter) ranged from 0.83 to 0.91 for fluid drilled and dry seeded Bejo 10, Bejo 11, Green Bunching and Hysol cultivars. Other cultivars showed a more elongated shape which bulb shape indices ranged from 0.93 to 1.03 (Table 7 & Plate 1). Bulbs from dry seeding tended to have a higher shape index than fluid drilled ones for most cultivars with Hysol being the only exception. A higher variation in shape index values were found for dry seeded compared to fluid drilled plots.

The significant but low negative correlation between bulb weight and bulb shape index (Fluid drilling: $P \leq 0.0039$, $r=-0.50$; Dry seeding: $P \leq 0.0420$, $r=-0.36$) indicated that large bulbs tended to be more flattened at the ends.

TABLE 7. Bulb shape index values of 8 onion cultivars sown by fluid drilling or dry seeding in 1982.

Cultivar	Bulb shape index (height/width)					
	Fluid Drilling			Dry Seeding		
	Mean value	Maximum value	Minimum value	Mean value	Maximum value	Minimum value
Bejo 10	0.87	0.88	0.87	0.90	1.00	0.97
Bejo 11	0.83	0.86	0.75	0.85	0.88	0.81
Green Bunching	0.86	0.88	0.82	0.91	0.97	0.86
Hysol	0.88	0.98	0.79	0.86	0.91	0.82
OE[1]-2497	0.99	1.06	0.91	1.03	1.13	0.94
OE[1]-2498	0.96	1.00	0.93	0.94	1.05	0.85
SWG[2]	0.93	1.00	0.84	1.02	1.11	0.93
Vista White	0.95	1.02	0.91	0.99	1.00	0.97
LSD (0.05)	0.07			0.10		

[1].OE : Ohlsens Enke cultivar
[2].SWG : Southport White Globe cultivar

Mean bulb weight

Mean bulb weights of cultivars Bejo 10 and Green Bunching were significantly greater than all other cultivars in both experiments (Figure 2a). Ohlsens Enke cultivars routinely produced the smallest and lightest bulbs. Fluid drilled bulbs were generally larger than dry seeded bulbs with the exception of the Ohlsens Enke series for which mean bulb weight of dry seeded bulbs was slightly higher than fluid drilled ones.

Fresh yield

Bejo 10 produced significantly higher yields than all other cultivars (Figure 2b). Its yield of 73.3 and 76.6 t ha^{-1} for fluid drill and dry seeds, respectively, were double those of the lowest series (Ohlsens Enke). Ranking among cultivars remained similar whether they were dry seeded or fluid drilled. Dry seeded cultivars yielded more than fluid drilled cultivars in all cases with increases of between 1.8 and 9.2 tons ha^{-1}. The average fresh yield for fluid drilled cultivars was 51.4 t ha^{-1} and 56.9 t ha^{-1} for dry seeded cultivars.

There was a significant correlation between time to emergence and fresh yield of fluid drilled cultivars ($P \leq 0.0052$, $r=-0.48$), and thus an early emergence tended to be accompanied by a high yield. Strong positive correlations ($P \leq 0.0001$) were found between bulb number (plant stand) and fresh yield for both fluid drilling ($r=+0.52$) and dry seeding ($r=+0.60$), and also between fresh yield and mean bulb weight (fluid drilling: $r=+0.90$; dry seeding: $r=+0.89$).

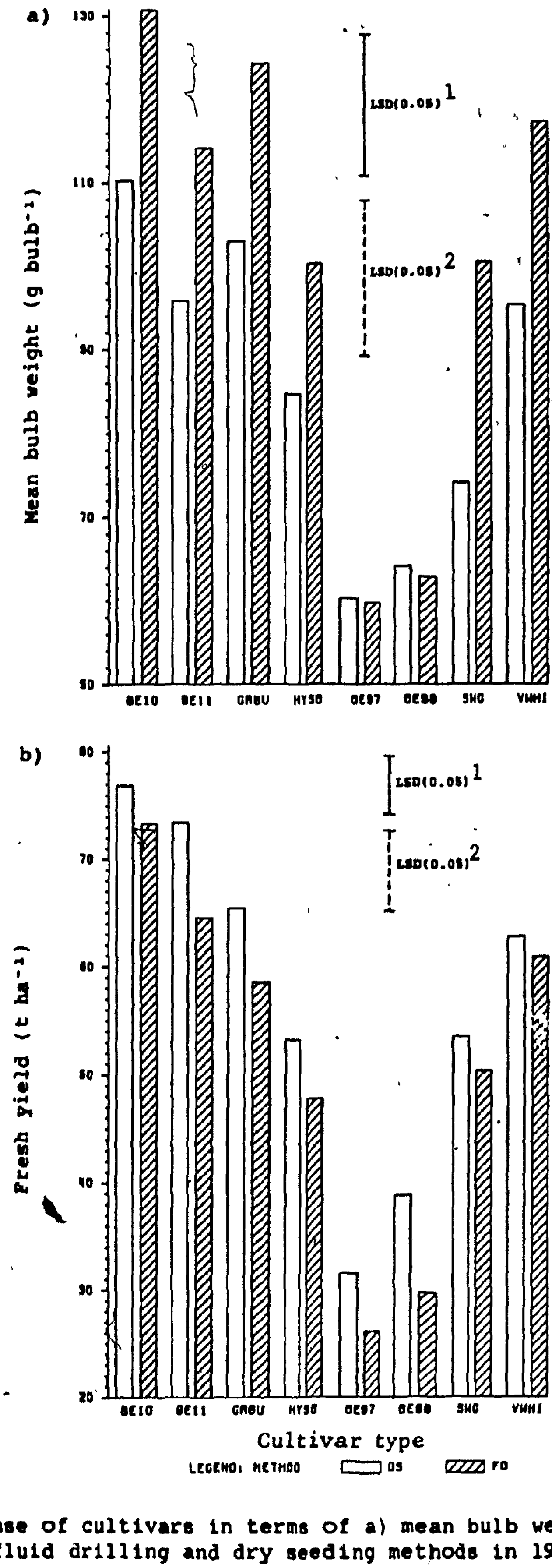


FIGURE 2. Response of cultivars in terms of a) mean bulb weight and b) fresh yield to fluid drilling and dry seeding methods in 1982.

1. LSD values for DS treatments 2. LSD values for FD treatments

Bulb dry matter

Bulb dry matter content ranged from 14.1 to 18.8% in the fluid drilling and from 14.1 to 19.1% in the dry seeding experiment (Figure 3a). In both experiments, cultivars Ohlsens Enke (2497 & 2498), Southport White Globe and Hysol showed a significantly higher dry matter percentage than the other cultivars. Dry seeded bulbs tended to have a higher dry matter content than fluid drilled bulbs with the exception of Green Bunching, Ohlsens Enke-2498 and Southport White Globe cultivars.

The high negative correlations ($P \leq 0.0001$) between bulb weight and bulb dry matter found among cultivars for fluid drilled ($r=-0.72$) and dry seeded ($r=-0.64$) treatments indicated that the smaller bulbs (Ohlsens Enke series) generally contained more dry matter than cultivars with bigger bulbs (Bejo series). There was also a highly significant correlation ($P \leq 0.0001$) between dry matter content and fresh yield among fluid drilled ($r=-0.76$) and dry seeded ($r=-0.68$) cultivars.

Dry matter yield

Dry matter per unit area or dry yield (t ha^{-1}) data showed that the Bejo 10 cultivar was superior to all cultivars in fluid drilled plots and equivalent to Bejo 11 in dry seeded ones (Figure 3b). Dry yields of cultivars Southport White Globe and Vista White were similar to those of the Bejo series. On the other hand, dry yields of the 2 Ohlsens Enke cultivars were significantly lower than all other cultivars tested. The average dry matter yield was 8.2 and 9.2 t ha^{-1} for fluid drilled and dry seeded treatments, respectively.

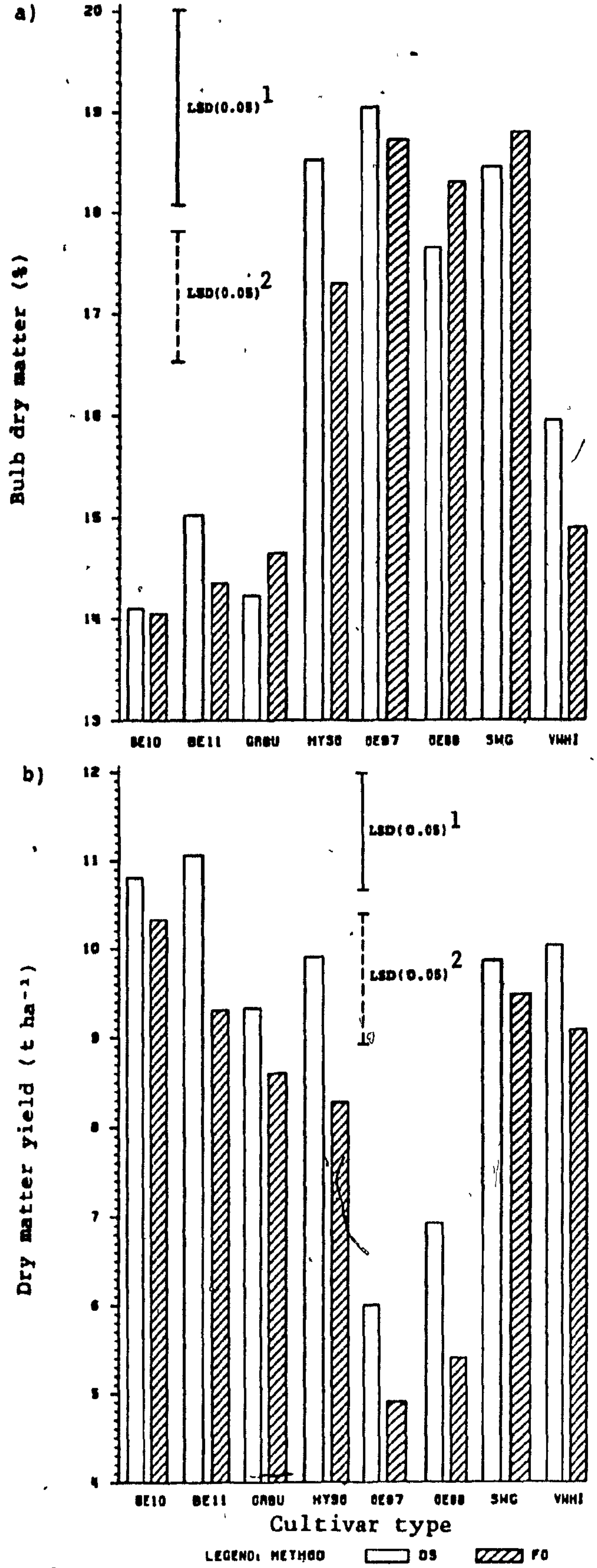


FIGURE 3. Response of cultivars in terms of a) bulb dry matter content and b) dry matter yield to fluid drilling and dry seeding methods in 1982.

1. LSD values for DS treatments 2. LSD values for FD treatments

3.2.4 Results for 1983

Time for emergence

Emergence was hastened by an average of 0.5 to 3.3 days by fluid drilling when compared to dry seeding (Figure 4a). While fluid drilled cultivars emerged within 9.3 to 14.8 days, dry seeded cultivars emerged in 11.8 to 15.3 days. The advantage conferred by fluid drilling was significant for all cultivars but Hysol. Among fluid drilled treatments, Green Bunching, Southport White Globe and Bejo 10 emerged significantly earlier while Hysol emerged significantly later than the other cultivars. The response pattern was similar for the dry seeded treatments.

Plant stand at harvest

Dry seeding resulted in higher plant counts at harvest than fluid drilling for all cultivars except Creoso and Primero (Figure 4b). The difference between sowing methods was significant only for the cultivar White Keeper which produced 59.3% more bulbs in the dry seeded plots. Regardless of the sowing method, plant stand was highest for Bejo 10 and lowest for Hysol. The mean percentage of survival was 41.6% (18.7 bulbs m^{-1}) for fluid drilled cultivars and 47.8% (21.5 bulbs m^{-1}) for dry seeded ones.

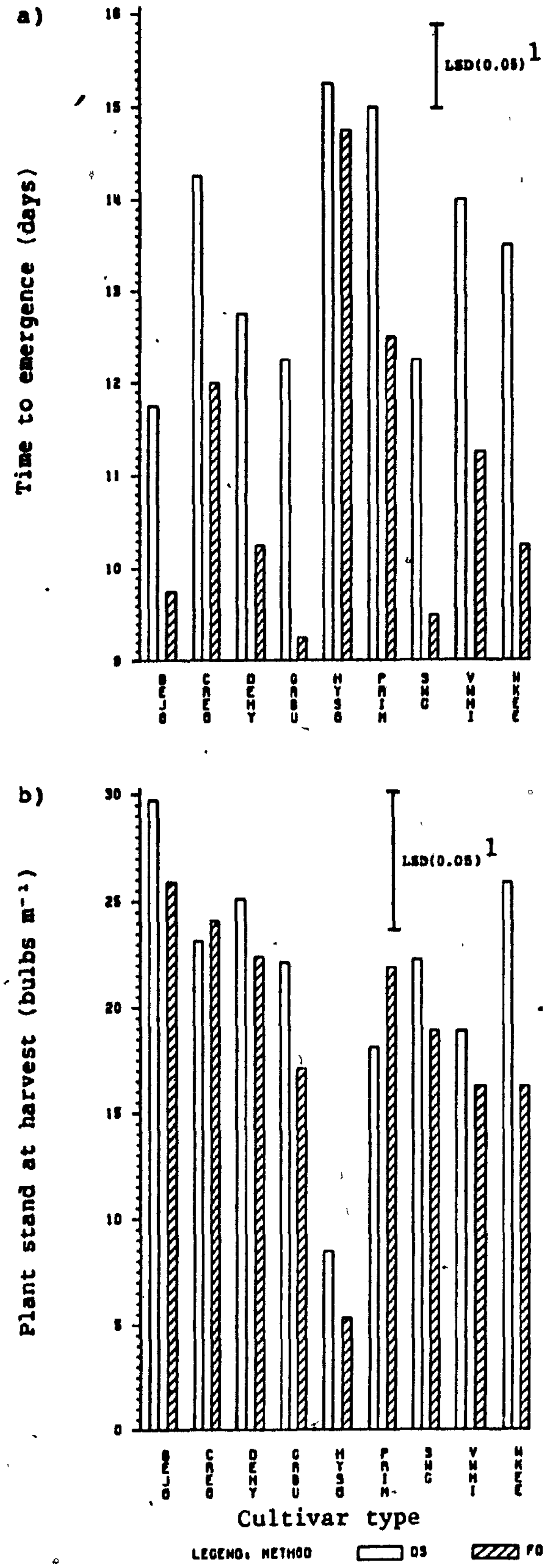


FIGURE 4. Effect of cultivar and sowing method on a) time to emergence and b) plant stand at harvest of white onion in 1983.

1. LSD values for both DS & FD treatments

Bulb shape index

Type of seeding did not have a significant effect on the bulb shape (Table A.3), and thus values were averaged for each cultivar. White Keeper, Vista White and Dehydrator-14 cultivars had higher bulb shape indices than all other cultivars (Table 8). White Keeper bulbs were of a high globe shape appropriate for dehydration; while Vista White, Southport White Globe and Dehydrator-14 bulbs had globe shapes and other cultivars flat globes (Plate 1).

Among cultivars, ones with higher shape indices tended to have more variation in the observed plant material.

Mean bulb weight

Fluid drilling yielded greater bulb weights than dry seeded treatments for all cultivars save Creoso and Primero (Figure 5). The advantage of fluid drilling ranged from 2.3% for Vista White to 41.9% for White Keeper cultivar. However, only for White Keeper and Hysol cultivars was there a significant difference between sowing methods.

White Keeper and Hysol yielded significantly larger bulbs in terms of weight than all other cultivars when fluid drilled. On the other hand, dry seeded Hysol gave larger bulbs than all other cultivars. Regardless of the sowing method, Creoso and Primero produced the smallest bulbs.

TABLE 8. Average values for bulb shape indices of 9 onion cultivars sown by fluid drilling and dry seeding in 1983.

Cultivar	Bulb shape index (height/diameter)		
	Mean value	Maximum value	Minimum value
Bejo 10	0.95	1.07	0.83
Creoso	0.93	0.96	0.86
Dehydrator-14	1.00	1.06	0.94
Green Bunching	0.96	1.02	0.89
Hysol	0.93	1.03	0.87
Primero	0.97	1.14	0.83
Southport White Globe	0.99	1.10	0.88
Vista White	1.09	1.24	1.01
White Keeper	1.16	1.29	1.01
LSD (0.05)	0.066		

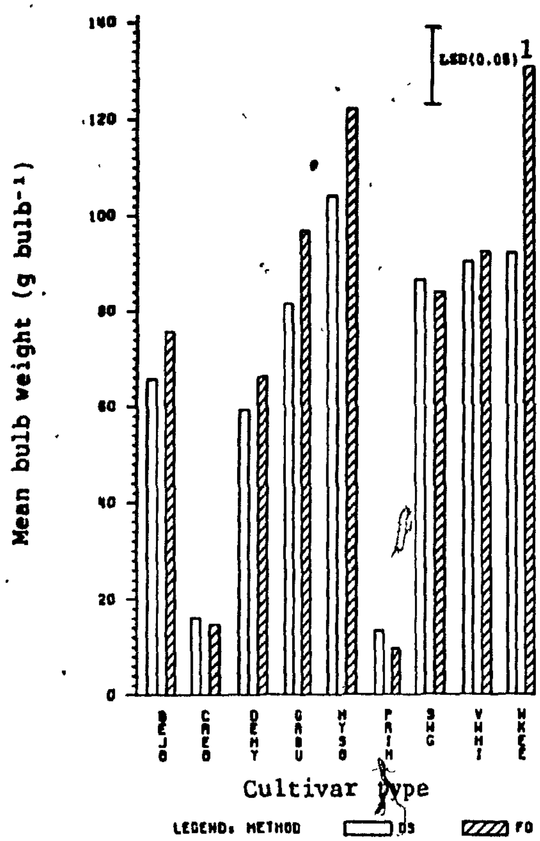


FIGURE 5. Effect of cultivar and sowing method on mean bulb weight of white onion in 1983.

1. LSD value for both DS & FD treatments

Fresh yield

Fluid drilling significantly depressed fresh yield by 15.3 to 17.6% compared to dry seeding for Green Bunching and Southport White Globe cultivars, respectively (Figure 6a). For all other cultivars, the difference in fresh yield between sowing methods was not significant. The average yield for fluid drilled treatments was 28.0 t ha^{-1} and 31.4 t ha^{-1} for dry seeding.

White Keeper was the highest yielding cultivar for both sowing methods, with an average yield of 49.2 t ha^{-1}. This was followed by Green Bunching, Bejo 10 and Southport White Globe which were not significantly different from each other. Creoso and Primero yielded significantly less (4.8 to 7.8 t ha^{-1}) than all other cultivars.

Fresh yield data were significantly correlated with mean bulb weight ($P \leq 0.0001$; $r=+0.62$), and also but to a lesser extent, with plant stand at harvest ($P \leq 0.0053$; $r=+0.33$). Fresh yield was significantly correlated ($P \leq 0.0001$) with the reciprocal of time to emergence ($r=-0.47$) and time to maturity ($r=+0.62$). Therefore, the shorter the emergence and the longer the maturity time, the higher the yield.

Dry matter yield

While dry matter yield was generally lower from fluid drilled plots than dry seeded plots, it was significant only for the cultivar Southport White Globe (Figure 6b). Creoso, Primero and Hysol had the lowest (1.1 to 3.7 t ha^{-1}) and Bejo 10 and White Keeper the highest (6.6 to 7.3 t ha^{-1}) dry matter yields of the cultivars tested.

Dry matter yield was negatively correlated ($P \leq 0.0001$) with time to emergence ($r=-0.45$) but positively correlated with time to maturity ($P \leq 0.0001$, $r=+0.64$).

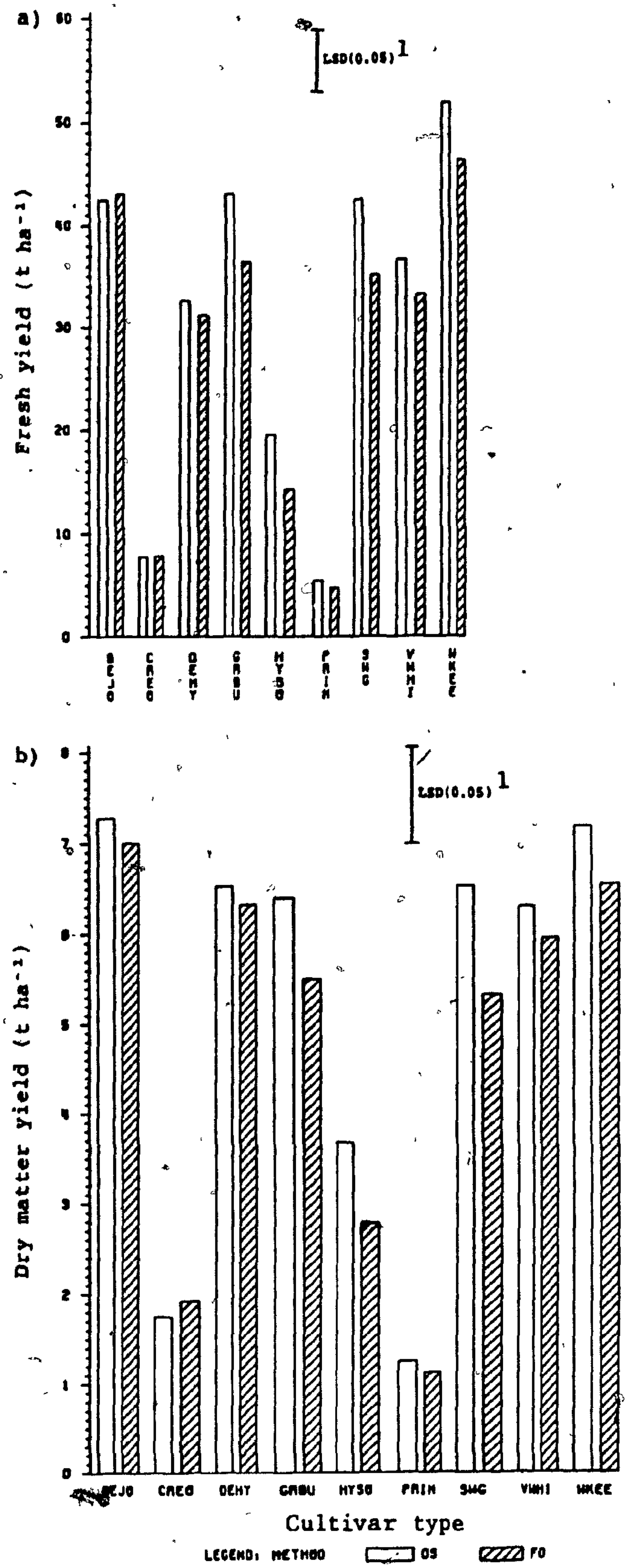


FIGURE 6. Effect of cultivar and sowing method on a) fresh yield and b) dry matter yield of white onion in 1983.

1. LSD values for both DS & FD treatments

Time to maturity

Seeding method did not have a significant effect on the time to maturity for the different cultivars (Table A.3), and thus fluid drilling and dry seeding values were averaged (Figure 7a). Creoso and Primero cultivars matured in 92.5 and 90 days, respectively. The average time to maturity for the other cultivars was 112.3 days. Among the other cultivars, Green Bunching was the first to mature after 106.8 days, followed by Southport White Globe, Bejo 10 and Dehydrator-14 which were not significantly different one from another.

Bulb dry matter

No significant effect of seeding method was found on bulb dry matter content (Table A.3). A significantly higher dry matter content per bulb was observed for Creoso and Primero bulbs (23.7 and 24% respectively) than all other cultivars. The lowest bulb dry matter values were recorded for Southport White Globe, Green Bunching and White Keeper (Figure 7b).

A highly significant ($P \leq 0.0001$) correlation was found between bulb dry matter content and both the reciprocal of mean bulb weight ($r=-0.75$) and of time to maturity ($r=-0.68$). This suggested that small bulbs tended to contain a higher dry matter content than large ones, and that an early maturity resulted in bulbs with a higher dry matter content. Fresh yield and dry matter data were also negatively correlated ($P \leq 0.0001$, $r=-0.85$), meaning that a low fresh yield was closely related to a high bulb dry matter content.

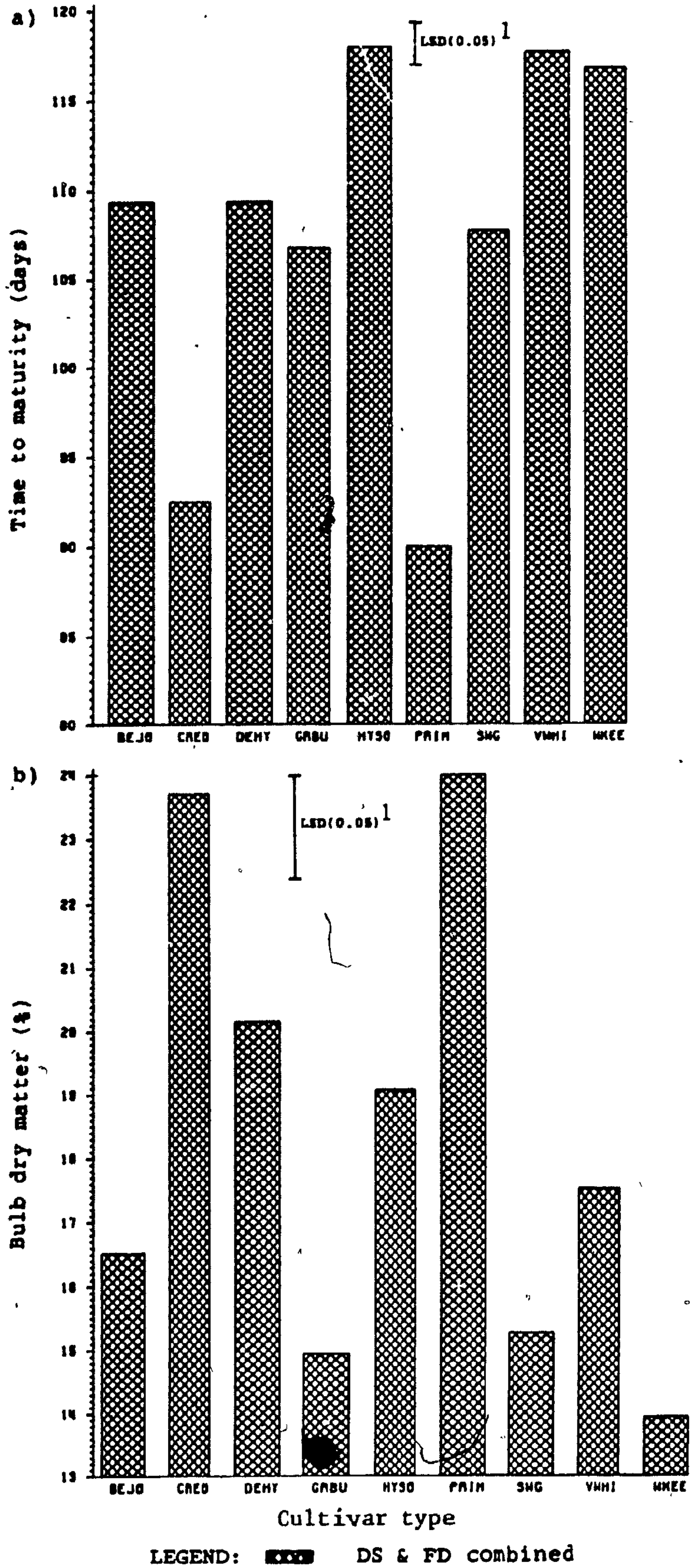


FIGURE 7. Effect of cultivar and sowing method on a) time to maturity and b) bulb dry matter of white onion in 1983.

1. LSD values for DS & FD combined treatments

4.1.5 Discussion

Results of the 1982 and 1983 field trials indicated the importance of adaptation in obtaining cultivars that could reach maturity and yield satisfactorily in the Ste-Clotilde region of Quebec. Some of the cultivars tested proved unsuitable under our climatic conditions where a maximum daylength of 15 hours 40 minutes was reached around June 21 (Table 3). In 1982, the Ohlsens Enke series from Denmark showed a high proportion of double bulbs with stiff upright necks which kept the bulbs from maturing properly. This reflected a problem of long-day cultivars adapted to areas of latitude above 55° (Denmark) being grown in our region (45° latitude) where the daylength was long enough to induce bulbing but not to allow a full development of the bulbs. Jones and Mann (1963) reported a similar case when Southport White Globe cultivar, grown at lower latitudes than its normal area of adaptation, gave stiff necks and bulbs that did not mature.

Furthermore, the occurrence of double bulbs was shown to depend on the genetic background of the plant and on environmental factors (Yamaguchi et al. 1975; Rabinovitch 1979). Conversely, the short day types grown in 1983, Creoso and Primero, started to bulb and mature very early (Figure 7a). The bulbs produced were small and yields low (Figures 5 and 6a&b). These cultivars had been adapted to a daylength of 12-14 hours and were ideal for southern regions such as California (30-40° latitude). Creoso and Primero thus were not suitable for dehydration purposes in the Quebec region since they did not make sufficient leaf growth prior to bulbing to be productive. All other cultivars tested were comparable to the standard cultivar Southport White Globe in terms of adaptation, as they showed normal growth in our climate (Figures 1 to 7). However, Bejo 11 was withdrawn from the second year's trial as the bulbs were yellow and were thus not suitable for dehydration.

In temperate zones, once critical daylength has been achieved, bulbing is initiated and growth then depends upon temperature. Optimum temperatures for bulbing and maturing occurred at 21-27°C and 25-30°C, respectively (Brewster 1977). Above these temperatures, bulbs matured earlier and yields have been reduced. This interaction between photoperiod and temperature may have helped to explain the yearly differences in response of cultivars where 1982 growth parameters and yields were routinely higher than their 1983 counterparts (Figures 1 to 7).

Following the results of combined trials, cultivars were ranked as to their suitability for production on the organic soils of Quebec (Table 9). The ranked order was as follows:

1. Dehyrator-14
2. Southport White Globe
3. Vista White
4. Bejo 10
5. White Keeper
6. Green Bunching
7. Hysol
8. Ohlsens Enke series, Creoso and Primero

TABLE 9. Principal characteristics of selected white onion cultivars used in 1982 and 1983 trials. Figures represent the means of both sowing methods and the 2 trial years.

Name	Emergence	Maturity	Survival	Bulb size	Shape[3]	Dry matter(%)	Yield
Dehydrator-14[1]	med.	early 109 days	high	small-med.	Globe SI=1.00	high 20.2	med-high
Southport White Globe	early	med. 115 days	med.-high	med.	Globe SI=0.98	med.-high 17.0	med-high
Vista White	med.	late 122 days	med.	large	Globe to high Globe SI=1.09	med.-high 16.5	med-high
Bejo 10	early	med. 114 days	high	med-large	Flat Globe SI=0.92	low-med. 15.3	high
White Keeper[1]	med.	med.-late 117 days	high	large	High Globe SI=1.16	low 13.9	high
Green Bunching	early	early 108 days	med.	large	Flat Globe SI=0.92	low-med. 14.7	med-high
Hysol[2]	late	early-med. 113 days	med.	med.	Flat Globe SI=0.87	high 18.0	med.

1. Means from 1983 trial only. Cultivar not used in 1982.
2. Means from 1982 trial only, due to the very low survival in 1983.
3. Bulb shapes are represented on Plate 1. SI: Shape Index

Of the cultivars tested, only Dehydrator-14 and Southport White Globe were consistently positive for each of the characters studied (Table 9). For others, while one character proved extremely positive another was negative and hence down graded the cultivar. An example of this was Bejo 10 which produced extremely high yields but with dry matter levels below that normally required for dehydration. It is important to note however that rankings were based only on 2 years of observations and that a more extensive study would have to be undertaken before commercial recommendations could be made.

The Ohlsens Enke series showed poor characteristics and should be excluded from further trials. Cultivars Creoso and Primero gave bulbs too small for dehydration (Figure 5), but they had a very high dry matter content (Figure 7) and could be useful for pickling.

The highly significant correlation found among cultivars between bulb dry matter and the reciprocal of mean bulb weight confirmed the findings of Mann and Hoyle (1945), McCullum (1968) and Nieuwhof et al. (1973). A relationship was also observed between bulb dry matter content and both fresh and dry yield in the present experiments, indicating that the most productive cultivars had the lowest dry matter content, for example: cvs. Bejo 10 and White Keeper (Figures 2, 3, 6 & 7; Table 9). This was in keeping with the results of Nieuwhof et al. (1973) who showed that with a 1% increase in dry matter content, the productivity of several cultivars decreased by 10%. There was however a point where this relationship leveled off as Dehydrator-14 (1983 only), Southport White Globe & Hysol (1982 only) had relatively high yields and a high dry matter content. Nevertheless, when selecting for high dry matter cultivars, attention should be paid to subsequent effects on yield.

Yamaguchi et al.(1975) found that high temperatures occurring during bulb formation led to an increase in the concentration of flavour components normally associated with high bulb dry matter content (Hoyle et al. 1972). This seemed to contradict Steer (1982) who reported that a high dry matter percentage in bulbs was to be expected at low temperatures. Both reports could be correct as it could have been an interaction between the inherent dry matter level of cultivar and temperature that determined the final percentage bulb dry matter. Varieties with relatively low dry matter levels responded to high temperatures by increasing their dry matter levels, while high dry matter cultivars responded to low temperatures. In the current study, cv. Southport White Globe produced higher dry matter bulbs in the summer of 1982 where maximum temperatures were around 23°C compared to 1983 where the temperatures reached 29-30°C.

During the trial years, the dry matter content of Southport White Globe bulbs ranged from 14.2 to 19.8% with a mean of 17.3%, while the range for Dehydrator-14 bulbs was from 19.2 to 20.9% with a mean of 20.2%. These findings were similar to the results of Hoyle et al. (1972) and Yamaguchi et al. (1975) who reported variations of 13 to 21% for Southport White Globe and 17 to 21% for Dehydrator-14. However, Mann and Hoyle (1945) noted a lower range (11 to 18.1%) in Southport White Globe bulbs. The differences in dry matter content between the various reports could be explained by 1. the method of sampling the bulbs for solids determination, 2. the method of drying and to what extent the tissues are dried and 3. the source of the seeds. Bulb sampling and drying as described in section 3.1.5 have ensured a reliable measurement of dry matter content.

Approximately 10% of the tissues were trimmed from the ends of the bulbs before dehydration. The amount trimmed depended however on the size and shape of the bulb. A high shape index value (around 1.8) refered to an ideal torpedo shape (Plate 1), whereas a low index (less than 1) indicated a flatter bulb shape which resulted in a 25% waste when trimmed. Therefore, considering both years of the trial, only a few cultivars :Vista White, White Keeper, Dehydrator-14 and Southport White Globe, reached a shape index greater than 1.0 (Tables 7 & 8). Even the highest value measured (1.29) belonged to an intermediate type (Plate 1), thus none of the cultivars presented the ideal torpedo shape. Although in 1982 there was a trend for smaller bulbs to be related to a high shape index, the correlation was not highly significant as had been found by McCullum (1968). The high heritability for bulb shape (62-89%) found by McCullum (1968) would make one expect a similar bulb shape from year to year for the same cultivar. This was not the case in the current experiments. In fact, although the ranking among cultivars for bulb shape remained the same for those used both years, shapes tended to be more elongated in 1983. This confirmed the results of Yamaguchi <u>et al</u>. (1975) who found a tendency for onion bulbs to exhibit a more elongated shape at higher temperatures. The importance of factors other than heredity had also been noted by Voss (1979) who reported that the shape of onions was partly determined by the cultivar but could be influenced by both environmental and cultural factors.

When comparing the 2 sowing methods, it was apparent that the fluid drilled plants started earlier but matured slower than their dry seeded counterparts (Figures 1, 4 & 7; Table 6). The great advantage of fluid drilling over dry seeding for early growth rates was achieved under cool soil conditions (1982), whereas in 1983, rapid drying and warming up of the soil caused these advantages to be lost. The higher plant stand of dry seeded plots may have been a determining factor in hastening plant development. Indeed, Frappell (1973) and Brewster (1977) showed that densely sown plants matured faster than those with a wider spacing.

That dry seeding was done with a machine equipped with a V-shaped belt (section 3.1.3) may have been in large part, responsible for the high plant stand at harvest of dry seeded onions (Figures 1 & 4). Optimally, a precision driller such as Stanhay gave the correct distance between the seeds at sowing, thus minimizing the competition for light, moisture and nutrients, improving growth and increasing yields with a more uniform size and shape of onions at harvest (Lorenz and Maynard 1980; OMAF 1983). The lower plant stand from fluid drilled treatments compared to dry seeds in both years of trial reflected a disadvantage of the fluid drilling system. In fact, Hegarty (1978b) suggested that sowing pregerminated seeds placed the seeds seriously at risk in the environment by removing germination control from the seeds' environmentally sensitive mechanisms. Furthermore, unfavourable weather delayed sowing in 1983 and the seeds were stored in cold aerated water (section 4.1.2). Although, this technique had proven efficient to maintain seeds at the proper stage for sowing when done at 1°C (Finch-Savage 1981), the variation in temperature (from 1 to 5°C) during storage may have caused either a loss of viability or some radicles to grow beyond the 2-5 mm ideal length. Therefore, the advanced chitted seeds were probably more negatively affected by the cold soil than were seeds with shorter radicles or dry seeds, and this would explain the poor initial plant stand. Similar findings have been reported by Hiron and Balls (1978) and Irwin and Price (1983). Generally, a poor initial field stand was translated into an equally low plant stand at harvest. Indeed, this proved to be the case for the fluid drilled material. Therefore, regarding the differences in yield between the sowing methods, the advantage of fluid drilling in time to emergence and bulb weight was not sufficient to compensate for the loss in survival, and the yields were always lower than from dry seeding (Figures 2, 3 & 6).

The differences in cultivar growth and development between the 2 trial years (1982 & 1983) could be directly attributed to climatic variation. The shorter growing season in 1983 caused by both delayed sowing and emergence coupled with an hastened maturity resulted in fresh yields that were 10 to 30 t ha^{-1} lower than in 1982 (Figures 1 to 7). While the early sowing and more evenly distributed rainfalls throughout the season further contributed to average yields largely above the normal in 1982: 54.2 t ha^{-1} (average yield of dry bulb onion in Quebec in 1982: 35.7 t ha^{-1}; Table 1), yields of 1983 season (36.3 t ha^{-1}) were closer to Quebec average yields: 28.4 t ha^{-1}. Jasmin <u>et al</u>. (1977) reported that yields as high as 56 to 68 t ha^{-1} were possible in Quebec on a productive organic soil. Moreover, in 1982, several cultivars reached a fresh yield of above 50 t ha^{-1} (Bejo 10, Green Bunching, Vista White and Southport White Globe; Figure 2b), but only White Keeper reached such a level in 1983 (Figure 6a).

The importance of the environment cannot be understated as it modified cultivar response to cultural and/or managerial techniques. Consequently, cultivars should be tested for at least 3 to 4 years to determine whether they would perform satisfactorily for consecutive years and what cultural changes would need to be made in order to produce a good crop for dehydration. Indeed, cultivars that did not seem to adapt at first such as Hysol may give a good performance with slight changes in cultural practice.

Although the generally poor emergence of onion seedlings would seem to indicate that fluid drilling would be of benefit to this crop (Gray 1981), this has not proven to be the case in current trials. Therefore, in order for the fluid drilling technique to be fully exploited over dry seeding, attention must be paid to the causes of low emergence and subsequent poor plant stands and yields.

4.2 SOWING DATES - Field trials 1982 & 1983

4.2.1 Introduction

It has been shown that for onions to reach the optimal physiological age at the time daylength influences bulb formation, the seeds have to be sown early in the spring (Brewster 1977). In this respect, the sowing of pregerminated seeds has been recommended as a method of overcoming problems of poor emergence and slow establishment of onions (Lipe and Skinner 1979; Salter 1978; Gray 1981). The earlier emergence obtained by fluid drilling germinated seeds has led to higher yields when compared to dry seeding (Currah 1975; Salter 1978). However, the crop response to the technique varies depending on soil temperature at the date of sowing (Hiron and Balls 1978). Although the effects of sowing pregerminated seeds are expected to be greatest earlier in the season when low temperatures delay or prevent germination of dry seeds, pregerminated onion seeds were shown to be more affected than dry seeds in a stress environment such as an extended period of drought or cold (Hegarty 1978b; Hiron and Balls 1978; Steckel and Gray 1980; Taylor 1977). Indeed, in many instances, emergence has been lower when onions were fluid drilled than when dry seeded (Currah 1976; Finch-Savage and Cox 1983; Salter 1978 and Taylor 1977), particularly in very early sowings (Hiron and Balls 1978). Cold damage (Steckel and Gray 1980: fluid drilled onions) as well as disease and soil impedance (Hegarty 1978a: dry seeded calabrese and carrots; Maude 1978: dry vegetable seeds) were shown to be important causes of seedling losses.

Based on the above observations, the following experiment was carried out in 1982 and repeated in 1983 to determine the effect of sowing date on emergence, growth and yield of fluid drilled onions compared to traditional dry seeding. More specifically, this work aimed to evaluate the potential for using the fluid drilling technique to hasten emergence and growth rates which would in turn extend the growing season and increase the dry matter content and yield of onion cv. Southport White Globe, widely used by the dehydration industry.

4.2.2 Materials and methods

Onion seeds cv. Southport White Globe were germinated for fluid drilling, and dry seeds were prepared as described in section 3.1.1. Laponite 508 gel preparation was done according to section 3.1.2. In 1982, the first dry and gel seeding were done as soon as the soil could be worked in the spring, whereas the cold wet conditions in 1983 (Table 3) delayed the first sowing by 2 weeks compared to the previous year. Consequently, in 1983, after being germinated for 3 days at 19-20°C, seeds were held for 3 more days in cold storage at 1-5°C (details in section 4.1.2). For each year, the second and third sowings followed at weekly intervals. Seeding and management procedures were outlined in sections 3.1.3 and 3.1.4. Sowing and harvesting dates and the length of the growing season are presented in Table 10.

Time to emergence, plant stand after establishment (6 weeks) and at harvest, mean bulb weight and diameter, fresh and dry yield, and dry matter content were measured (details in section 3.1.5) and included in the statistical analysis for both years. In addition, plant stand after emergence (3 weeks) and time to maturity (85% neck fall in the plot) were recorded in 1983. Treatments sown on the third date did not reach maturity by September 8, date considered to be the limit to pull the plants in order to ensure minimum curing before the first frost. Therefore, maturity was determined as the percentage of plants showing neck collapse in each plot on that date.

In 1982, fluid drilled and dry seeded treatments were randomized and analysed in a separate block design with 4 replicates for each sowing date (Table A.4). Means separations were done using a Duncan's Multiple Range test. Because of the experimental design used, no statistical comparisons could be made among either fluid drilled or dry seeded treatments between sowing dates.

In 1983, fluid drilled and dry seeded treatments were replicated 4 times and a split-plot arrangement was done in a randomized complete block design where the main plot unit was the sowing date and the sub-plot unit, sowing method. An analysis of variance was performed on the 1983 data (Table A.5). Means separations were done using a Duncan's Multiple Range test. For plant stand (3 & 6 weeks), bulb diameter, dry matter yield and bulb dry matter, date X sowing method interactions did not occur. Main effects were either not significant or significant for only one factor (Table A.5), and therefore were considered separately (Tables 16 & 18). When date X sowing method interactions occurred or date and sowing method main effects were both found (Table A.5), simple effects were examined and presented (Tables 15 & 17). Data from the 2 years could not be analysed together as the experimental designs were not identical.

TABLE 10. Sowing and harvesting dates and time from sowing to harvest in 1982 and 1983 field trials.

Year of trial	Sowing date	Harvesting date	Days from sowing to harvest
1982	1- April 29	Sept,20	144
	2- May 6	Sept.20	137
	3- May 13	Oct.10	146
1983	1- May 13	Sept.13[1]	123
	2- May 19	Sept.13	117
	3- May 25	Sept.13	111

[1]. Early harvest in 1983 due to unfavourable weather for bulb field curing.

4.2.3 Results for 1982

Time to emergence

Emergence was significantly hastened by fluid drilling compared to dry seeding at all sowing dates (Table 11). The advantage gained was 4.0, 3.5 and 4.7 days for sowing dates 1, 2 and 3, respectively. Emergence tended to be slower from the first sowing date than from the 2 later sowings, when comparing fluid drilled or dry seeded onions over the 3 dates.

Plant stand after establishment

Fluid drilling led to 42.1, 10.3 and 28.7% lower plant stands than dry seeding after 6 weeks, for the first, second and third sowing dates, respectively (Table 12). Among fluid drilled treatments, plant stand was highest in the second sowing date, whereas it was highest at the first date in dry seeded plots.

Plant stand at harvest

From establishment to harvest, plant losses ranged from 7.7 to 9.9 bulbs per meter in fluid drilled plots, and from 6.6 to 14.8 bulbs per meter in dry seeded plots (Table 12). Plant losses were greatest when seeds were sown at the first date. There was a strong correlation between the number of plants in the plots after 6 weeks and the final plant stand ($P \leq 0.0001$; $r = +0.82$), showing that plant counts after 6 weeks of growth gave a good indication of the number of harvestable bulbs.

As a result, plant stands at harvest ranged from 35.8 to 69.8% of the initial seed rate (45 seeds m^{-1}). Fluid drilling resulted in significantly lower bulb number than dry seeding. The greatest difference was obtained for the first sowing date where fluid drilling decreased plant stand by 46.7%, while the decrease was 20.7 and 28.1%

for sowings 2 and 3, respectively. Regardless of the seeding treatment, the highest plant stand was obtained with the middle sowing date (Table 12). A significant positive correlation existed between the time to emergence and the number of bulbs per meter at harvest ($P \leq 0.001$; $r=+0.62$). This indicated a tendency toward a lower plant survival as seedlings emerged faster.

Mean bulb weight

Bulb weight was significantly increased by fluid drilling compared to dry seeding at all sowing dates (Table 13). The advantage of fluid drilling was respectively 51.8, 31.4 and 34.3% over dry seeding for dates 1, 2 and 3. When comparing each sowing treatment over the 3 dates, both resulted in smaller bulbs when sowing was done on May 6 (second date). A significant negative correlation ($P \leq 0.0001$; $r=-0.91$) was found between bulb number and mean bulb weight, suggesting that a higher density of bulbs in the row at harvest was associated with a decrease in bulb weight.

Bulb diameter

Although no significant differences in bulb diameter were found between fluid drilling and dry seeding at any of the sowing dates (Table A.4), bulbs tended to be larger in diameter when fluid drilled (Table 13). Among treatments, a low number of bulbs at harvest corresponded to a high bulb diameter as shown by the significant negative correlation ($P \leq 0.0001$; $r=-0.70$) between bulb diameter and bulb number at harvest. In addition, a positive correlation existed between bulb diameter and bulb weight ($P \leq 0.0001$; $r=+0.74$), thus wide bulb diameter tended to be associated with a high bulb weight.

Fresh yield

Seeding method did not significantly affect fresh yield of onions from either sowing date (Table 14). Fresh yield ranged form 45.8 to

57.1 t ha^{-1}. Fluid drilling decreased yields by 16.1 and 2.8% compared to dry seeding for sowing dates 1 and 3, respectively, while it increased yields by 4% for the second sowing.

Dry seeding resulted in 10 t ha^{-1} higher yield when sown at the first date compared to the 2 later sowings. On the other hand, highest yield from fluid drilling was obtained in plots sown on the second date.

Dry matter yield

Differences in dry yield between fluid drilling and dry seeding were not significant for each sowing date (Table 14). However, dry matter yields were 16.2 and 6.4% lower with fluid drilling than dry seeding at sowing dates 1 and 2 respectively, although it was identical for the sowing methods at sowing date 3. Dry yield tended to decrease as the sowing was done later for both fluid drilling and dry seeding.

There were highly significant correlations between fresh yield and dry yield data ($P \leq 0.0001$; $r = +0.92$), and between bulb number at harvest and dry yield ($P \leq 0.005$; $r = +0.59$).

Bulb dry matter

Fluid drilling resulted in bulbs with a significantly lower dry matter content than their dry seeded counterparts at the second sowing date (Table 14). However, the disadvantage of fluid drilling was not significant at sowing date 1, and fluid drilling actually produced a small increase (0.4%) in bulb dry matter content at date 3. There was a tendency for dry matter content to be higher in bulbs from earlier sowings.

TABLE 11. Effect of date of sowing and sowing method on time to emergence of onion cv. Southport White Globe in a 1982 field trial.

Sowing date	Sowing method	Time to emergence (days)
1- April 29	Fluid drilling	9.0 b
	Dry seeding	13.0 a
2- May 6	Fluid drilling	8.0 b
	Dry seeding	11.5 a
3- May 13	Fluid drilling	7.8 b
	Dry seeding	12.5 a

a,b For each sowing date, paired means followed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range test.

TABLE 12. Effect of date of sowing and sowing method on plant stand of onion cv. Southport White Globe, after establishment (6 weeks) and at harvest in 1982.

Sowing date	Sowing method	Stand (6 weeks) (plants m^{-1})	Stand (harvest) (bulbs m^{-1})
1- April 29	Fluid drilling	26.0 b	16.1 b
	Dry seeding	45.0 a	30.2 a
2- May 6	Fluid drilling	34.1 b	24.9 b
	Dry seeding	38.0 a	31.4 a
3- May 13	Fluid drilling	25.6 b	17.9 b
	Dry seeding	35.9 a	24.9 a

a,b For each sowing date, paired means followed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range test.

TABLE 13. Effects of date of sowing and sowing method on bulb weight and bulb diameter of onion cv.Southport White Globe in 1982.

Sowing date	Sowing method	Mean bulb weight (g bulb^{-1})	Bulb diameter (mm)
1- April 29	Fluid drilling	129.3 a	66.6 a
	Dry seeding	85.2 b	56.9 a
2- May 6	Fluid drilling	88.8 a	59.8 a
	Dry seeding	67.6 b	50.4 a
3- May 13	Fluid drilling	115.1 a	61.3 a
	Dry seeding	85.7 b	55.0 a

a,b For each sowing date, paired means followed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range test.

TABLE 14. Effects of date of sowing and sowing method on fresh and dry yields, and on bulb dry matter content of onion cv. Southport White Globe in 1982.

Sowing date	Sowing method	Fresh yield (t ha^{-1})	Dry matter yield (t ha^{-1})	Bulb dry matter (% bulb^{-1})
1- April 29	Fluid drill	47.9 a	9.3 a	19.3 a
	Dry seed	57.1 a	11.1 a	19.5 a
2- May 6	Fluid drill	49.0 a	8.8 a	18.0 b
	Dry seed	47.1 a	9.4 a	19.9 a
3- May 13	Fluid drill	45.8 a	8.2 a	17.9 a
	Dry seed	47.1 a	8.2 a	17.5 a

a,b For each sowing date, paired means followed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range test.

4.2.4 Results for 1983

Time to emergence

Emergence was faster for fluid drilled plots compared with dry seeded plots, for all sowing dates (Table 15). Regardless of the seeding method, time to emergence was significantly shorter for the second sowing date.

Time to maturity

Maturity (Plate 2, stage 10: 85% neck fall) was reached significantly later in fluid drilled plots compared to dry seeded ones for date 1, and significantly earlier for date 2 (Table 15). The time to maturity was not significantly different between dates 1 and 2 for fluid drilled treatments, but it was significantly longer for sowing date 2 than date 1 for dry seeded plots.

Although maturity was not reached in plots sown at the last seeding date, it was observed that an average of 73.5% of the plants showed neck fall in fluid drilled plots by september 8, while only 63.8% neck fall was reached with the dry seeded material.

Plant stand after emergence

After maximum emergence has been reached (3 weeks), no significant differences in plant stand were found between sowing methods or dates (Tables 16 & A.5). Nevertheless, there was a tendency for plant stand to be higher in the plots sown the earliest, and in dry seeded plots compared to fluid drilled plots.

Plant stand after establishment

During the 3 week period from emergence to stand establishment (6 weeks from sowing), losses of 24.0, 2.5 and 9.7% were noted in plots of sowing date 1, 2 and 3, respectively. Fluid drilled plots showed 15.4% decrease in plant counts from emergence to establishment, whereas the decrease was only 9.5% in dry seeded plots.

Consequently, after 6 weeks of growth, plant stand was significantly greater for dry seeded than fluid drilled treatments (Table 16). However, no significant difference was observed among sowing dates.

Plant stand at harvest

Main effects of both sowing date and sowing method on plant stand at harvest were not significant (Table A.5). However, a significant interaction existed between sowing date and method.

Dry seeding resulted in higher number of bulbs per meter than fluid drilling for date 1 and 3 and in a lower plant stand for date 2, the difference being significant only for date 1 (Table 17). In fluid drilled plots, plant stand was significantly higher at date 2 than at the other dates. On the other hand, plant stand was highest at date 1 and lowest at date 2 in dry seeded plots. The resulting percent survival from initial seed rate ranged from 31.5 to 47.6%.

Mean bulb weight

A significant interaction was found between sowing date and sowing method treatments (Table A.5), and thus the simple effects were examined. No significant differences were found between sowing method at either sowing date (Table 17).

Although there was no significant differences in bulb weight among fluid drilled treatments sown on May 13, 19 or 25, a tendency toward a lower bulb weight with later sowing existed. On the other hand, dry seeding led to significantly larger bulbs form sowing date 2 compared to the other dates.

Bulb diameter

There were no significant differences in bulb diameter among sowing dates or between the 2 sowing methods (Table A.5). However, bulb diameter tended to be greater for early sowings (Table 18), and ranged from 52.3 to 54.3 mm.

<u>Fresh yield</u>

A significant interaction between date and method of sowing (Table A.5) resulted in higher fresh yield for dry seeded rather than fluid drilled plots for date 1 and 3, but these advantages were not significant. Fluid drilling resulted in significantly lower fresh yield when plots were sown on May 25 (date 3) compared to the other dates (Table 17). On the other hand, dry seeded plots yielded significantly higher at date 1 compared to the later sowings.

<u>Dry matter yield</u>

Dry yield was significantly higher for sowing dates 1 and 2 rather than date 3 (Table 18). No significant difference was found between the two seeding types. The significant correlations found between dry yield and both bulb number at harvest ($P \leq 0.0001$; $r = +0.73$) and fresh yield ($P \leq 0.0001$; $r = +0.93$), indicated the importance of a high survival and a high fresh yield to obtain high dry matter yield.

<u>Bulb dry matter</u>

There was no significant effect of sowing date or sowing method on the bulb dry matter content (Tables 18 & A.5). Nevertheless, dry matter percentage tended to be higher in plots sown earlier rather than from later sowings.

TABLE 15. Effect of date of sowing and sowing method on time to emergence and to maturity of onion cv. Southport White Globe in 1983.

Sowing date	Sowing method	Time to emergence (days from sowing)	Time to maturity (days from sowing)
1- May 13	Fluid drilling	9.5 cd	109.5 b
	Dry seeding	13.0 a	107.5 d
2- May 19	Fluid drilling	9.0 d	109.0 bc
	Dry seeding	11.5 b	112.5 a
3- May 25	Fluid drilling	9.8 c	-----[1]
	Dry seeding	12.5 a	-----

a-d Means within columns followed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range test.

[1]. Maturity was not reached by the time of pulling

TABLE 16. Effect of date of sowing and sowing method on plant stand of onion cv.Southport White Globe, after emergence (3 weeks) and after establishment (6 weeks) in 1983.

Treatment	Plant stand (3 weeks) (plants m^{-1})	Plant stand (6 weeks) (plants m^{-1})
Sowing date[1]		
1- May 13	34.6 a	26.2 a
2- May 19	31.7 a	30.9 a
3- May 25	32.1 a	29.0 a
Sowing method[2]		
Fluid drilling	31.8 a	26.9 b
Dry seeding	33.7 a	30.5 a

a,b Within columns and within treatment groups, means followed by the same letter are not significantly different at the 5% level by Duncan's Multiple Range test.

[1]. Values for each sowing date are means of 8 observations, from the 2 sowing methods with 4 replications.

[2]. Values for each sowing method are means of 12 observations, from the 3 sowing dates with 4 replications.

TABLE 17. Effect of date of sowing and sowing method on plant stand at harvest, bulb weight and fresh yield of onion cv.Southport White Globe in 1983.

Sowing date	Sowing method	Stand (harvest) (bulbs m^{-1})	Bulb weight (g $bulb^{-1}$)	Fresh yield (t ha^{-1})
1- May 13	Fluid drilling	16.3 bc	101.4 ab	36.3 ab
	Dry seeding	21.4 a	87.0 b	41.7 a
2- May 19	Fluid drilling	19.6 ab	99.5 ab	43.0 a
	Dry seeding	15.4 bc	107.1 a	36.6 ab
3- May 25	Fluid drilling	14.2 c	92.5 ab	29.1 b
	Dry seeding	17.1 abc	88.6 b	33.4 b

a-c Means within columns followed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range test.

TABLE 18. Effect of date of sowing and sowing method on bulb diameter, dry matter yield and bulb dry matter content of onion cv.Southport White Globe in 1983.

Treatment	Bulb diameter (mm)	Dry yield (t ha^{-1})	Dry matter (% $bulb^{-1}$)
Sowing date[1]			
1- May 13	54.3 a	6.3 a	16.1 a
2- May 19	53.7 a	5.9 a	14.9 a
3- May 25	52.3 a	4.8 b	15.5 a
Sowing method[2]			
Fluid drilling	53.0 a	5.6 a	15.6 a
Dry seeding	54.0 a	5.7 a	15.4 a

a,b Within columns and within treatment groups, means followed by the same letter are not significantly different at the 5% level by Duncan's Multiple Range test.

[1]. Values for each sowing date are means of 8 observations, from the 2 sowing methods with 4 replications.

[2]. Values for each sowing method are means of 12 observations, from the 3 sowing dates with 4 replications.

4.2.5 Discussion

The trial results demonstrated that spring weather conditions markedly influenced the response of the white onion crop to the fluid drilling technique.

Fluid drilled plants emerged consistently earlier than those sown by dry seeding (Tables 11 & 15). This advantage of the fluid drilling technique was primarily associated with germination of seeds under optimal conditions prior to sowing, thereby reducing the unpredictable effects of weather and seedbed conditions on radicle emergence (Salter 1978; Ghate 1982) and giving a head start to seedling growth. Earlier emergence has been the most widely reported effect obtained by fluid drilling seeds of over 20 crops, with a range of soil and environmental conditions (Salter 1978). Up to 15 days earlier field emergence has resulted from gel seeding of onions, compared to dry seeding, the advantage depending on soil moisture (Bierhuizen 1981), temperature (Hiron and Balls 1978), and on cultivar (Gray 1981). Earliness in emergence from fluid drilling was generally more important in the first year of the trial where soil moisture levels were lower and temperatures warmer at sowing (Table 3). This could indicate that the gel was able to provide a portion of the water necessary for the early stages of growth, an hypothesis put foreward by Elliott (1967) and Darby (1980). This may apply more specifically to the third sowing of the 1982 season (Table 11).

On the other hand, the very wet conditions that persisted during most of the sowing period of 1983 most likely limited the rate and reduced the level of emergence because of the limited amount of oxygen available to the growing seedlings. Limited oxygen diffusion in water saturated soil has been reported to more markedly affect the emergence of pregerminated seeds than that of dry seeds because in the former, metabolic processes were activated and thus required more oxygen than the initial physical imbibition process (Bierhuizen 1981). Although little work has been done on oxygen requirement of seeds in gel. Brocklehurst et al. (1980) has shown that Laponite gel reduced the rate of oxygen uptake by the seeds which may explain the lower level of emergence and subsequently of final plant stand obtained from fluid sowing in both years of trial. Thus the capacity of onion seeds to start germinating in soil with moisture slightly above the permanent wilting point to field capacity and the resistance of dry onion seeds to cold stress as reported by Lorenz and Maynard (1980) could explain the similarities when comparing each sowing date between the two years where the conditions were very different at sowing.

Plant stand was consistently reduced by fluid drilling at all dates and in both seasons (Tables 12, 16 & 17). This was a problem similar to that encountered by Chevrier (personal communication). Limited emergence or growth and subsequent death of seedlings may have occurred during the season because of a hardening of Laponite gel as reported by Orzolek (1982b) and Pill and Watts (1983). Plant loss from emergence to establishment and harvest was partly attributed to the gel which has been suspected to create and ideal environment for the spread of diseases (Entwistle and Munasinghe 1981). In fact, the earlier emergence achieved by fluid drilling in the current trials would be expected to involve less risks of attack by insects and soil pathogens, according to Currah (1978b). However, onion maggot and smut were observed to be more important problems than with dry seeded plots. This was particularly true for sowing date 1 of both years where insecticides have not yet been applied to control the first flush of onion maggot. It is important to note that at the time of sowing, pregerminated seeds were at a stage more susceptible to stress conditions such as disease and insect attacks (Maude 1978; Westcott 1979), cold (Hiron and Balls 1978) and low/high soil moisture contents (Hegarty 1978b).

The fluid drilled treatments during 1982 were placed along the ditch side of the experimental field. The treatment effects in 1982 trial were very probably confounded by the position of the plots in the field because of a moisture gradient created by the field sloping toward the ditch and it was therefore difficult to interprete the effects of the fluid drilling treatments. In order to avoid this problem the plots were randomized differently in 1983. Nevertheless, the results of the current trials confirmed those of Hiron and Balls (1978) who obtained a lower percentage emergence in fluid sown rather than in dry seeded plots, particularly for early sowings, where the soil was very cold and wet. They attributed this response to two possible causes: firstly, the soil temperature may have been too low at the early sowing date to allow growth of the germinated seeds but dry seeds were still able to imbibe; and this would have reduced the advantage of the germination prior to sowing. Secondly, as a result of variation of imbition and germination rate between individual seeds (Hegarty 1978b), the seeds were not equally germinated at sowing and seeds with the longest radicles may have died due to breakage during handling and to greater susceptibility to cold conditions (Irwin and Price 1983).

Cold damage occurred when germinated seeds were exposed to freezing temperatures ($\leq 1°C$) for a period as short as 2 days, while dry seeds were not affected in their subsequent seedling emergence (Steckel and Gray 1980). Gray and Steckel (1983) showed that a temperature of $-6.5° \pm 2.3°C$ killed germinated onion seeds presumably as a result of intracellular ice formation or dessication damage, but imbibed seeds were not affected. Onions have been dry sown on organic soil before frost is completely out of the ground and usually the earlier the seeds were sown within 2 weeks after the soil is workable, the larger the yield for both early and late cultivars (Tiessen et al. 1970). However, this did not apply to germinated seeds, at least not when cold and wet conditions persisted as in the spring of 1983 (Table 3). Although the seeds were sown at a depth of 2 cm, soil temperatures were most likely several degrees lower than the air temperatures reported in Table 3, particularly at the earlier sowing. This might have impeded subsequent growth and development of the seedling. However, by the third sowing, the soil was warmer and allowed a faster emergence than the earlier sowings in 1982. But this was not the case in 1983, probably because seeds of the last sowing started to grow when the soil was dry at seeding depth and may have absorbed the moisture from the gel. Later sowings could thus have benefited from being sown deeper where a cooler temperature and a higher moisture level remained.

Therefore, contrary to the general expectations of the fluid drilling technique mentioned by Taylor (1977), Currah (1976) and Salter (1978), its advantage over dry seeding was not greatest in the earliest sowing in the case of the white onion. The greater advantage of the technique at early sowings, i.e. where temperature is normally suboptimal for germination of dry seed, would seem to apply better for direct seeding of warm-season crops such as tomatoes (Bussell and Gray 1976; Gray, Steckel and Ward, 1979) and peppers (Irvin and Price 1983), or for a crop like lettuce requiring cool conditions for germination (Gray 1978). The same problem of low plant stand at early sowings resulted from fluid drilled parsnip, celery and sugar beet

(Gray 1981).

Although earlier emergence and maturity in some cases has been achieved by fluid drilling, the subsequent problems of plant stand resulted in no yield benefits in the present trial. In earlier studies, the effects of fluid sowing on the yields of mature bulbs have generally been small and inconsistent (Currah 1976). The performance of fluid drilling and dry seeding were not different in terms of yield as the low plant stand in the former was generally compensated by larger bulbs as measured by weight and diameter (Tables 13, 17 & 18). Therefore, the large bulb size produced by fluid drilling has been obtained at the expense of the number of bulbs harvested as reported by Currah (1976) and Lipe and Skinner (1979), rather than from an extension of the growing season (Salter 1978a). Although mean bulb diameters tended to be smaller from the second sowing, they were still an acceptable size for processing (≥50mm) (Hoyle _et al_. 1972). Spread of emergence has been shown to be greater at low temperatures (Lipe and Skinner 1979) and to result in more variable bulb size and more extremes in size (Hoyle _et al_. 1972). Therefore, the greater mean diameter obtained in the earlier sowings did not necessarily reflect a real advantage over the later sowings.

In 1982, more favourable conditions were present at sowing, a more constant rainfall during the season favoured steady growth and a relatively warm and dry weather at the end of the season was favourable for field curing. All these factors contributed to higher plant survival, longer growing season, and higher yields than in 1983. Therefore, the delayed sowings in 1983 were probably a cause for lower yields as shorter time was allowed to achieve an optimum leaf cover before increasing daylength induced bulb formation which was visible around mid-July in both years. Yamaguchi _et al_. (1975) reported that a

3 week earlier sowing date had resulted in the formation of as many as 4 to 6 more foliage leaves before bulbing commenced. Furthermore, while bulb dry matter accumulation ranged from 17.5% to 19.9% in 1982, it was only from 14.9 to 16.1% for the same cultivar in 1983 (Tables 14 & 18) due to the longer growing season obtained in 1982 (Table 10). In the same order of idea, the higher dry yield from the 2 earlier sowings was probably due to the extension of the growing season in the early spring. A growing season of 21, 20 and 35 longer days, respectively, in 1982 compared to 1983 for sowing dates 1 to 3 (Table 10) resulted in dry matter increases of respectively 1.3, 1.1 and 0.7 t ha^{-1} per week, the greatest advantage being obtained with the earlier sowings. This confirmed the advantage of an earlier establishment of onions or an extention of leaf cover at the end of the season, from a rather cool and wet summer as in 1982, both of which could have increased dry yields by about 0.2 t ha^{-1} per day (Brewster 1977).

Therefore, the extension of the growing season by an early sowing date appeared to be crucial to optimize yield and dry matter accumulation of the white onion which required a long growing season. However, since cold injury is most likely to reduce the possible advantage of the fluid drilling technique over traditional dry seeding, it is recommended that sowing take place between 1 and 2 weeks after the soil can be worked when soil conditions seem most favourable. As organic soils normally retain a high moisture content, water should not be limiting at that time. The influence of favourable soil conditions could be seen in that much better emergence, higher plant stands and yields were found with the second sowing date. However, any later sowing should be avoided as the season became too short for proper plant maturity, and thus yields were reduced and bulb qualities impaired.

4.3 DENSITY OF SOWING - Field trials 1982 & 1983

4.3.1 Introduction

In Quebec, the short growing season appears to be the main limiting factor for producing good quality bulbs and achieving maximum yields of white dehydrating onions (Woods Gordon, 1982). Crop spacing can be a valuable way of controlling crop size, shape and yield, and it can influence growth rates. When the onions are densely planted, the competition for light, water and nutrients is high and the rate of development is generally hastened as the sowing density increases. However, high density plantings tend to yield small bulbs which are not desirable for dehydration purposes, but large bulbs (diameter above 50 mm) have only been obtained at the expense of some loss in total yield (Bleasdale 1966; Frappell 1973). On the other hand, varieties with small bulb size have been associated with high dry matter content (McCollum 1968; Nieuwhof et al. 1973), and tight row spacing with a high fresh yield up to a certain maximum density, above which yield becomes independent of density (Bleasdale 1982). The Government of Quebec (MAPAQ 1982) recommended, when growing fresh market bulb onions, to sow seeds on 40 cm apart rows at a rate of 40-50 plants m^{-1}, which is equivalent to 100 and 125 plants m^{-2} respectively, and about 4 kg seeds ha^{-1}. In California, varieties grown for dehydration were reported to give maximum yields at densities of 83 to 100 plants m^{-2} which takes 3.5 to 4 kg of seeds ha^{-1} (Voss 1979).

Consequently, an experiment was designed in 1982 and continued in 1983 with two dehydrating onion cultivars. The objective was to determine at which sowing rate a compromise could be reached in obtaining high yields of large elongated bulbs with a high dry matter content.

4.3.2 Materials and methods

For both years of trial, dry seeds of cultivars Southport White Globe and Dehydrator-14 were coated with Progro systemic fungicide and counted as described in section 3.1.1. The 2 cultivars were dry sown (section 3.1.3) in standard plots of 4 rows each 5 meters long with an inter row spacing of 45 cm and three different sowing rates: 35, 45 and 55 seeds m^{-1}. The sowing rates were chosen so that there was one above and below the Quebec standard. Based on the results of the 1982 trial, a fourth treatment (25 seeds m^{-1}) was incorporated in 1983. Considering the fixed inter row spacing of 45 cm, sowing rates of 25, 35, 45 and 55 seeds m^{-1} corresponded to plant densities of 56, 78, 100 and 122 seeds m^{-2}, respectively. Cultural and managerial procedures were as outlined in section 3.1.4.

Time to emergence and to maturity, plant stand and percentage survival at harvest, mean bulb weight and diameter, bulb shape index, total fresh yield, bulb dry matter content and dry matter yield were measured. In 1982, treatments were sown on May 3 and harvested after 133 to 140 days. In 1983, all treatments were sown on May 19 and harvested on September 13, 117 days later. The shorter growing season in 1983 resulted from delayed sowing caused by poor spring weather conditions (Table 3).

The experiment was distributed in a 3X2 factorial arrangement in 1982 and in a 4X2 arrangement in 1983. In both years, the treatments combinations were randomized in a block design with 4 replications. All data were subjected to analyses of variance which are detailed in

Tables A.6 and A.7 for 1982 and 1983 trials, respectively. Comparisons of means were performed using the Duncan's Multiple Range test. The main effects of sowing rate and cultivar are presented in Tables 19 to 22 and the specific responses of cultivars at each sowing rate are shown in Figures 8 to 12.

4.3.3 Results for 1982

Time to emergence

Although seeding rate did not significantly affect the time to emergence, there was a tendency for faster emergence in more densely sown plots (Table 19). Seedlings of cultivar Dehydrator-14 emerged significantly faster than those of Southport White Globe (Table 19 & Figure 8a).

Time to maturity

Both sowing rate and cultivar had significant effects on the time to maturity (Table A.6). Plants sown at a rate of 55 seeds m^{-1} reached maturity significantly earlier than at lower rates, for both cultivars (Table 19 and Figure 8b). Maturity was reached earlier by cultivar Southport White Globe than Dehydrator-14, when considered as a main effect (Table 19) and on an individual, rate by rate, basis (Figure 8b).

The significant correlation ($P \leq 0.005$; $r=+0.79$) found between the time to emergence and the time to maturity for cultivar Southport White Globe indicated a tendency for treatments emerging faster to mature faster as well.

Plant stand and percentage survival (at harvest)

As the sowing rate was increased from 35 to 45 and 55 seeds m^{-1}, significantly more bulbs per meter were harvested. However, the resulting percentage of plant survival from initial sowing was significantly higher in the 35 seeds m^{-1} treatment than in the other treatments (Table 20; Figure 9a&b). Cultivar Dehydrator-14 gave higher percent survival than Southport White Globe at all sowing rates (Figure 9a&b).

Mean bulb weight

Mean bulb weight significantly decreased with increasing seeding rate (Table 21) for both cultivars (Figure 10a). For all density treatments, cultivar Southport White Globe yielded larger bulbs compared to Dehydrator-14 (Figure 10a).

Among all treatments, the higher the plant stand at harvest the lower the bulb weight tended to be ($P \le 0.0001$; $r = -0.85$).

Bulb diameter

While differences in bulb diameter among sowing rate treatments were not statistically significant, a significant interaction was found between rate and cultivar (Table A.6). As a result, only at the 45 seeds m^{-1} rate were Southport White Globe bulbs significantly larger than Dehydrator-14 bulbs (Figure 10b).

Bulb shape index

Bulb shape was not significantly affected by the sowing rate, but bulbs of Dehydrator-14 cultivar had a more elongated shape (higher shape index) than those of Southport White Globe (Table 21 & Figure 11a).

Fresh yield

Fresh yield was not affected by either rate or cultivar treatments (Tables 22 & A.6). However, there was a tendency for Southport White Globe to yield more than Dehydrator-14 at all sowing rates (Figure 11b).

There was a significant correlation ($P \le 0.05$; $r = +0.48$) between the mean bulb weight and the final fresh yield per area.

Dry matter yield

Dry yield was not significantly affected by either rates or cultivars used. However, Dehydrator-14 tended toward a higher dry yield than Southport White Globe. (Table 22 & Figure 12a).

Bulb dry matter (%)

Seeding rate had no significant effect on the bulb dry matter content (Table 22) but the effect of cultivar was significant as Dehydrator-14 bulbs showed higher dry matter percentage then those of Southport White Globe (Figure 12b).

A bigger bulb in terms of diameter was correlated ($P \leq 0.005$; $r=-0.56$) with a lower bulb dry matter content.

TABLE 19. Effect of sowing rate and cultivar on time to emergence and time to maturity of white onion in 1982 and 1983 field trials.

Treatment	Time to emergence (days from sowing)		Time to maturity (days from sowing)	
	1982	1983	1982	1983
Sowing rate[1] (seeds m^{-2})				
25	----[3]	11.6 a	----	115.0 a
35	12.3 a	11.0 b	115.6 a	113.8 a
45	12.0 a	10.9 b	115.0 a	105.0 b
55	11.8 a	10.6 b	113.1 b	103.4 b
Cultivar[2]				
Southport White Globe	12.3 a	10.6 b	113.7 b	108.6 b
Dehydrator-14	11.7 b	11.5 a	115.5 a	110.0 a

a,b Within columns and within treatment groups, means followed by the same letter are not significantly different at the 5% level by Duncan's Multiple Range test.

[1]. Values for each sowing rate are means of 8 observations, from the 2 cultivars with 4 replications.

[2]. Values for each cultivar are means of 12 observations in 1982 (3 sowing rates with 4 replications) and 16 observations in 1983 (4 sowing rates with 4 replications).

[3]. Treatment not used in 1982.

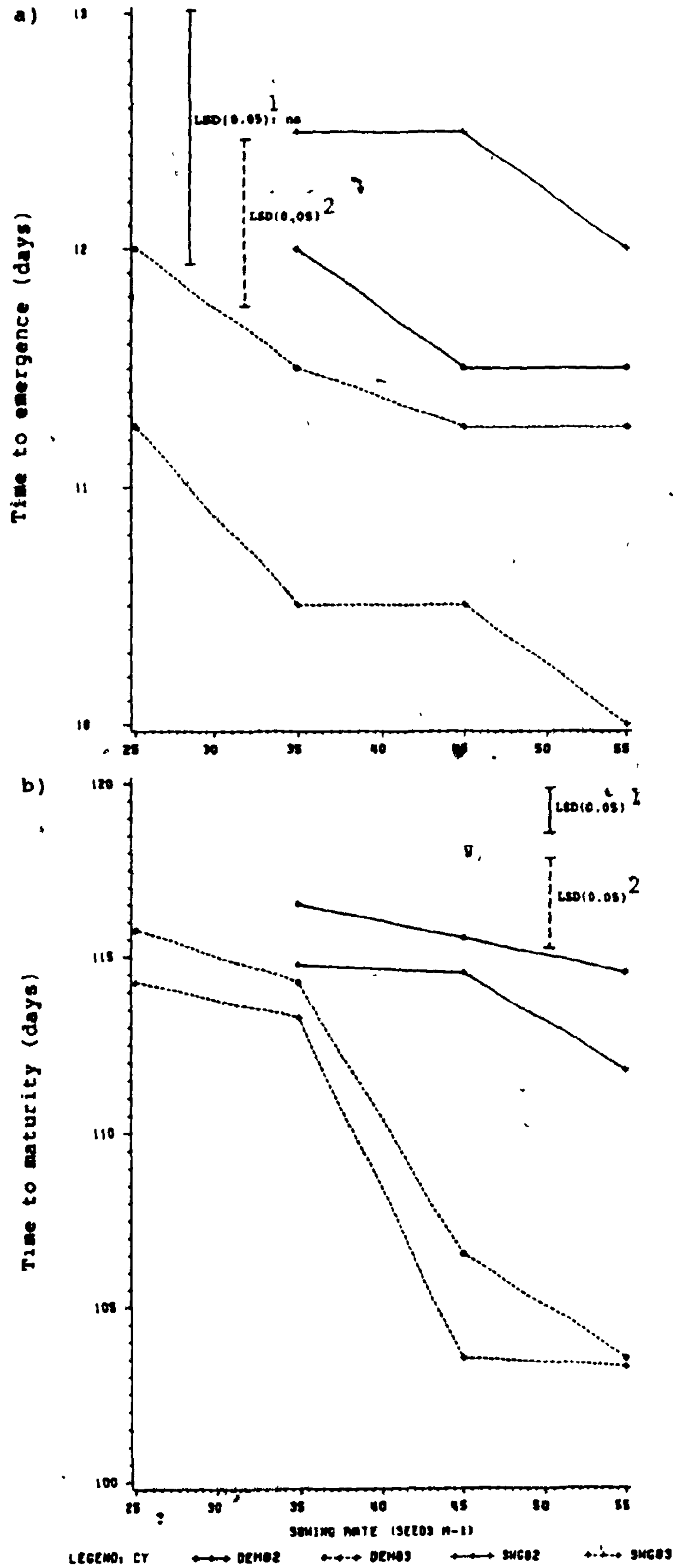


FIGURE 8. Effect of sowing rate and cultivar on a) time to emergence and b) time to maturity of white onion in 1982 and 1983.

1. LSD values for 1982

2. LSD values for 1983

TABLE 20. Effect of sowing rate and cultivar on plant stand and percentage survival at harvest of white onion in 1982 and 1983.

Treatment	Plant stand (bulbs m^{-1})		Percentage survival (% from sowing rate)	
	1982	1983	1982	1983
Sowing rate[1] ($seeds\ m^{-1}$)				
25	----[3]	12.7 d	----	50.6 a
35	29.2 c	15.6 c	83.3 a	44.5 a
45	33.9 b	21.3 b	75.3 b	47.3 a
55	40.4 a	25.4 a	73.5 b	46.3 a
Cultivar[2]				
Southport White Globe	33.4 b	17.4 b	75.0 b	44.3 b
Dehydrator-14	35.6 a	20.1 a	79.7 a	50.1 a

a-d Within columns and within treatment groups, means followed by the same letter are not significantly different at the 5% level by Duncan's Multiple Range test.

[1]. Values for each sowing rate are means of 8 observations, from the 2 cultivars with 4 replications.

[2]. Values for each cultivar are means of 12 observations in 1982 (3 sowing rates with 4 replications) and 16 observations in 1983 (4 sowing rates with 4 replications).

[3]. Treatment not used in 1983

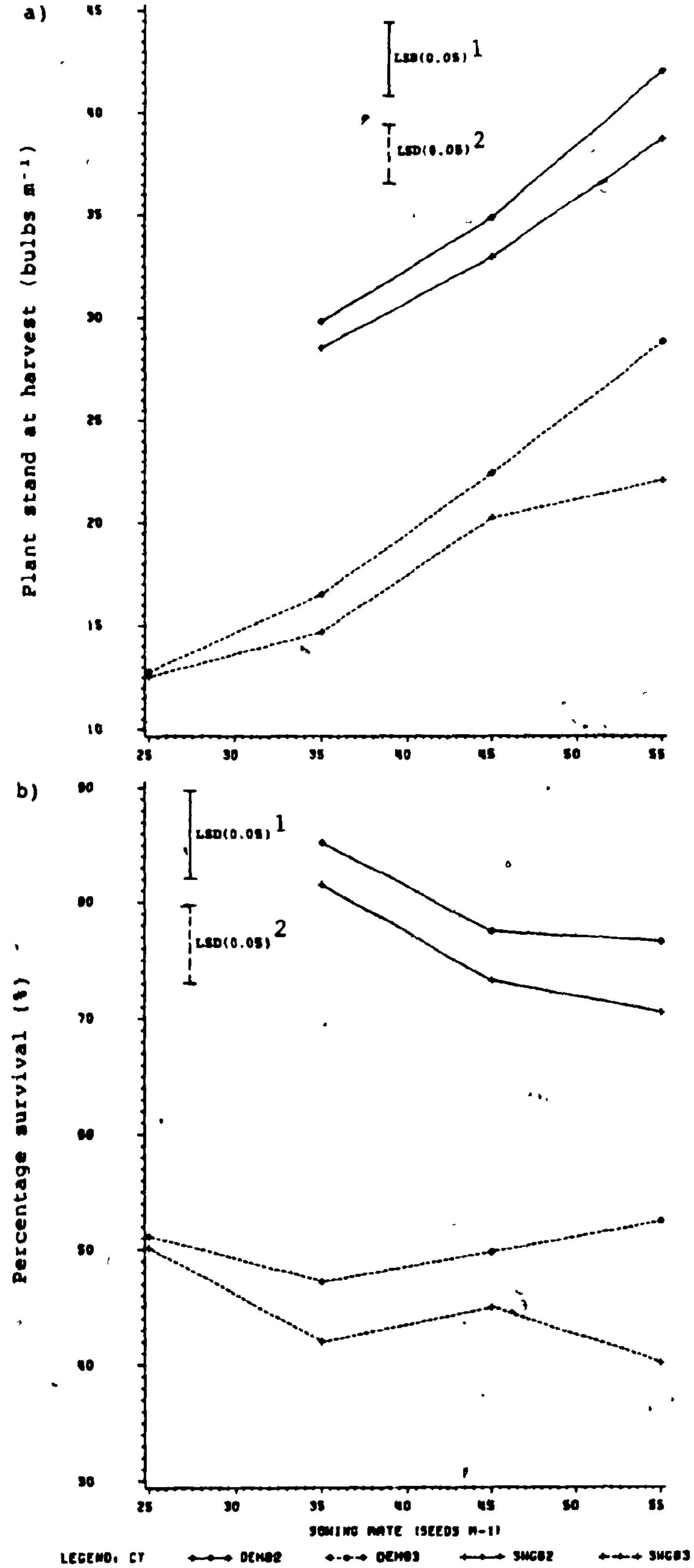


FIGURE 9. Effect of sowing rate and cultivar on a) plant stand at harvest and b) percentage survival of white onion in 1982 and 1983.
1. LSD values for 1982 2. LSD values for 1983

TABLE 21. Effect of sowing rate and cultivar on mean weight, diameter and shape index of white onion bulbs in 1982 and 1983.

Treatment	Bulb weight ($g\ bulb^{-1}$)		Bulb diameter (mm)		Shape index (height/diameter)	
	1982	1983	1982	1983	1982	1983
Sowing rate[1] ($seeds\ m^{-1}$)						
25	----[3]	90.3 a	----	55.1 a	----	0.97 a
35	80.1 a	82.3 a	60.0 a	55.8 a	0.96 a	1.00 a
45	68.3 b	68.4 b	57.1 a	50.5 b	0.96 a	1.03 a
55	57.4 c	56.3 c	59.0 a	49.8 b	0.93 a	1.03 a
Cultivar[2]						
Southport W.G.	72.0 a	85.2 a	60.3 a	55.0 a	0.91 b	0.99 a
Dehydrator-14	65.2 b	63.4 b	57.2 b	50.5 b	0.99 a	1.02 a

a-c Within column and within treatment groups, means followed by the same letter are not significantly different at the 5% level by Duncan's Multiple Range test.

[1]. Values for each sowing rate are means of 8 observations, from the 2 cultivars with 4 replications.

[2]. Values for each cultivar are means of 12 observations in 1982 (3 sowing rates with 4 replications) and 16 observations in 1983 (4 sowing rates with 4 replications).

[3]. Treatment not used in 1982.

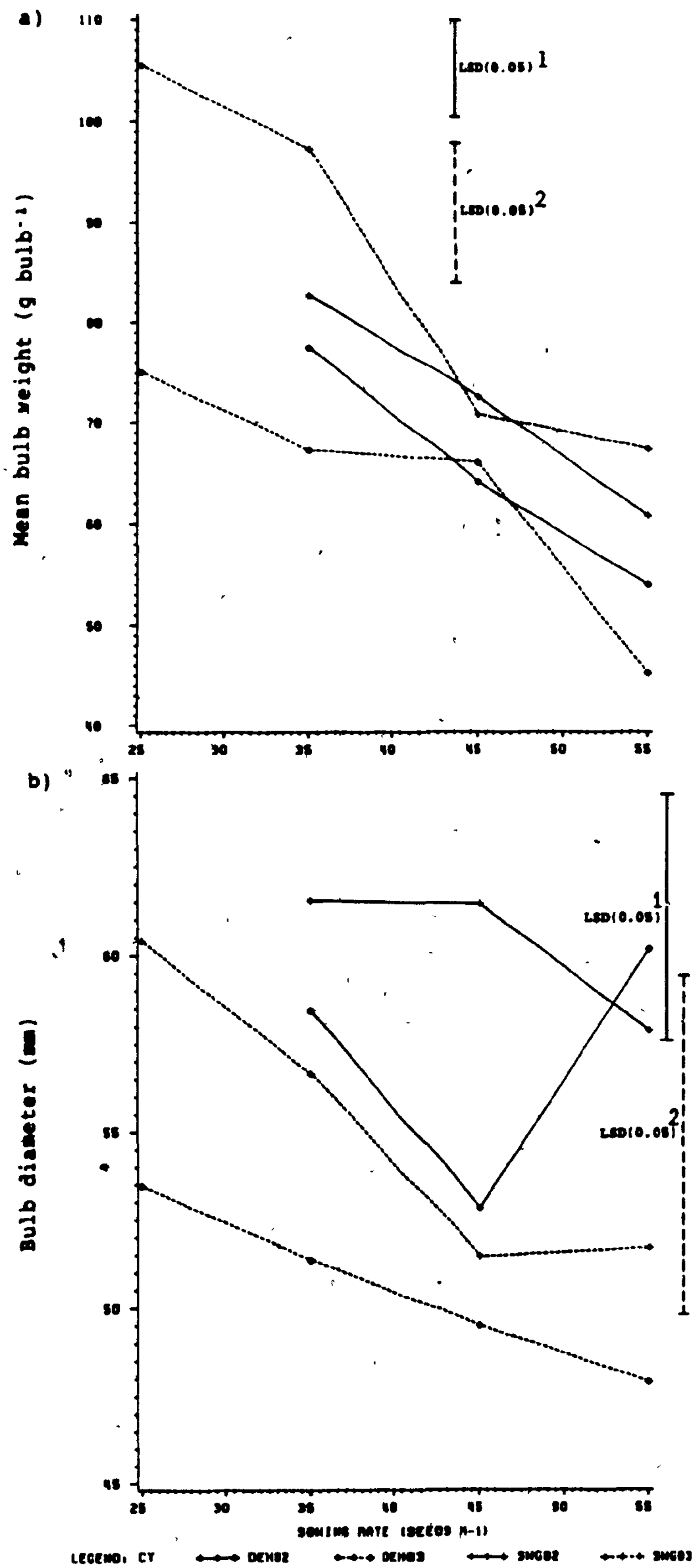


FIGURE 10. Effect of sowing rate and cultivar on a) mean bulb weight and b) bulb diameter of white onion in 1982 and 1983.

1. LSD values for 1982

2. LSD values for 1983

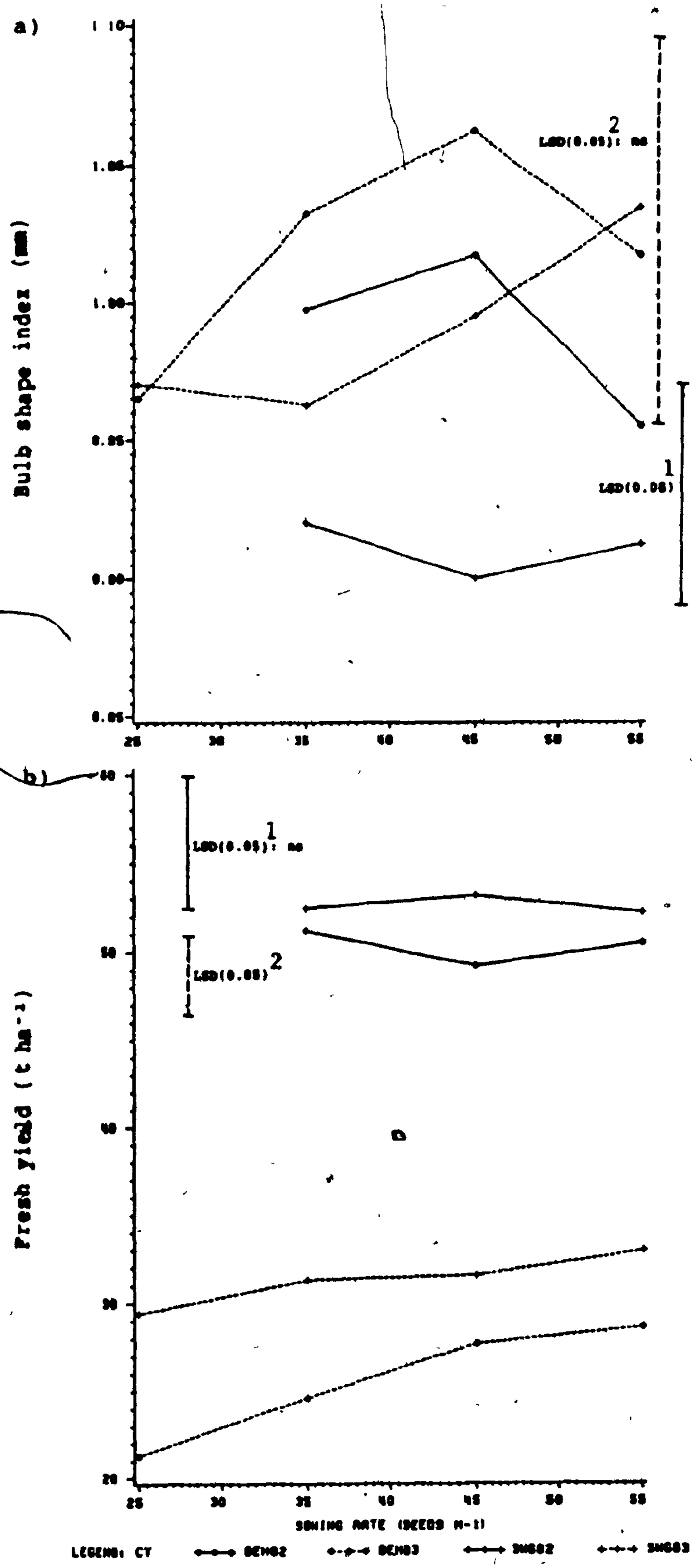


FIGURE 11. Effect of sowing rate and cultivar on a) bulb shape index and b) fresh yield of white onion in 1982 and 1983.
1. LSD values for 1982 2. LSD values for 1983

TABLE 22. Effect of sowing rate and cultivar on fresh and dry matter yields and on bulb dry matter content of white onion in 1982 and 1983.

Treatment	Fresh yield ($t\ ha^{-1}$)		Dry yield ($t\ ha^{-1}$)		Dry matter (% $bulb^{-1}$)	
	1982	1983	1982	1983	1982	1983
Sowing rate[1] ($seeds\ m^{-1}$)						
25	----[3]	25.3 b	----	4.3 c	----	17.1 a
35	51.8 a	27.9 ab	10.6 a	4.8 b	20.6 a	17.6 a
45	51.2 a	29.6 a	10.4 a	5.1 ab	20.3 a	17.2 a
55	51.4 a	30.8 a	10.4 a	5.5 a	20.2 a	18.0 a
Cultivar[2]						
Southport W.G	52.6 a	31.3 a	10.3 a	4.8 a	19.6 b	15.3 b
Dehydrator-14	50.3 a	25.5 b	10.6 a	5.0 a	21.1 a	19.6 a

a-c Within columns and within treatment groups, means followed by the same letter are not significantly different at the 5% level by Duncan's Multiple Range test.

[1]. Values for each sowing rate are means of 8 observations, from the 2 cultivars with 4 replications.

[2]. Values for each cultivar are means of 12 observations in 1982 (3 sowing rates with 4 replications) and 16 observations in 1983 (4 sowing rates with 4 replications).

[3]. Treatment not used in 1982.

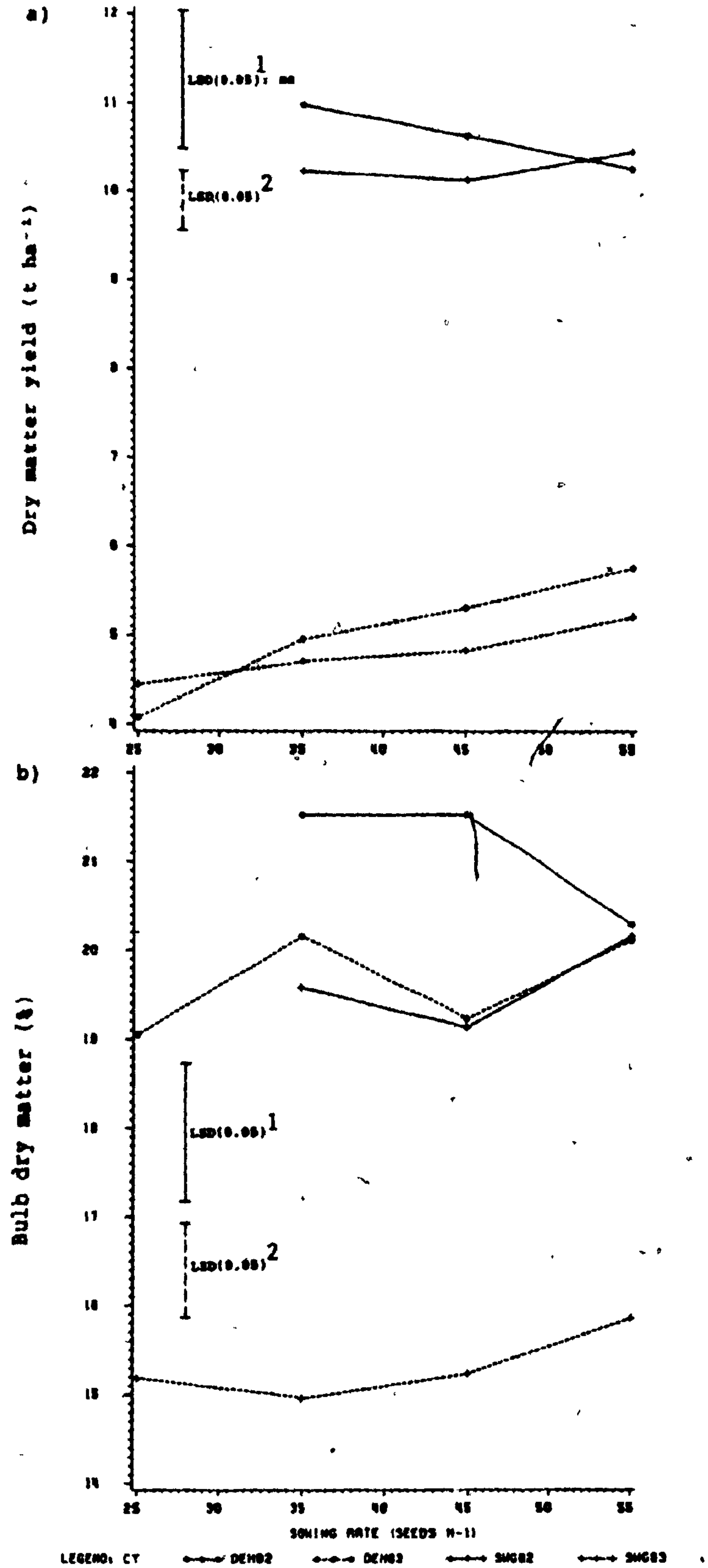


FIGURE 12. Effect of sowing rate and cultivar on a) dry matter yield and b) bulb dry matter of white onion in 1982 and 1983.
1. LSD values for 1982 2. LSD values for 1983

4.3.4 Results for 1983

Time to emergence and to maturity

Both sowing rate and cultivar treatments had a significant effect on the time to emergence and maturity of white onions (Tables 19 & A.7), with no rate X cultivar interaction.

Emergence took significantly longer in the 25 seeds m^{-1} plots than at the higher rates. Maturity was reached significantly earlier in the 55 and 45 seeds m^{-1} than in the 25 and 35 seeds m^{-1} treatments (Table 19). In general, onions of both cultivars emerged and matured earlier as seeding rate increased from 25 to 55 seeds m^{-1}.

Cultivar Southport White Globe emerged and matured earlier than Dehydrator-14 at all densities (Table 19 & Figure 8a&b). A positive and significant relationship ($P \leq 0.0.01$; $r = +0.43$) found between the above variables indicated that the earlier the emergence, the earlier the maturity tended to be.

Plant stand at harvest

A significant interaction existed between sowing rate and cultivar (Table A.7) and thus, the variation in number of bulbs per meter among sowing rate treatments was dependent on the cultivar. For Dehydrator-14 plant stand significantly increased with sowing rate. On the other hand, there was a clustered response of Southport White Globe to sowing rate. The 2 lowest rates were not significantly different but were lower than the 2 highest which in turn were not significantly different (Figure 9a).

Only at the higher density were there a significantly higher plant stand in Dehydrator-14 plots compared to plots of Southport White Globe.

Percentage survival at harvest

Seeding rate did not significantly affect the percentage of surviving plants (Table 20). Dehydrator-14 yielded a significantly greater percentage of bulbs compared with Southport White Globe (Figure 9b).

Mean bulb weight

Mean bulb weight tended to decrease with increasing sowing rate (Table 21), but the significant interaction between rate and cultivar (Table A.7) resulted in significantly higher bulb weights at the two lower rates for Southport White Globe, while only at the highest rate was there a lower bulb weight for Dehydrator-14 (Figure 10a).

Southport White Globe generally yielded significantly larger bulbs than Dehydrator-14, with the exception of the 45 seeds m^{-1} rate where the cultivars were not found to be significantly different (Figure 10a).

While a later maturity was generally correlated with a heavier bulb ($P \leq 0.001$; $r=+0.57$), a higher plant stand was correlated with a lower bulb weight ($P \leq 0.0001$; $r=-0.76$).

Bulb diameter

Bulb diameter was significantly greater in the 25 and 35 seeds m^{-1} treatments than at the higher rates, and greater for Southport White Globe than Dehydrator-14 at all sowing rates (Table 21 and Figure 10b).

Bulb shape index

Despite the non significant difference between treatments in terms of bulb shape (Table A.7), there was a tendency for a higher bulb shape index as sowing rate increased. Similarly, Dehydrator-14 produced bulbs with a higher shape index than did Southport White Globe (Table 21; Figure 11a).

Fresh yield

The denser the planting, the greater the fresh yield (Table 22). Dehydrator-14 cultivar yielded significantly less than Southport White Globe at all sowing rates (Figure 11b).

There were negative correlations found between fresh yield and both emergence ($P \leq 0.001$; $r = -0.69$) and maturity ($P \leq 0.01$; $r = -0.46$) data; and a positive correlation between fresh yield and plant stand at harvest ($P \leq 0.05$; $r = +0.39$).

Dry matter yield

Dry matter yield was significantly higher for the 55 seeds m^{-1} treatment than for the 2 lowest rates, but not significantly different from the 45 seeds m^{-1} density (Table 22).

No significant difference was found between the 2 cultivars despite the trend for higher dry yield for Dehydrator-14 (Table 22 and Figure 12a).

Bulb dry matter (%)

Whereas seeding rate had no effect on bulb dry matter percent, Dehydrator-14 bulbs were significantly higher in dry matter than those of Southport White Globe at all densities (Table 22 & Figure 12b).

From significant negative correlations, a large bulb in terms of weight ($P \leq 0.0005$; $r = -0.60$) and in terms of diameter ($P \leq 0.01$; $r = -0.45$) were both associated with a low bulb dry matter content.

4.3.5 Discussion

The results of the experiments conducted in 1982 and 1983 have shown that the rate of growth, bulb size and quality, and yield of white dehydrating onions were significantly affected by both the sowing rate and cultivar used.

A seeding rate of 35 seeds m^{-1} resulted in larger bulbs in terms of weight and diameter without a significant delay in seedling emergence or loss in total yield compared to commercial rates. (Tables 19 to 22). Differences were observed between the cultivars Southport White Globe and Dehydrator-14 (Figures 8 to 12). Dehydrator-14 proved to be superior to the standard cultivar in terms of plant survival, bulb shape and dry matter content. However, it generally yielded smaller bulbs.

Each trial year, sowing rate had an effect on time to emergence and time to maturity, thus it affected the length of growing period which in turn influenced the accumulation of reserves and size of bulbs, dry matter content and final yields. The earlier maturity obtained in denser plantings could be partly explained by the more intense shading in high density plantings which would tend to change the growth pattern at the end of the season and to result in more rapid maturity than low density plantings, according to Frappell (1973). An early maturity offered the advantage that curing and harvesting occurred under favourable conditions and this should result in better bulb quality (Brewster and Barnes 1981).

Dehydrator-14 constantly took more days to mature than Southport White Globe, but the maturity was still within the 137 to 152 days frost-free period in the region of Ste-Clotilde where the trials were undertaken. In these conditions, and because of the longer growing season, more reserves were likely to accumulate leading to higher dry matter yields (Figure 12a), conferring an advantage for a later maturing cultivar. Furthermore, an early maturity was not always desirable. For instance, Brewster (1977) found that in a hot dry summer, top collapse occurred 4 weeks earlier than in a cool wet summer in the same location. This implied that an extra 4 weeks of growth at full leaf canopy was obtained in the second case, thus at maximum growth rates, this represented about 0.476 t ha^{-1} of dry matter, according to Brewster (1977). The high growing temperatures and soil moisture deficits such as in the mid-summer of 1983 were likely to have hasten both bulbing and maturation, as had been reported by Brewster et al. (1975). Therefore, smaller bulbs were produced as less leaves were formed before bulb initiation and consequently the faster maturity resulted in smaller dry matter accumulation.

In 1982, early planting and subsequent emergence meant that the majority of bulb growth took place early in the season when the percentage of solar irradiation was higher, according to Brewster and Butler (1982). Furthermore, a more regular supply of precipitations throughout the 1982 summer and more ideal temperatures allowed favourable bulb development thus increased bulb size, and a dry and warm fall favoured neck fall and field curing. These factors, coupled with the extended growing season, help to explain why 1982 yields were much higher than those in 1983.

The smaller size of Dehydrator-14 bulbs (Table 21) was not a major disadvantage as the higher dry matter content and the higher plant stand compensated for the lower fresh yield and resulted in an equivalent dry matter yield. Furthermore, the elongated shape of the Dehydrator-14 bulbs tended to minimize trimming loss during the dehydration process. Bulb dry matter content was not significantly affected by sowing rates (Table 22) within the range used in the (25 to 55 plants m^{-1}). This confirmed the findings of McGeary (1985) who worked with rates of 13 to 40 plants m^{-1}.

It is interesting to note that in the 1982 trial, the highest percentage survival was obtained with the lowest density, thus resulting in more efficient use of material and equipment. This was accentuated by the fact that the lowest rate gave the largest bulbs and yields equivalent to the denser plots. A similar trend was not found in 1983 as percentage survival did not differ significantly among sowing rates (Table 20). This could have been due to the much lower survival rate in 1983 and its subsequent effect on competition. In 1983, the 25 seeds m^{-1} treatment gave no significant advantage over the higher densities. The larger bulbs obtained did not compensate for the lower yields because of the much reduced plant stand. With a smaller inter row spacing than that used in this trial (45 seeds m^{-1}), results of a low sowing rate may prove to be more interesting according to Salter <u>et al</u>. (1979). The cooler soil conditions and the higher level of precipitation in the early spring of 1983 may have created an ideal environment for the spread of diseases which in turn could explain the poor plant stand and 50 % lower yields than that achieved in 1982 (Figures 9 & 11). While fresh yield was significantly correlated with bulb weight in 1982, it was correlated with bulb number (plant stand) at harvest in 1983. This indicated that when the survival was low (around 50%) as in 1983, the yield depended mainly on the number of bulbs at harvest, while when survival was around 75-80% (1982), yield depended on bulb weight.

As reported by Frappell (1973) the increase in bulb size afforded by the lower densities was obtained at the expense of fresh and dry yields (Tables 21 & 22). This trend was more important in 1983 where yields were lower than in 1982. Therefore, since the dehydration market requires large bulbs, maximum yields were not likely to be achieved. Under normal field conditions in temperate regions, individual bulb size, at densities higher than 70 plants m^{-2}, is not limited because ceiling yields are achieved but because the length of the growing season is restricted and bulbs planted at high density do not have time to attain an acceptable size due to the slower rate of bulb enlargement engendered by increased competition (Brewster 1977). This is likely to be the case in the current trials where treatments of 35, 45 and 55 seeds m^{-1} corresponded to densities of 78 plants m^{-2} and above.

When considering the two trial years, faster emergence and maturity were obtained from denser sowings. Higher sowing rates produced higher plant stands but these were not significantly different from the low sowing rate treatments. Larger bulbs in terms of weight and diameter were also obtained at low rates (25 and 35 seeds m^{-1}). Furthermore, fresh and dry yields were equivalent for 35 and 45 seeds m^{-1} densities, but there was no significant difference in dry matter percentage of bulbs grown at different densities. Therefore, considering all growth characters, bulb quality and yield variables measured, the most efficient row density was 35 seeds m^{-1} when used with an inter row spacing of 45 cm (equivalent to 78 plants m^{-2}) for both years, particularly when using cv. Dehydrator-14. This density compared to that used in California for dehydrator onions: 83 to 100 plants m^{-2}. Therefore, the crop has to be spaced according to its optimal needs, i.e. to minimize competition in order to produce the maximum proportion of large bulbs.

4.4 Gel types

4.4.1 Growth cabinet experiment

4.4.1.1 Introduction

Previous studies have indicated that the benefit of fluid drilling was considerably affected by the choice of carrier gel, especially under moisture stress conditions (Darby 1980; Gray 1981). The most common problems encountered with gel carriers were the requirement of a high shear force to mix the gel with water, the sensitivity of certain gels to hard water, and a rapid dessication of some gels in dry soil, trapping the seeds and reducing emergence (Darby 1980; Gray 1978; Gray 1981). Some gels have even been phytotoxic (Darby 1980; Skipper 1983).

Laponite 508 was chosen as the standard gel for 1982 experiments based on the conclusion of Darby (1980) who found that gel best suited for emergence and growth of fluid drilled onions. However, sowing pregerminated seeds with Laponite 508 in 1982 trials was generally accompanied by a lower percentage of emergence compared to dry seeded material (sections 4.1, 4.2 and 4.5). Therefore, a preliminary growth cabinet study was carried out to compare the effect of 7 gel types on seedling establishment of white onion sown on organic soil.

The possibility that the carriers might provide a complete environment for seedling growth without being covered by soil (Darby 1980) was also investigated.

4.4.1.2 Materials and methods

The composition of the 7 gels tested and their incorporation rates are listed in Table 23. The ratios of gel powder:water were based on manufacturer's directions when available, on previous work (Darby 1980; Ghate 1982; Price, personal communication), and on laboratory tests to obtain a gel consistency similar to Laponite 508 at 15 g l^{-1}. The gels had to be consistent enough to suspend the seeds, but liquid enough to be squeezed out easily from the plastic bags at sowing (details in section 3.1.2).

Onion seeds (cv. Southport White Globe) were pregerminated prior to sowing as described in section 3.1.1. Pregerminated seeds sown without gel were used as a control treatment for the gel effect. While the 2 Laponite gels and Water-Lock B200 required a blender for mixing (section 3.1.2), the other gels dissolved rapidly in water and thickened within 10 minutes. All gels were used at an extrusion rate of 15 ml per flat (4 X 12.5 cm rows=50 cm) to be equivalent to the recommended field rate for onions (30 ml m^{-1}; Fluid Drilling Ltd.: Anonymous 1980). For each treatment, 24 pregerminated seeds were placed individually into the gel on the 4 rows along the long axis of the peat flats filled with organic soil (details in section 3.2.1). The control pregerminated seeds were put directly in the rows. In each flat, 2 rows were covered with 1 cm of soil whereas the 2 other rows were left uncovered. Flats were watered as required to keep the soil moist. Treatments (7 gels and 1 no gel control) were replicated 4 times, resulting in a total of 32 flats. The experiment was arranged in a split-plot within a completely randomized design, with the gel type as the main plot unit and the presence or absence of soil covering as the sub-plot unit, Environmental conditions in the growth chamber were presented in section 3.2.1.

Emergence time and percentage were taken. Survival, total weight and mean weight were recorded after 41 days, as described in section 3.2.2. Analyses of variance were performed on all the data (Table A.8). Means were compared using an LSD test.

TABLE 23. Gel materials used in the growth cabinet and field experiments.

Gel name	Gel rate (g l⁻¹) Preliminary (growth cabinet)	Adjusted (field)	Composition
Laponite 508[1] (L508)	15	15	Magnesium silicate
Laponite 445[1] (L445)	7	20	Magnesium silicate
Liquagel[2] (Liqua)	6	8	Starch-acrylate, potassium polymer
Agrigel(Viterra)[3] (Agri)	13	13	Potassium propeonate, propenamide copolymer
Water-Lock B-100[4] (WL-B100)	9	12	Starch graft copolymer
Water-Lock B-200[4] (WL-B200)	6	12	Starch graft copolymer
Water-Lock J-550[4] (WL-J550)	3	5	Starch graft copolymer

Source: [1]. Laporte Inc., New Jersey (U.S.A.).
[2]. Miller Chemical and Fertilizer Corp., Pa (U.S.A.).
[3]. Nepera Chemical Inc., New York (U.S.A.).
[4]. Grain Processing Corp., Iowa (U.S.A.).

4.4.1.3 Results

Time to emergence

Emergence was hastened by 0.1 and 0.3 days compared to the pregerminated control when seeds were sown with Agrigel and WL-J550, respectively (Figure 13a). All other gels led to a slower emergence than the control but the delay was significant only with Liquagel and WL-B100.

In all cases, leaving the seeds or gel uncovered resulted in a significantly faster emergence, from 1.4 to 3.6 days, compared to the covered treatments. No significant differences were noted among gels when left uncovered.

Percentage emergence

The percentage emergence in the covered gels was not significantly different from the covered control with the exception of WL-B100 which showed 20.9% less emergence than the control (Figure 13b).

The effect of soil cover on emergence varied depending on the gel. While the absence of soil cover significantly decreased the emergence percentage for the control treatment and WL-J550 gel, it did not signficantly affect all other gels. Uncovered pregerminated seeds gave a significantly lower seedling emergence (61%) than all uncovered gels, with the exception of WL-J550 for which emergence was only 43% of the initial seed number. Among the uncovered gels, Laponite 508 gave the highest percentage of emergence.

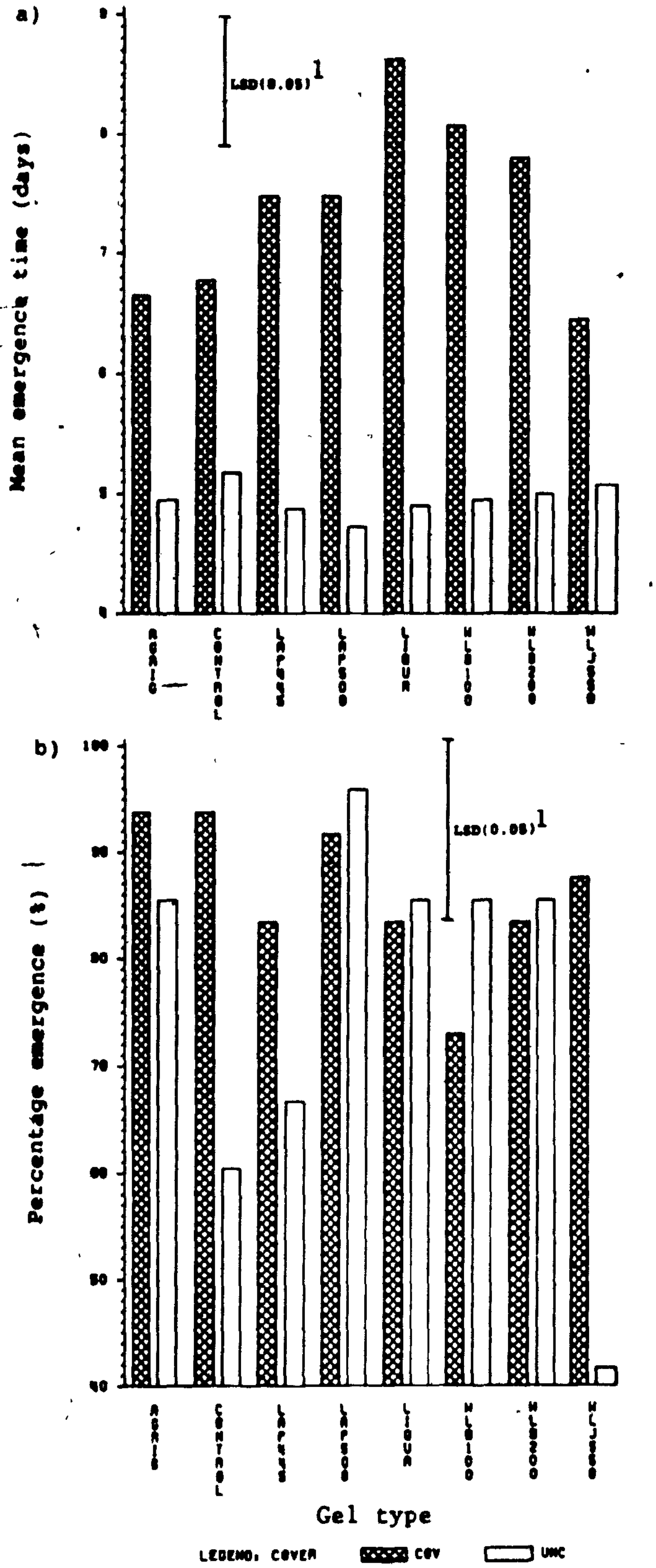


FIGURE 13. Effect of gel type and soil covering on a) mean emergence time and b) percentage emergence of fluid drilled onion cv. Southport White Globe in a growth cabinet experiment.

1. LSD values for both COV & UNC treatments

<u>Percentage survival</u>

A positive correlation ($P \leq 0.0001$, $r=+0.80$) was found to exist between percent emergence and survival, where treatments with a high seedling count after emergence exhibited high survival rates after 41 days. Plant survival of uncovered treatments was reduced by 12.5 to 39.6% from emergence to the end of the experiment. Seedling loss was greatest for uncovered Laponite 445 and Liquagel. There was no important reduction in seedling counts for the covered gels (Figures 13b & 14).

At the end of the experiment, although the covered control and Laponite 508 gel gave a higher percentage survival than all other gels, the advantage was significant only over WL-B100 (Figure 14). When comparing uncovered to covered gels, there was no significant difference in plant stand for either WL-B100 or Laponite 508 gels. While for the other gels, a reduction ranging from 20.5 to 67.5% was found to exist when the gels were left uncovered. Plant survival of the control treatment was reduced from 93.8 to 41.7% of the initial seed number when seeds were left uncovered.

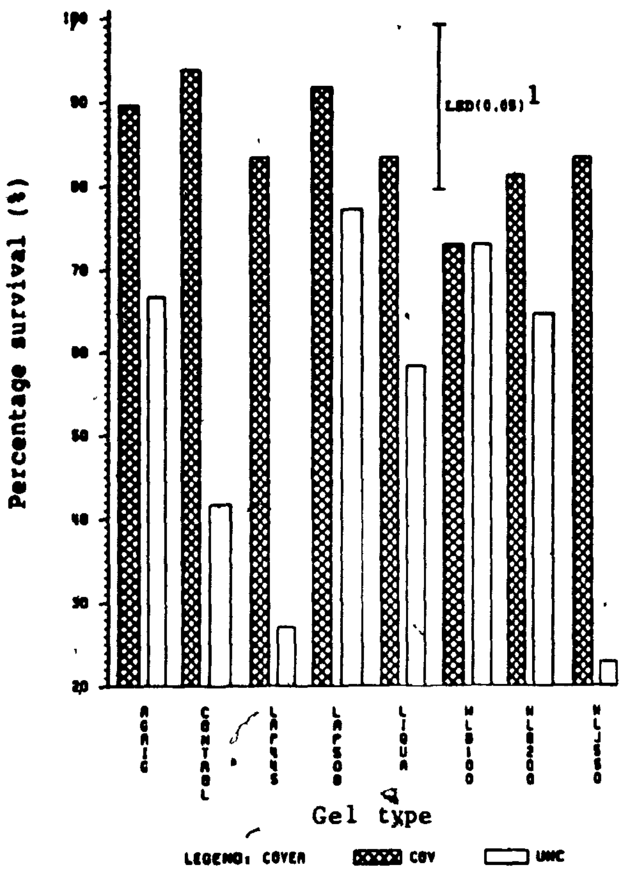


FIGURE 14. Effect of gel type and soil covering on percentage survival of fluid drilled onion cv. Southport White Globe.

1. LSD value for both COV & UNC treatments

Total plant weight

For the covered seeds, total plant weight was significantly reduced by Liquagel and WL-B200 compared to the control; only small differences were found among the other gels (Figure 15a).

Leaving the seeds and gels uncovered resulted in a significant decrease in total weight for all treatments compared to their covered counterparts. Total plant weight for Agrigel, Laponite 445 and WL-J550 gels decreased by 75, 78 and 79%, respectively when left uncovered. Laponite 508, WL-B100 and WL-B200 decreased by only 32, 29 and 42%, respectively.

Mean plant weight

Mean plant weight was slightly increased by Agrigel, WL-B100 and WL-J550 compared to the control and Laponite 508 gel, but these differences were not significant (Figure 15b). Sowing with Liquagel or WL-B200 resulted in lower mean plant weights than for all other gels.

The uncovered seeds and gels gave lower mean plant weight than their corresponding covered counterparts. Decrease in mean plant weights for the uncovered control and Laponite 508 gel was less than all other gels: means of 10.7 and 19.8%, respectively. The control and WL-B100 gel resulted in significantly higher mean plant weight than Agrigel and Laponite 445 when uncovered.

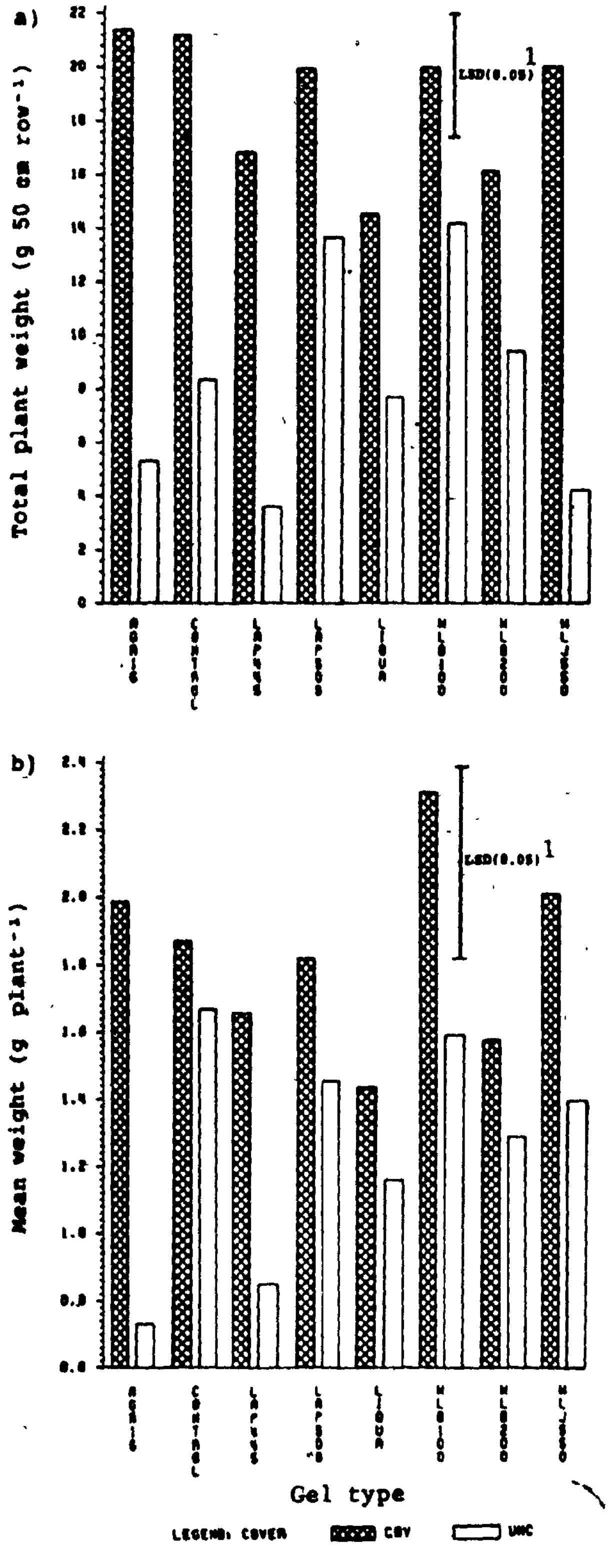


FIGURE 15. Effect of gel type and soil covering on a) total plant weight and b) mean plant weight of fluid drilled onion cv. Southport White Globe.

1. LSD values for both COV & UNC treatments

4.4.1.4 Discussion

The results of this preliminary experiment indicated that the type of gel had significant effects on emergence and weight of fluid drilled onions grown under controlled conditions.

When covered, Agrigel, and Water-Lock J550 gels produced earlier and higher emergence compared with the other carriers (Figure 13a&b). Although the differences were not significant, seeds sown with Laponite 508 emerged earlier and had a higher percentage emergence than those sown with either WL-B100 or Liquagel. These findings were similar to those of Ghate and Phatak (1983), in a greenhouse study, who reported no significant difference in emergence time of peppers with Laponite 508 and Water-Lock B100 although Laponite was slightly later. Furthermore, Pill and Fieldhouse (1982) reported that emergence time and percentage of tomato, under controlled conditions, was not significantly affected by the gel type, when comparing Laponite 508 and 3 other gels among which SPG104K, a gel with a composition similar to that of Liquagel. Gray (1981), and Pill and Watts (1983) speculated that the specific microenvironment of the seeds in the gel such as oxygen concentration, osmotic pressure and pH, which varied with gel concentration and was limiting in certain gels, caused responses to differ among the crops and gels. Darby (1980) stated that the advantage of one gel type over another for field establishment depended on the crop, gel extrusion rate and soil moisture level.

Leaving the gels uncovered hastened emergence; this was also true for the pregerminated control although to a lesser extent. This was in direct conflict with the findings of Darby (1980) who reported significantly delayed emergence by not covering lettuce seeds and gels with soil, in a greenhouse study. The difference in the results was likely to be due to the crops and soil types used in the studies. The high moisture retention capacity of the organic soil used in these trials may have contributed to the high plant stand of uncovered gel treatments. It is important to note that if the seeds or seeds/gel combinations were left uncovered, they lost any buffering capacity afforded by the soil and became more subject to environmental stress. When one considered the poor emergence and plant stand response of the uncovered pregerminated seeds (Figures 13b & 14), it became apparent that one of the functions of most gels was to provide water to the emerging seedlings. Moreover, the limited plant stand obtained with Water-Lock J550 was also due to the loss of structure observed when left uncovered. The problem of emergence encountered with uncovered Laponite 445 arose from the hardening of the gel around the seedlings thereby preventing them from emerging. This solidification of Laponite 445 has been reported by Pill and Watts (1983). Similar observations have been made with sodium alginate gel in dry soil conditions (Darby 1980; Chevrier 1983), and with Laponite 508 and Liquagel (Orzolek 1982b).

Total and mean plant weight were significantly affected by the presence or absence of gel, the gel type and whether or not the seeds and gels were covered with soil (Figure 15). Agrigel, Laponite 508 and Water-Lock J550 gave higher plant weight than the other gels. Leaving Agrigel uncovered did not significantly affect survival but reduced total and mean plant weight markedly, probably due to the aggregation of firm gel particles around the seedlings which could have restricted seedling expansion.

Over all, leaving the gels uncovered did not provide an adequate environment during the establishment period, even with the best performing gels, under ideal temperature and watering treatments. Thus it was likely that temperature and moisture variations present in the field would further stress the uncovered gels. Laponite 508 was the only gel for which no significant disadvantages of leaving the gel uncovered were observed in growth cabinet. Perhaps, if the other gels had been used at different concentrations and extrusion rates, they would have performed more satisfactorily.

Therefore, gel should be covered in the field to avoid unacceptably low emergence. Furthermore, concentrations of the gels particularly Water-Lock J550 and Liquagel should be adjusted to ensure that the gels would be thick enough to suspend the seeds during sowing and remain around the seedlings during early growth. Agrigel, Laponite 508 and Water-Lock J550 all performed well in the growth cabinet situation and should therefore be tested under field conditions.

4.4.2 Field trial 1983

4.4.2.1 Introduction

When compared to gel materials such as sodium alginate, starch polyacrynonitrile, guar gum, potato starch and polyacrylamide, synthetic clay proved best for improving field emergence of several crops, including onion (Darby 1980). However, from the results of the preliminary growth cabinet experiment (section 4.4.1), several gels proved equal to Laponite 508 (synthetic clay) in terms of emergence, survival and plant fresh weight for fluid drilled white onions. These gels were therefore tested under field conditions for their effect on emergence, survival, growth and yield of onions.

4.4.2.2 Materials and methods

The same gels used in the preliminary test were compared under field conditions. Laponite 508 was chosen as the standard gel for this experiment. From the results obtained in the growth cabinet experiment, several gels appeared too diluted. Thus, concentrations of all gels save Agrigel and Laponite 508 were increased. Gel specifications are presented in Table 23.

After 3 days, most of the seeds had radicles of 2-5 cm long and were ready to sow. However, they had to be held in cold storage for an additional 3 days due to cold and wet weather in the early spring (Table 3). Gels were prepared as for the preliminary test (section 4.4.1.2). The pregerminated seeds were fluid sown in the field with a gel extrusion rate of 30 ml m^{-1} as described in section 3.1.3. Since the gels left uncovered did not provide an adequate medium for seedling growth under controlled conditions except for Laponite 508, all gels were covered with 2 cm of top soil. Land preparation and management methods have been described in section 3.1.4.

Treatments were replicated 4 times and distributed in a randomized complete block design. Time to emergence, maturity (determined as the percentage neck fall at pulling), plant stand after emergence (3 weeks) and at harvest, mean bulb weight and total fresh yield were measured. The procedures were explained in section 3.1.5. All data were subjected to analyses of variance (Table A.9) and to a comparison of means by the Duncan's Multiple Range test.

4.4.2.3 Results

Time to emergence

While the time to emergence was slightly delayed for the Laponite gel treatments, seeds sown with Agrigel emerged 0.5 to 1.5 days earlier, but not significantly so, than all other gels (Table 24).

Maturity

Plant maturity was significantly more advanced at pulling in the Agrigel plots which exhibited 25% more neck fall than the Laponite 508 control (Table 24). Only in plots sown with Laponite 445 was the percentage of neck fall lower than that reached with the control; however, the difference was not significant. An early emergence was found to be correlated ($P \leq 0.005$; $r = -0.54$) with an more advanced plot maturity at time of harvest.

TABLE 24. Effect of gel type on emergence and maturity of fluid drilled onion cv.Southport White Globe in a 1983 field trial.

Gel type	Time to emergence (days)	Maturity[1] (% neck fall)
Agrigel	9.0 a	88.8 a
Laponite 445	10.5 a	62.5 b
Laponite 508	10.3 a	63.8 b
Liquagel	10.0 a	66.3 b
Water-Lock B100	10.0 a	70.0 b
Water-Lock B200	9.5 a	75.0 ab
Water-Lock J550	10.0 a	78.8 ab

a,b Within columns, means followed by the same letter are not significantly different at the 5% level, using Duncan's Multiple Range test.

Plant stand

No significant difference was observed in plant stand after emergence (Table 25). By harvest, plant stand was considerably decreased in all gel treatments compared to that reached after emergence. The loss of plants was greatest for Laponite 508 and 445 with a decrease of 78.8 and 79.3%, respectively.

Plant stand was significantly different among gel types at harvest (Table 25). In plots sown with Agrigel, Liquagel and WL-J550 the number of bulbs harvested per meter of row were respectively, 52.9, 19.1 and 19.1% higher than that reached with Laponite 508 gel. A significant negative correlation ($P \leq 0.001$; $r = -0.64$) existed between the time to emergence and the final plant stand.

Mean bulb weight

Significantly lower mean bulb weights were recorded for the Laponite gels. All other treatments were statistically equivalent (Table 26).

Fresh yield

Plots sown with Agrigel has significantly higher yields than that of the other gels except WL-J550 , and double that of Laponite 508 (Table 26).

Fresh yield was significantly correlated with the reciprocal of time to emergence ($P \leq 0.0001$; $r = -0.70$), and the stage of maturity reached ($P \leq 0.0001$; $r = +0.68$). This showed that treatments emerging and maturing the fastest produced the highest yields. In addition, a high positive correlation between bulb number at harvest and fresh yield ($P \leq 0.0001$; $r = +0.91$) indicated that a high yield was highly dependent on a large number of bulbs.

TABLE 25. Effect of gel type on plant stand reached after emergence (3 weeks) and at harvest of fluid drilled onion cv. Southport White Globe in 1983.

Gel type	Plant stand at emergence (plants m^{-1})	Plant stand at harvest (bulbs m^{-1})
Agrigel	27.9 a	10.4 a
Laponite 445	31.4 a	6.5 b
Laponite 508	32.0 a	6.8 b
Liquagel	31.3 a	8.1 ab
Water-Lock B100	24.0 a	6.1 b
Water-Lock B200	31.0 a	6.6 b
Water-Lock J550	31.3 a	8.1 ab

a,b Within columns, means followed by the same letter are not significantly different at the 5% level, using Duncan's Multiple Range test.

TABLE 26. Effect of gel type on mean bulb weight and total fresh yield of fluid drilled onion cv.Southport White Globe in 1983.

Gel type	Mean bulb weight (g bulb^{-1})	Total fresh yield (t ha^{-1})
Agrigel (Viterra)	110.0 a	25.2 a
Laponite 445	85.6 b	12.4 b
Laponite 508	86.4 b	13.3 b
Liquagel	93.8 ab	17.0 b
Water-Lock B100	106.4 a	14.5 b
Water-Lock B200	109.1 a	16.2 b
Water-Lock J550	108.1 a	19.6 ab

a,b Within columns, means followed by the same letter are not significantly different at the 5% level, using Duncan's Multiple Range test.

3.5.2.4 Discussion

Under field conditions, gel composition was found to significantly affect growth and yield responses of fluid drilled onions. Darby (1980) reported similar conclusions after testing a range of crops with 6 different gel types.

Agrigel sown plants had the fastest emergence and maturity, as well as the highest stand, bulb weight and fresh yield. The advantages of Agrigel may be partly explained by the presence of 10% available potassium in the gel structure. This could have been responsible for an improved early growth which in turn affected the yield by helping to avoid early disease problems (smut, damping off) and prolonging the growing season.

Laponite gels gave the poorest emergence and growth responses of all the gels (Tables 24, 25 & 26). Although exhibiting higher plant responses, Liquagel was not significantly better than Laponite. Similar findings have been reported by Orzolek (1982b) who attributed his results to the fact that the 2 gels did not diffuse through the soil and maintained a firm gelatinous structure which may have limited seedling emergence and growth. Pill and Watts (1983) also reported that Laponite gels had a tendency to dehydrate, while Chevrier and Stewart (1985) found the same problem with a sodium alginate gel. The high pH (8-9) of Laponite gels may have affected seedling growth, since the optimal pH range required by the onion for its development was from 5.5 to 6.5 (Brewster 1977). Such a high pH could therefore be expected to have an adverse effect on all pregerminated seeds sown, however, this was not the case as seedlings emerged from all treatments (Table 25). The natural differences in growth rates of individual seeds may have caused a large proportion of seeds to be more sensitive to high pH, which would explain the lowest emergence and the greatest decrease in plant stand between emergence and harvest (Table 25) for the Laponite gels. Although not significantly different from Laponite 508, Laponite 445 consistently displayed lower emergence and growth characteristics. It was likely the higher pH of the Laponite 445 that caused responses to differ between the two magnesium silicate gels. Moreover, the higher concentration of Laponite 445 required to form a gel (Table 23) may have caused this gel to harden more easily than Laponite 508 under stress conditions. Three other gels, Agrigel, Liquagel and Water-Lock B100 were reported to be less alkaline than Laponite (Minero, personal communication) and thus if pH were a problem, they would have a less detrimental effect on seedling development.

Although Southport White Globe cultivar viablity was 81% in 1983 (Table 5), field emergence was between 53 and 71% of the initial seeding rate (45 seeds m^{-1}), depending on the gel type. In addition to a differential response to gel type, it was likely that the temperature which varied between 1 and 5°C during the 3 days cold storage was too high to prevent radicle elongation (Brocklehurst et al. 1980) Wurr, Darby and Fellows, 1981). As such, most radicles were 2-5 mm long prior to cold storage and they were longer than the recommended length at sowing (Finch-Savage and Cox 1983), thus more subject to breakage during handling, and to cold injury (Steckel and Gray 1980; Irvin and Price 1983). Wurr et al. (1981) suggested that if drilling had to be delayed, the pregerminated seeds should be stored at about 0°C in order to minimize both radicle elongation and the spread of seedling emergence. The cold and wet conditions at sowing were probably responsible for the high occurrence of smut symptoms observed during plant establishment in all plots. This disease was most likely an important cause for the considerable decrease in plant stand throughout the season for all treatments.

Of the three starch graft copolymer gels (Water-Lock series), J550 showed consistent advantages over B100 and B200 which were in turn not significantly different from one another (Tables 24, 25 & 26). The 3 Water-Lock gels had a similar formulation but the different particle size of the gels seemed to affect their performance when used as fluid carriers. Two gels (WL-B100 and WL-B200) gave slightly but not significantly better results than Laponite 508. This agreed with the findings of Ghate and Phatak (1983) who reported no significant difference in emergence percentage of peppers when sown with Laponite 508 and Water-Lock B100.

Taking all growth responses into consideration, the gels could be divided into 3 main groups depending on the effects on onion (cv. Southport White Globe) emergence and growth; Agrigel and Water-Lock J-550 performed best, Water-Lock B100 and B200 and Liquagel ranked next, with Laponite 508 and 445 being the least promising under the environmental and experimental conditions encountered in this trial. While most gels possessed the essential characteristics of an acceptable gel carrier as listed by Darby (1980), synthetic clays (Laponite) and Water-Lock B200 required a high shear force and specialized equipment to be mixed with water, which was not desirable. In order to select the most suitable gel, several criteria must be used. Plant response to the gels has been discussed previously. An equally important aspect to consider was gel price. On a straight kilogram basis, the two most expensive gels were Liquagel and Agrigel, and the two cheapest were the Laponite series (Table 27). However, it was important to take into account the viscosity properties of gel powder since this determined rates required to form a gel (Table 23). Consequently, on an hectare basis, the most expensive gel was Laponite 445, followed by Agrigel, whereas Water-Lock J550 was at least 50% cheaper than all the other gels. Over all, Water-Lock J550 was the gel with the greatest commercial promise of all those tested in this trial.

TABLE 27. Prices of different gel types in 1983

Gel type	Price kg^{-1} ($)[1]	Price ha^{-1} ($)[2]
Agrigel (Viterra)	13.09[1]	87.00
Laponite 445	7.30	97.00
Laponite 508	6.60	65.00
Liquagel	14.00	75.00
Water-Lock B100	7.94	64.00
Water-Lock B200	7.94	64.00
Water-Lock J550	8.95	30.00

[1]. Figures compiled from respective companies' (Table 23) 1983 price lists.
[2]. The prices per hectare are based on a gel extrusion rate of 30 ml m^{-1}row and on adjusted gel concentrations used in this trial, in terms of g l^{-1} (Table 23).

4.5 GEL ADDITIVES

4.5.1 Preliminary field trial 1982

4.5.1.1 Introduction

Growth and yield of onions have been promoted by the application of growth stimulants or protectants to the seeds (Heydecker and Coolbear 1977; Khan, Kansen, Leve and Roe 1979; Brocklehurst and Dearman 1983 a&b), roots (Entwistle and Munasinghe 1980; Utkede and Rahe 1982; Ojala, Janell, Menge and Johnson 1983) or foliage (Lipe 1975; Brewster 1977).

However, few references were found to exist on the use of gel additives with fluid drilled onions. White rot of onions has been controlled by adding Iprodione fungicide to the gel carrier (Entwistle and Munasinghe 1981). Finch-Savage and Cox (1983) reported increases in seedling dry weight when a mixture of ammonium phosphate and potassium phosphate was added to the gel. The authors attributed these advantages to the close contact between the additive and the seed in the fluid drilled system. Consequently, a preliminary test was undertaken in 1982, to determine the effect of a range of gel additives on growth and development of the white onion crop.

4.5.1.2 Materials and methods

Onion seeds cv. Southport White Globe were pregerminated as described in section 3.1.1. The four gel additives and their rates of application are listed in Table 28. These treatments were compared to a plain gel control. Laponite 508 gel (15 g l^{-1}) was the standard gel base for all treatments (section 3.1.2). Pro-Gro fungicide was added to the gel powder prior to mixing with water whereas the seaweed and fertilizer liquid additives were dissolved in the water first, to ensure a uniform distribution in the gel.

The rate of Pro-Gro was calculated so as to be equivalent to the recommended dose for seed dusting (25 g kg^{-1} dry seeds; Crête and Tartier 1973). The liquid seaweed extract as well as the fertilizer were used at 0.25 times their recommended rate (Table 28), following the suggestion that chemicals could be added in smaller quantities than required by conventional methods when placed close to the seeds in the gel and still be effective in improving growth (Ohep Gruny 1981). Leek root material containing endomycorrhiza was finely chopped before being mixed with the gel to ensure maximum contact with the germinated seeds. A dry seeded control was also employed. The dry seeds were dusted with Pro-Gro, a standard procedure in muck soils (Crête and Tartier 1973).

Dry and pregerminated seeds were sown according to procedures outlined in section 3.1.3. Land preparation and management methods have been described in section 3.1.4. Time to emergence, time to maturity, plant stand 3 weeks after sowing and at harvest, mean bulb weight, fresh yield dry yield and bulb dry matter were measured. The measurement procedures are detailed in section 3.1.5.

The treatments (4 gel additives, 1 gel control and 1 dry seed control) were replicated 4 times and distributed in a randomized complete block design. An analysis of variance was performed on all the data, details of which are presented in Table A.10. Data of variables for which no treatment effect was found are presented on Table 29, while all other data are presented on Figure 16 & 17. Means were compared by a Duncan's Multiple Range test.

TABLE 28. Gel additives used in the 1982 field trial.

Product	Composition	Rate in the gel	
Pro-Gro systemic fungicide[1]	30% Carbathiin	48 ppm :	0.16 g l^{-1}
	50% Thiram	80 ppm :	
Liquid seaweed[2]	0.005% kinetin	0.4 ppm :	
	1% K_2O	75 ppm :	7.5 ml l^{-1}
	2% organic matter	150 ppm :	
Peter's fertilizer[3]	5% N	10 ppm :	
	11% P_2O_5	22 ppm :	0.2 g l^{-1}
	26% K_2O	52 ppm :	
	micronutrients		
Endomycorrhiza[4]	*Glomus epigeus* grown on *Fraxinus* sp. cultured on leek roots		20 g l^{-1}

Source: 1. Uniroyal Chemical, Elmira, Ontario.
2. Eaton Valley, Sawyerville, Quebec.
3. W.R. Grace, Ajax, Ontario.
4. Agriculture Canada, St-Jean-sûr-Richelieu, Quebec.

4.5.1.3 Results

Time to emergence

Gel additives decreased the time to emergence by 0.3 to 2.5 days when compared to the gel control. However, emergence was significantly earlier only in the case of the fertilizer treatment (Figure 16a). Seedlings from the dry seeded control emerged significantly later than all other treatments.

Time to maturity

Plants treated with gel additives tended to mature prior to the control gel. Maturity was hastened by 0.3 to 2.3 days with the addition of mycorrhiza and fertilizer, respectively (Table 29). However, those differences were not statistically significant. Dry seeded plots took 0.7 days longer to mature than the fluid drilled control. A highly significant correlation ($P \leq 0.0001$) was found between time to emergence and time to maturity ($r = +0.71$).

Mean bulb weight

Gel additives decreased mean bulb weight by 1.2 to 12.8 g compared to the gel control, but this decrease was significant only for the seaweed additive (Figure 16b).

Dry seeding produced the lowest mean bulb weight for any of the treatments but this was significant only in the case of the gel control which produced bulbs 26.4% heavier than its dry seed counterparts (Figure 16b). A strong negative correlation ($P \leq 0.0001$; $r = -0.71$) was found between bulb weight and bulb number.

Plant stand

The number of emerged seedlings in the fluid drilled plots, 3 weeks after sowing, was increased by all additives. The increases ranged from 10.7 to 33.5% (3.4 to 10.7 bulbs m^{-1}) but were significant only for the seaweed and Pro-Gro additions (Figure 17a). The number of seedlings was higher from the dry seeds than any of the fluid drill treatments, although not significantly as compared to gel seeding with Pro-Gro or seaweed additions.

Dry seeding significantly increased plant stand at harvest over all other treatments, resulting in 30% more plants at harvest than the gel control (Figure 17b). The number of bulbs at harvest was also significantly increased with the addition of growth promoters and protectants in the gel. Increases ranged from 6.7% (1.8 bulbs m^{-1}) for the mycorhyizal addition, to 17.4% (8 bulbs m^{-1}) for the addition of Pro-Gro, over the fluid drilled control.

In general, treatments having a high plant stand after 3 weeks had a high plant stand at harvest as well (Figure 17a&b). This was confirmed by the highly significant correlation found between plant stand at 3 weeks and at harvest ($P \leq 0.0001$; $r = +0.71$). However, individual variations were observed as the loss in plant stand was proportionally greater for the seaweed gel additive (27.6%) and lower for the fertilizer additive (15%) than for all other treatments.

Fresh yield

Fresh yield of fluid drilled plots was increased by 0.2 to 5.5% (0.1 to 2.7 t ha^{-1}) by the addition of Pro-Gro and mycorrhiza, respectively, over the gel control. Other gel additives tended to slightly decrease the fresh yield (Table 29). Dry seeding yielded 3% (1.5 t ha^{-1}) more than the gel control. Nevertheless, the difference in yield was not significant among the treatments (Table A.10).

Dry matter yield

Although there was no significant differences in dry yield between the treatments (Table A.10), the addition of mycorrhiza to the gel resulted in a 3% (0.3 t ha^{-1}) increase in dry yield compared to the control gel, whereas the other additives gave lower yields (Table 29). Dry seeding increased the yield by 2% (0.2 t ha^{-1}) over fluid drilled control.

Bulb dry matter

Only small differences in bulb dry matter percent were noted among treatments and were not statistically significant (Table 29).

TABLE 29. Effect of various gel additives on the maturity and the yield of fluid drilled onion cv. Southport White Globe in a 1982 field trial.

Treatment	Time to maturity (days from sowing)	Fresh yield (t ha^{-1})	Dry yield (t ha^{-1})	Dry matter (% $bulb^{-1}$)
DS[1]-Control	114.5 a	51.0 a	10.0 a	19.7 a
FD[1]-Control	113.8 a	49.5 a	9.8 a	19.8 a
FD-Fertilizer	111.5 a	48.3 a	9.6 a	20.1 a
FD-Mycorrhiza	113.5 a	52.2 a	10.1 a	19.9 a
FD-Pro-Gro	113.0 a	49.6 a	9.4 a	19.5 a
FD-Seaweed	112.5 a	48.6 a	9.7 a	18.8 a

a Within columns, means followed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range test.
[1]. DS: Dry Seeding; FD: Fluid Drilling

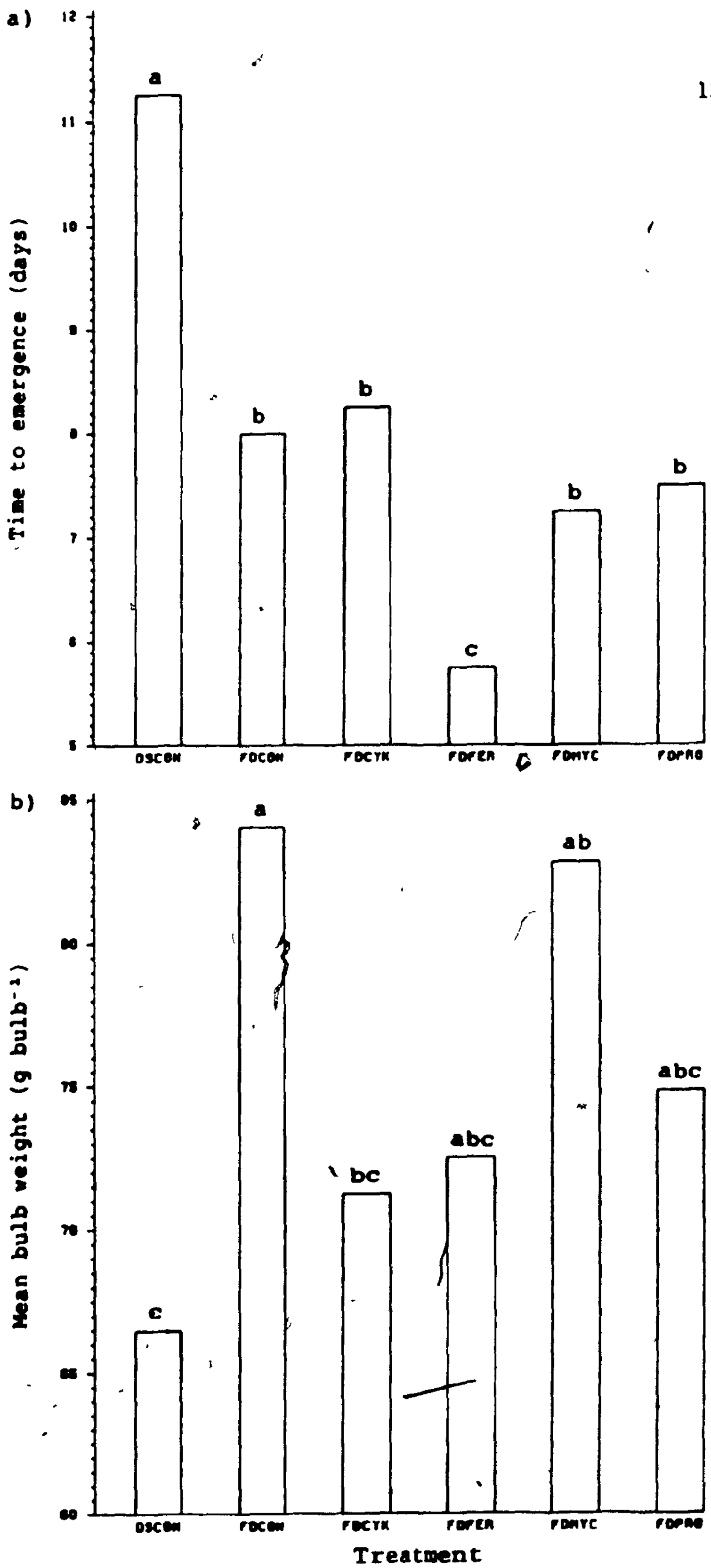


FIGURE 16. Effect of gel additives on a) time to emergence and b) mean bulb weight of fluid drilled onion cv. Southport White Globe in 1982.

a-c For each variable, columns headed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range test.

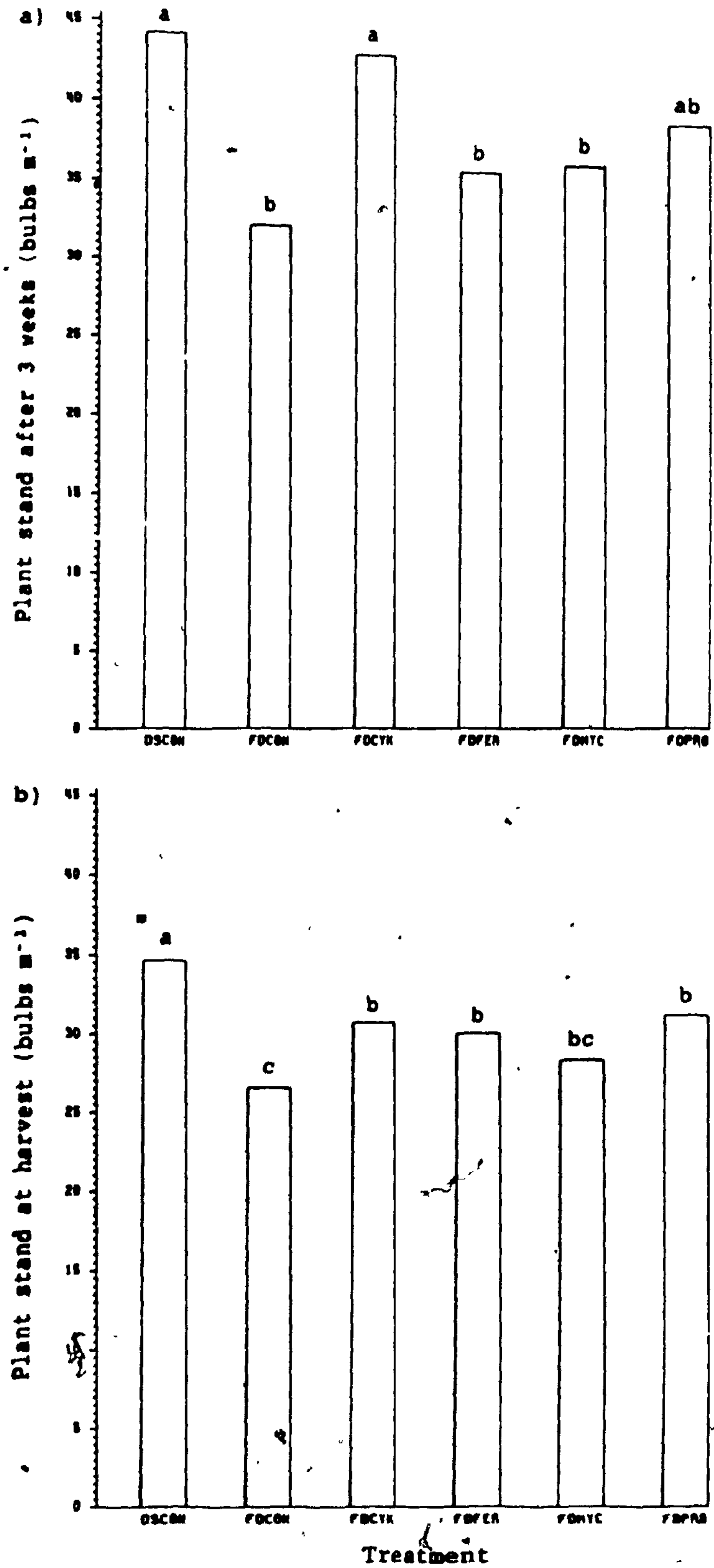


FIGURE 17. Effect of gel additives on a) plant stand after 3 weeks and b) plant stand at harvest of fluid drilled onion cv. Southport White Globe in 1982.
a-c For each variable, columns headed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range test.

4.5.1.4 <u>Discussion</u>

The results from this trial suggest that the incorporation of chemicals in the gel of fluid drilled onions can result in various benefits over plain gel.

Earlier emergence and maturity than the control was observed from all treatments; the best advantage was obtained by adding fertilizer to the gel (Figure 16a & Table 29). This was in agreement with Finch-Savage and Cox (1983) who reported that nutrient addition to the gel promoted early seedling growth in onion and lettuce, even when the recommended levels of broadcast fertilizer was applied. The hastened emergence and maturity obtained was probably due to the accurate placement of the nutrients within the limited area permeated by the seedling roots (Costignan and Locasio 1982; Finch-Savage and Cox 1982). Onions exploit a very small soil area due primarily to the limited root density, particularly that arising from the basal plate at bulbing. This coupled with the immobile nature of phosphorus itself may explain why small quantities of phosphorus placed close to the seeds can be particularly effective in improving early growth (Brewster 1977). The positive correlation existing between emergence time and time to maturity indicated that treatments leading to earlier emergence, matured earlier as well. However, the advantage in time to emergence obtained from the use of gel additives became smaller and non significant by maturity. This loss in emergence meant that the growing period between emergence and maturity was very similar for all treatments (Figure 16a & Table 29), and consequently, the accumulation of dry matter did not significantly differ.

The additions of seaweed extract and Pro-Gro fungicide were particularly beneficial for improving plant stand after emergence

(Figure 17a). Mycorrhiza and fertilizer additives also improved early plant stand over the gel control, but to a somewhat lesser extent. This was in agreement with Finch-Savage and Cox (1983) who found no reduction in the number of onion seedlings when up to 30 g l^{-1} of nutrients were added to the gel. The well established plant stand obtained by the seaweed additive may be due to the combination of the stimulating effects of kinetin on root development (Khan 1977) and of potassium on early growth rates (Burns and Hutsby 1983). The effect of Pro-Gro seemed more lasting as the loss of seedlings between 3 weeks and harvest was less than the seaweed treatment and the final plant stand was the highest of all the treatments.

The high plant stand obtained at harvest by the use of gel additives was generally associated with a low bulb weight (Figure 16b & 17b). Bulb weight was particularly low for the seaweed and the fertilizer treatments. Competition between the plants may have limited the size of the bulbs. Although a supplement in nutrients in the seaweed and fertilizer treatments may have had a beneficial effect on the early growth of the onions, it did not seem to be adequate to overcome the effect of competition between the plants at later stages of growth. Zink (1966) found that during the early growth, the rate of nutrient removal was relatively slow but the period from early bulbing until tops start to dry corresponded to the most rapid growth and the plants then removed 68% of their total N, 75% of the P and 47% of the K used during the entire season. It therefore seemed likely that in plots with a high plant density, an adequate supply of nutrients was not present in the root zone when the demand was greatest for bulb formation.

Considering that the fresh yield was lowest for the fertilizer and seaweed treatments (Table 29), it could also be suggested that nutrients and growth regulators were not available to the plants due to a change in structure of Laponite 508 gel with time, despite the relatively low concentration of nutrients and kinetin in the gel (Table 28). Indeed, loss of structure of Laponite 508 gel has been reported only when more than 10 g l^{-1} (Finch-Savage and Cox 1983) or 900 ppm (Ghate 1982) nutrients were added. Nevertheless, there were several explanations based on gel/nutrient interactions which could account for limited bulb growth. It was possible that an interaction between the synthetic clay structure of the gel and the nutrient additive produced a level of available ions toxic to the germinating seedlings (Ohep Gruny 1981). Another possibility was that the nutrient ions were inactivated for a period of time by being bound by the gel structure. Indeed, Ghate (1982) reported a problem of gel structure when nutrients or herbicides were added to Laponite 508. A loss of viscosity was also noted by Finch-Savage and Cox (1983) and Pill and Watts (1983) when nutrients were added to Laponite 508 and 445. A similar raction could have occurred between the gel and the fertilizers, insecticides, herbicides and fungicides applied to the soil prior to sowing (Table 4) which could have caused a change in gel structure capable of limiting plant growth.

The mycorrhiza treated plots produced a relatively high plant stand and bulb weight. Although no distinct studies were made in this trial to determine whether the endomycorrhiza was effectively acting in symbiosis with the onion plants, it was likely based on increases in bulb weight and fresh yield over the control that the plants were able to absorb more nutrients due to an extension of the roots by the fungus hyphae (Brewster 1977; Brochu 1983). Moreover, mycorrhized plants have been shown to have better water relations than non mycorrhized plants (Ojala *et al*.1983), and this could be of prime importance for the onion which needed a regular supply of water to ensure steady growth, higher yields and better quality bulbs (Tiessen et al. 1970, MAPAQ 1982).

Benefits from pregermination were seen when considering the effects on emergence, maturity and mean bulb weight (Table 29 & Figure 16a&b). However, plant stand was higher from dry seeding. Problems with Laponite gels have been discussed previously.

Fluid drilled onions sown with Laponite 508 reacted better to environmental stress with the addition of growth promoters or protectants in the gel. The addition of endomycorrhiza or Pro-Gro appeared most promising. However, the addition of seaweed and fertilizer used in this experiment tended to decrease yield. Therefore, evaluations of the use of different rates of the products and other sources of growth regulators and nutrients would have to be considered in future investigations.

4.5.2 Field trials 1983 - Cytokinins and fungicides

4.5.2.1 Introduction

The preliminary trial of 1982 (section 4.5.1) indicated that the use of gel additives showed better results than the plain gel in terms of emergence, plant stand and time to maturity. Therefore in 1983, further tests were undertaken to investigate the effect of two specific types of additives on the growth and yield of Southport White Globe onions. The first experiment was designed to test Cytex, a cytokinin containing material, registered for use as foliar spray. In this trial, the product was used in the gel to improve rooting and consequently seedling establishment and yield. In the second experiment two fungicides, Pro-Gro and Rovral, were tested as gel additives, for their efficiency to protect the onion seedlings from soilborne organisms such as smut (*Urocystis magica*) which cause heavy losses in organic soils (Crête and Tartier 1973; Tartier, Crête and Hogue 1976), and subsequently to improve yields and quality of the product.

4.5.2.2 Materials and methods

Cytokinin test - The experiment tested a range of concentrations of Cytex (Table 30) incorporated into the gel, compared to the plain gel. The basic rate chosen (1%) have shown positive effects on emergence and growth of various species when used as foliar spray (Burris and Robbins 1980), seed soak (Button and Noyes 1959; Wilczek and J Ng 1982) and gel additive (Gray and Bryan 1978; Ohep Gruny 1981). As no such experiments have been reported on onions, 5 rates were investigated to determine the most efficient for this crop. The highest rate chosen was 5% v/v as concentrations above this were reported to retard growth (Button and Noyes 1959).

Cytex, an aqueous extract from Laminariaceae and Fucaceae seaweed species, was registered for use in increasing cell division, root initiation, and for delaying senescence. In this trial, Cytex replaced the Liquid seaweed used in 1982. Both the Cytex and the seaweed solution contained cytokinins. Cytex was dissolved in tap water (pH 6.5) at the required concentrations, prior to the addition of gel powder. This procedure was done to ensure uniform distribution of the product. Laponite 445 gel, designed to tolerate additives, was used at 20 g l^{-1}. Seed material preparation has been described in section 3.1.1.

Seeds were germinated 2 days at 19-20°C and held in cold aerated water for 2 more days to slow down radicle emergence. Standard fluid sowing techniques were employed (section 3.1.3). Land preparation was according to procedures described in section 3.1.4.

Time to emergence, maturity (percentage neck fall), plant stand after emergence (18 days) and at harvest, mean bulb weight and total fresh yield were measured. Details of the measuring procedures are presented in section 3.1.5. The six treatments were randomized on 24 plots in a complete block design. An analysis of variance was performed on the data; details are presented in Table A.11.

TABLE 30. Treatments used in the 1983 gel additive field trials

Product	Composition	Rates used
Cytex[1]	Mixed cytokinins (20-30 ppm) mostly zeatin-like	in gel: 0.25, 0.5, 1.0, 2.5 & 5% v/v
Pro-Gro systemic fungicide[2]	30% Carbathiin 50% Thiram	dry seed: 25 g kg^{-1} in gel: 0.16 g l^{-1}
Rovral fungicide[3] (wettable powder)	50% Iprodione	dry seed: 250 g kg^{-1} in gel: 1.5 g l^{-1}

Source: [1]. Atlantic and Pacific Research, Florida (U.S.A).
[2]. Uniroyal Chemical, Ontario (Canada).
[3]. May and Baker, Ontario (Canada).

Fungicide test - This experiment was designed to compare survival and yield of plants treated with Pro-Gro and Rovral fungicides. Pro-Gro systemic fungicide has been registered for controlling onion smut caused by Urocystis magica. It has been recommended over many other systemic fungicides for its superiority in controlling the disease in smut infested organic soils in Quebec (Tartier et al. 1976). Rovral was included in this trial because of its wide spectrum of activity as it acts against several molds and fungi. Rovral has proven particularly effective in controlling onion white rot caused by Sclerotium cepivorum, when used as seed dust, stem-base spray or gel additive (Entwistle and Munasinghe 1980 & 1981). In this trial, the two products were used both as seed dusts and gel additives. The fungicides and rates used were listed in Table 30. Plain dry and plain gel (Laponite 445, 20 g l^{-1}) seeding were the two control treatments.

Seeds were germinated and held in cold aerated water as described in the Cytex test. Seeding was done on section of land infested with smut organisms from previous experiments (Crête and Tartier 1973; Tartier *et al*. 1976). The seeding procedures followed the methods outlined in section 3.1.3.

Treatments were replicated 4 times and distributed in a 3 X 2 factorial arrangement within a randomized complete block design. During the season, data were taken on the following variables: time to emergence, percentage neck fall at pulling, plant survival throughout the season, percentage smut in the plots at days 26 and 33, mean bulb weight, fresh and dry yields and bulb dry matter content. Details of measuring procedures have been described in section 3.1.5. Analyses of variance were performed on the above variables (Tables A.12 & A.13) and means were compared using the Duncan's Multiple Range test. When fungicide X sowing method interaction occurred, or when both fungicide and sowing method main effects were found (Tables A.12 & A.13), simple effects were examined and are presented on Figures 18 & 19. For data which showed no significant interaction or no significant main effects from fungicide treatment and/or sowing method, the main effects were considered and were presented in Table 32.

4.5.2.3 **Results and discussion: Cytokinins**

Time to emergence

The addition of Cytex in the gel did not significantly affect time to emergence compared to the control. However, the three highest rates produced a slight delay of 0.5 days in emergence (Table 31).

Percentage maturity

There was a slight but non significant trend toward a reduction in percentage maturity as the Cytex concentration increased from 0.25 to 2.5% (Table 31). However, the 5% concentration level actually reduced neck fall percentage reached at pulling.

Plant stand

Plant stand at 18 days after sowing was not significantly improved by Cytex addition to the gel (Table 31). Survival ranged from 50% to 70% (22.8 to 31.3 bulbs m^{-}) of the initial seeding rate (45 seeds m^{-1}) for the control and the 2.5% treatment, respectively. During the time from establishment to harvest, there was a decrease in plant stand (50%) for all treatments. This was largely attributed to smut and onion maggot attacks, the two most frequent problems of onions grown on Quebec muck soils.

At harvest, differences in plant stand were non significant although slightly more numerous in the control (12.4 plants m^{-1}) rather than in the treated plots (10.1 to 12.3 plants m^{-1}).

Mean bulb weight

Cytex additions to the gel had a non significant effect on mean bulb weight at harvest. Nevertheless, bulb weight ranged from 83.2 g to 125.4 g for rates of 0.5% and 5% Cytex, respectively (Table 31).

Total fresh yield

Fresh yield did not differ significantly between the control and any of the treatments. Response to Cytex was variable: the three lowest concentrations depressed yields compared to the control whereby the two highest levels actually increased it (Table 31).

TABLE 31. Effects of Cytex concentration on emergence, plant stand, maturity, mean bulb weight and total fresh yield of fluid sown Southport White Globe onion in 1983.

Cytex rate (%)	Time to emergence (days)	Maturity at pulling (% neck fall)	Plant stand at 18 days (bulbs m^{-1})	Plant stand at harvest (bulbs m^{-1})	Mean bulb weight (g blb^{-1})	Total fresh yield (t ha^{-1})
0	9.5 a	72.5 a	25.8 a	12.4 a	92.0 a	25.3 a
0.25	9.5 a	73.8 a	22.8 a	10.3 a	103.6 a	24.2 a
0.5	9.5 a	75.0 a	27.0 a	12.3 a	83.2 a	22.4 a
1.0	10.0 a	75.0 a	25.6 a	10.2 a	103.6 a	22.8 a
2.5	10.0 a	82.5 a	31.3 a	10.7 a	117.7 a	26.8 a
5.0	10.0 a	71.3 a	26.6 a	10.1 a	125.4 a	26.8 a

a Within columns, means followed with the same letter are not significantly different at the 5% level according to Duncan's Multiple Range test.

Discussion: Cytokinins

The results of this experiment indicated that the incorporation of Cytex into Laponite 445 gel significantly improved neither seedling establishment nor yield of fluid sown Southport White Globe onions when used at rates of 0.25 to 5%. These results were generally in agreement with Gray and Bryan (1978), Orzolek (personal communication) and Minero (personal communication) who, working with fluid drilled tomatoes, obtained no significant improvement from the use of Cytex. However Cytex used at 1.3% slightly improved emergence and dry weight for celery seedlings (Gray and Bryan 1978). The addition of 2% Cytex increased the plant stand and yield of cucumbers (Orzolek, personal communication).

The lack of response in terms of emergence time and level to Cytex inclusion could be explained by the very low temperatures prevailing during the sowing time in 1983 (Table 3). As reported by Wilcek and J Ng (1982), the effect of Cytex on beet seeds emergence was affected by the temperature, with the most beneficial effects being obtained at 15°C. Furthermore, it was reported (MAPAQ 1982) that growth regulators were often affected by climatic conditions, the type of soil and the cultivar used, and that the expected results were often not met. Therefore, the Cytex may have been rendered ineffective, or as Ohep Gruny (1981) indicated, the product may have been leached and thus unavailable. Although Laponite gels have been reported to be stable with time and temperature (Ghate 1982), there remained the possibility that an interaction between cytokinins and gel lead to the loss of gel integrity. As previously discussed, the emergence of the seed may have been hindered by both the cold storage period and the alkaline nature of the gel.

The tendency for mean bulb weight to be higher from the 2.5 and 5% Cytex treated plots was noted. This was attributed to rapid seedling emergence and establishment which in turn hastened plant development prior to bulb formation. These larger seedlings would more likely have attained the minimum physiological age to be receptive to daylength and would thus have a head start for bulb formation (Brewster 1977).

Addition of 0.25 to 5% Cytex in the gel thus failed to significantly improve growth and yield of fluid drilled onions. Thomas (1973) and Wilczek and Ng (1983) reported cultivar/growth regulator interactions for celery and beet, respectively. This suggested that the range of concentrations used for this experiment may not have been adequate for the cultivar Southport White Globe used in this trial.

4.5.2.4 Results and discussion : Fungicides

Time to emergence

Time to emergence was not improved by the addition of fungicides to the gel. Furthermore, Rovral delayed emergence by 1.2 days compared to the gel control (Figure 18a). Although Pro-Gro slightly delayed emergence when applied to dry seeds, the differences were not significant compared to the dry control. In all cases, fluid drilling hastened the emergence compared to dry seeding.

Percentage maturity

Maturity was significantly more advanced at pulling in the Pro-Gro treated plots compared to the control, whether onions were fluid drilled or dry seeded (Table 32) Rovral also resulted in a greater percentage of neck fall compared to the control, but this advantage was not significant. As a main effect, fluid drilling did not significantly hasten maturity compared to dry seeding.

Percentage survival

Analyses of variance computed on survival percentage throughout the growing season (Table A.13) showed that main effects of both fungicide and seeding treatments existed from day 59 to 117. However, no interaction were found between fungicide and seeding method. The interaction and main effects noted on day 12, 21 and 33 did not persist until the next recording day, and were thus probably due to the sampling procedure rather than treatment effects. Marked differences in survival between the treatments could be seen from day 59 to harvest on Figure 19.

An addition of Pro-Gro or Rovral to the gel or on dry seeds significantly increased the plant survival at harvest compared to their respective controls (Figure 18b). Moreover, Pro-Gro applications resulted in higher survival at harvest than Rovral for both fluid drilling and dry seeding. Although there was a tendency for survival to be lower at emergence (day 18) for the gel than for the dry seed treatment, gel seeding consistently increased plant survival at harvest. Increases over dry seeding were 119, 64 and 99% for the control, Rovral and Pro-Gro treatments, respectively.

A significant negative correlation was found between time to emergence and plant survival at harvest ($P \leq 0.001$; $r=-0.63$), suggesting that a faster emergence tended to lead to a higher plant survival at harvest.

Percentage smut

Smut symptoms were noted on the onion seedlings 26 and 33 days after emergence. The control plants were significantly more affected by the pathogen than either Rovral or Pro-Gro treated plants (Table 32). This was true on both days of measurement although differences were not significant among the treatments at day 33. The percentage of plants showing smut symptoms was slightly lower in the fluid drilled plots compared to the dry seeded ones. The higher percentage of plants affected by smut on day 26 compared to day 33 may be explained by the rapid death of diseased seedlings between those 2 dates (Table 32).

Mean bulb weight

The addition of fungicides into the gel or on dry seeds resulted in a greater mean bulb weight than the controls (Table 32). Fluid drilling also increased the weight of bulbs compared to dry seeding but differences were not significant in either case.

Fresh yield

Fresh yield of fluid drilled onions was increased by 125 and 29% by the addition of Pro-Gro and Rovral, respectively compared to the fluid drill control (Figure 20a). When fungicide was applied to dry seeds, results were similar to that for fluid drilling although to a lesser extent with Pro-Gro and Rovral increasing yields by 38% and 45%, respectively. Fluid drilling treatments thus significantly improved yields compared to dry seeding for all cases. The increases obtained were 68, 49 and 104% for the control, Rovral and Pro-Gro treatments, respectively. Significant correlations existed between fresh yield and both the stage of maturity reached at pulling ($P \leq 0.0005$; $r = +0.67$) and plant survival at harvest ($P \leq 0.0001$; $r = +0.95$).

Dry matter yield

Trends similar to that for fresh yield were obtained from dry yield results. A Pro-Gro addition increased dry yields by 133 and 86% compared to the fluid drilled and dry seeded control, respectively (Figure 20b). Similarly, the Rovral treatment was efficient in enhancing yield by 40 and 48% over the fluid drilled and dry seeded control, respectively. Fluid drilling consistently improved dry yield over dry seeding for all treatments, the advantage being more important for the Pro-Gro (107%) rather than the Rovral (56%) or the control (66%) treatments (Figure 20b). Significant correlations existed between dry yield and both the stage of maturity reached at pulling ($P \leq 0.0005$; $r = +0.60$) and plant survival at harvest ($P \leq 0.0001$; $r = +0.95$).

Bulb dry matter

The effect of fungicide additions on dry matter content of the bulbs was not significant, despite the higher percentage obtained from the Pro-Gro and Rovral treatments (Table 32). However, seeding method had a significant effect on dry matter as fluid drilling resulted in 0.6% more dry matter than did dry seeding.

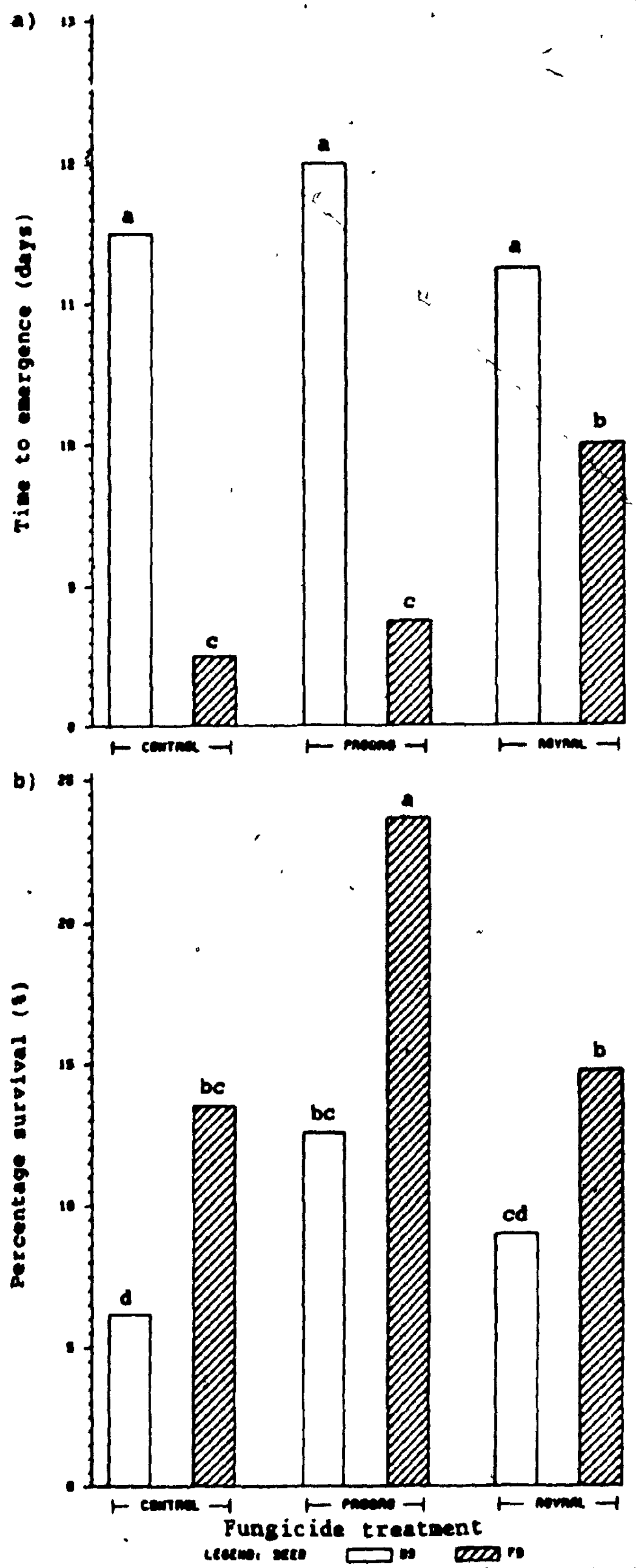


FIGURE 18. Effect of fungicide and sowing method on a) time to emergence and b) percentage survival of onion cv. Southport White Globe in 1983.
a-d Columns headed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range test.

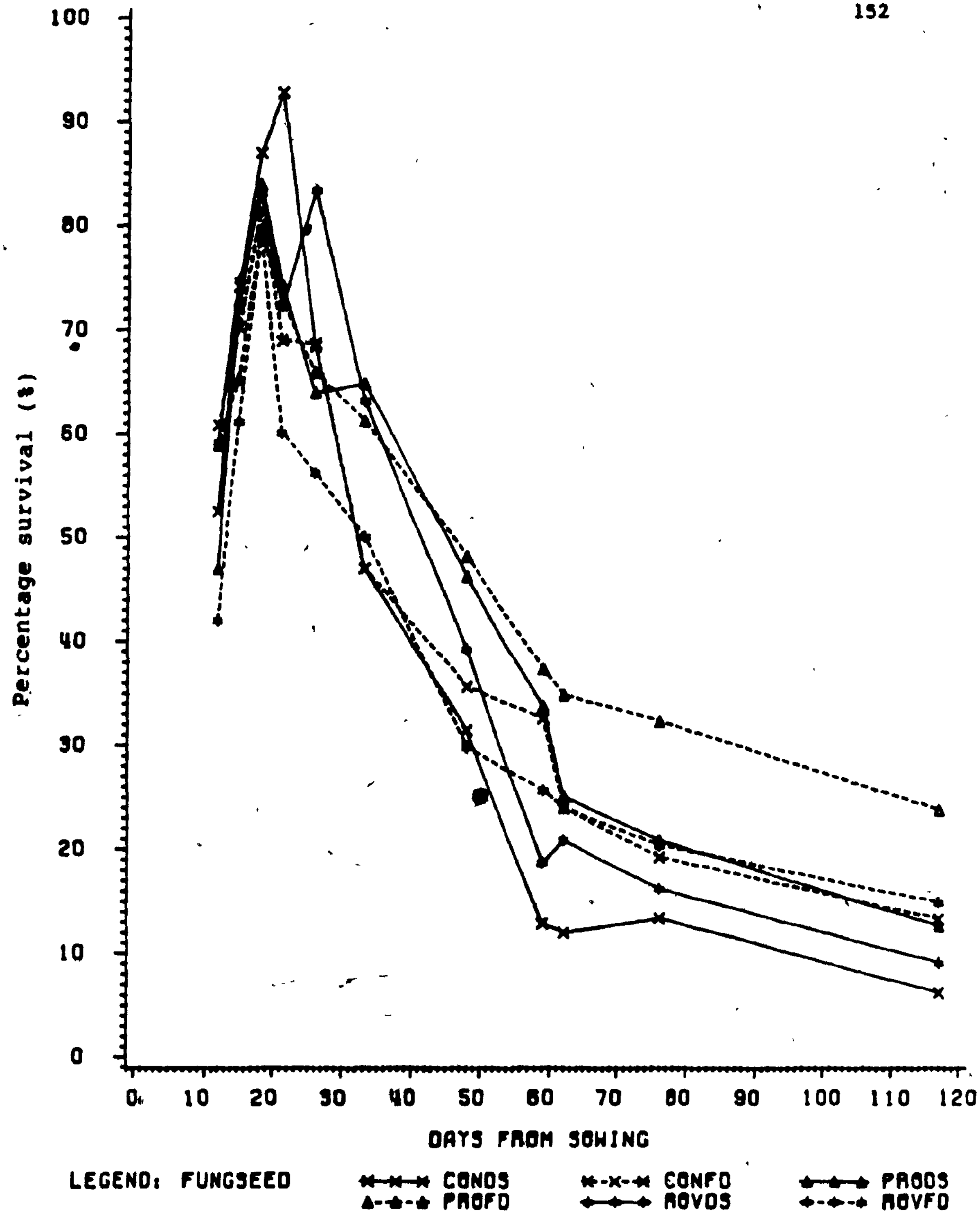


FIGURE 19. Percentage survival throughout the growth season of onion cv. Southport White Globe as affected by fungicide application and sowing method in 1983.

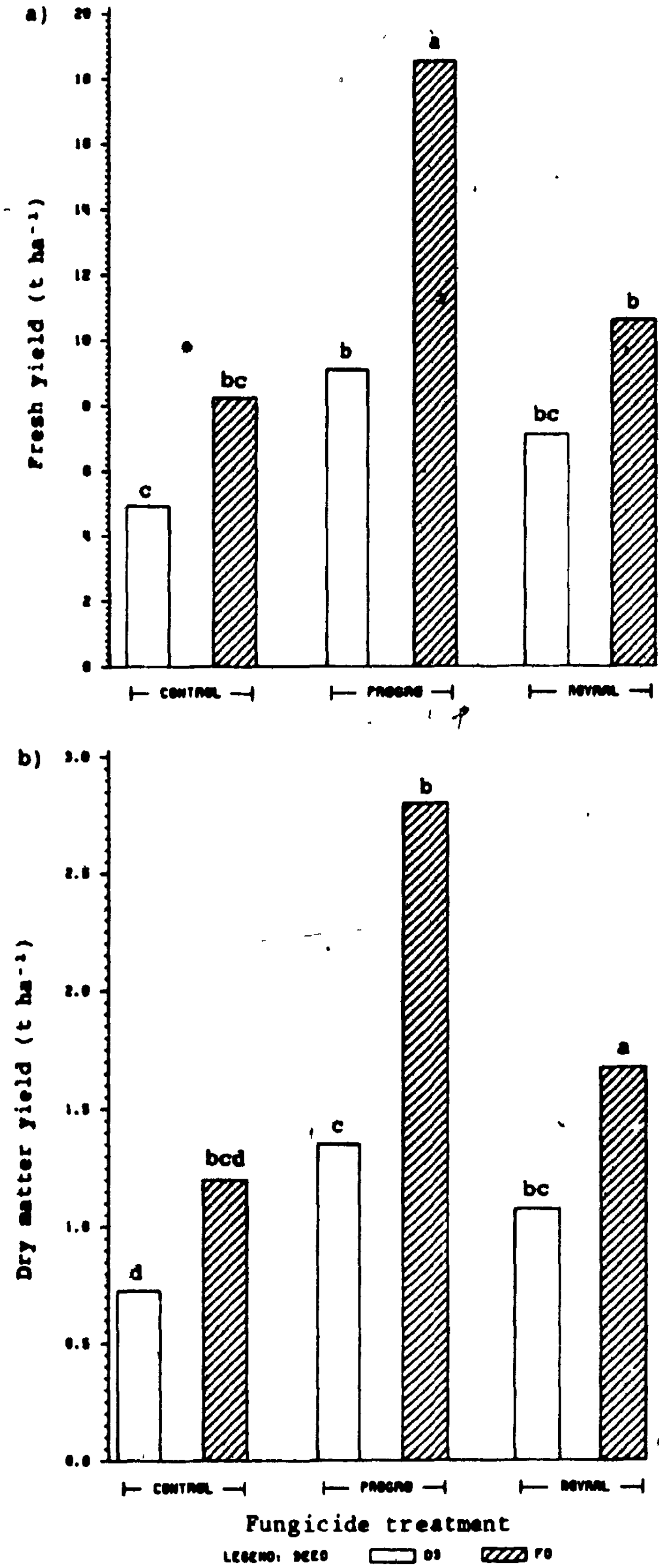


FIGURE 20. Effect of fungicide and sowing method on a) fresh yield and b) dry matter yield of onion cv. Southport White Globe in 1983.
a-d Columns headed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range test.

TABLE 32. Effect of fungicide treatment on the maturity, mean bulb weight, dry matter content and smut percentage of onion cv. Southport White Globe sown by fluid drilling and dry seeding in 1983.

	Maturity (% neck fall)	Bulb weight (g bulb^{-1})	Dry matter (% bulb^{-1})	Smut % (26 days)	Smut % (33 days)
Fungicide[1] treatment					
Control	43.1 b	71.9 a	14.7 a	67.6 a	25.7 a
Rovral	55.6 b	78.0 a	15.3 a	28.6 b	17.5 a
Pro-Gro	64.4 a	74.8 a	15.0 a	20.3 b	15.0 a
Seeding[2] treatment					
FD[3]	57.3 a	78.5 a	15.3 a	31.2 a	16.2 a
DS[3]	51.3 a	71.3 a	14.7 b	46.5 a	22.9 a

a,b Within columns, means followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

1. The values for each fungicide treatment are averages of 8 observations, from the 2 seeding treatments with 4 replicates.

2. The values for each seeding treatment are averages of 12 observations, from the 3 fungicide treatments with 4 replicates.

3. DS: Dry Seeding, FD: Fluid Drilling

Discussion: Fungicides

In general, the results from this experiment showed that the use of Pro-Gro systemic fungicide was beneficial for improving maturity, survival and yield components of Southport White Globe onion, especially when used in conjunction with the fluid drilling system. When used as seed dust or gel additive, Pro-Gro was more efficient than Rovral to protect onion seedlings grown on Quebec organic soils infested with Urocystis magica.

Gel seeding hastened the emergence as compared to dry seeding. However, the addition of fungicides particularly Rovral, on dry seeds or in the gel tended to delay emergence (Figure 18a). This problem also occurred in a previous study where a seed treatment of Iprodione (Rovral) delayed emergence when soil moisture was 60%, and moreover depressed percentage emergence when soil moisture reached 70% (Entwistle, Brocklehurst and Jones 1981). Soil moisture in the muck soil was normally around 60% at sowing time at the Ste-Clotilde Research Station, and the particularly wet weather in the early 1983 most probably raised the soil moisture level to values which could have affected the action of the fungicides.

Although fungicide treatments tended to depress emergence percentage at day 18 when maximum plant emergence was reached, no significant differences were found between thw treatments (Figure 19 & Table A.13). This confirms the findings of Ghate and Phatak (1983) who reported no adverse effect on emergence percentage from adding Metalaxyl in the gel of fluid drilled pepper seeds. This may be a sign of an absence of gel/fungicide interaction. Indeed, Ghate (1982) reported that metalaxyl addition to Laponite 508 gel at rates comparable to those recommended for dry seeds did not alter gel integrity. The case may be similar for Pro-Gro and Rovral fungicides and Laponite 445 gel. However, no study have yet been reported on the effect of fungicides on other gel properties such as pH and osmotic potential. Since the percentage of plants after emergence (day 18) was close to 80% for all treatments, no major factor seem to have limited emergence level. The great seedling loss occurring between days 18 and 48 (Figure 19) was most probably a reflection of the systemic nature of the smut infection. Chupp and Sherf (1960) indicated that smut normally affects the seeds during the period from 2 days after germination until the first leaf stage (about 15 days) and then spreads through the plants which die progressively when highly contaminated.

Plant stand was significantly higher for the fungicide treatments than the controls from day 59 to harvest, showing the effectiveness of the fungicides (Figure 19). Survival was significantly increased by the addition of Pro-Gro which was more effective than Rovral. This was probably due to the specific control of the Pro-Gro on smut. However, Pro-Gro did not completely control the fungus This confirmed the conclusions of Crête and Tartier (1973) and Tartier et al. (1976) who also obtained incomplete control of smut for dry sown onions in an infested soil. The high occurrence of dead seedlings showing blackish lesions typical of onion smut suggested that the soil was heavily infested. Therefore, despite the wider spectrum of activity of Rovral, it was less effective in protecting the seedlings in a soil where smut was a predominant problem. The cold and wet conditions prevailing at sowing were most likely responsible for the very low final percent survival (Figures 18b & 19) as those conditions favoured infection (Maude 1978).

Fluid drilled onions in the absence of fungicide seemed to be more resistant to smut infection than plants grown from dry untreated seeds as shown by final survival values (Figure 18b). This is in conflict with the findings of Enwistle and Munasinghe (1981) who obtained more susceptibility to white rot from fluid drilled onions. They attributed this to the gel which they thought provided a substrate for the spread of the fungus to adjacent plants. However in this trial, the gel seems to act as a protectant around the seedlings. Indeed, fluid drilling led to a faster emergence than dry seeding, thus involved less risks of attack by soil pathogens (Chupp and Sherf 1960; Westcott 1979), and resulted in a better control of plant population. In fact, the high correlation between time to emergence and final plant survival showed that the more rapid the emergence the higher plant survival (Figure 18b). The time of infection of the smut fungus, i.e. from 2 to 15 days after germination, indicates the importance of an early application of an effective fungicide.

The higher survival obtained from the use of Pro-Gro and Rovral in the gels compared to the dry seed dusts could have been due to two other factors. Firstly, although the rates of fungicides applied in the gel and on the dry seeds were equivalent, the application of the fungicide in the root zone with the gel may be more effectively placed than on the dry seed coat and so provide better and longer protection to the seedlings. Secondly, Rovral was applied as a dust on the dry seeds as recommended for Pro-Gro. However, Maude (1978) and Entwistle and Munasinghe (1981) showed that a surfactant such as methyl cellulose was required on onion seeds to ensure a prolonged contact and protection from fungicides. Thus, perhaps the Rovral was washed away from the seed hence did not give the required protection.

A low bulb number might explain the lack of significance in terms of mean bulb weight between the treatments as they was relatively little competition to affect bulb development. However, the relatively low bulb weight (71 to 78 g) and low percentage neck fall at pulling (51 to 64%) indicated that perhaps absence of competition slowed down the growth rate. Indeed, the significant interaction ($P \leq 0.005$; $r = +0.59$) between final plant survival and maturity showed that the highest plant survival (Figure 18b) corresponded to the most advanced stage of maturity (Table 32). Similarly, the high correlation between final survival and yield (fresh and dry matter yields) indicated that the number of surviving plants was a determining yield factor when a disease caused heavier losses in plant stand. Therefore, the Pro-Gro gel addition appeared to be the best treatment, as far as plant survival and yields were concerned.

From the results of this experiment, the cultivar Southport White Globe did not appear to be resistant to infection by smut organisms. Utkhede and Rahe (1982) noted that this cultivar showed 50% infection by <u>Urocystis magica</u> in heavily infested organic soils in British Columbia while three plant introductions and one commercial cultivar (Hardy White Bunching) were completely resistant to the disease.

This experiment demonstrated the feasibility of partially controlling smut which in turn improved plant survival and yield of fluid sown onions. This was of particular importance since the preferred dehydrating cultivar (Southport White Globe) showed inherent susceptibility to the disease. Furthermore, Pro-Gro and Rovral in combination could have proved effect since the first product controlled a specific disease and the second had a wide spectrum of control.

4.5.3 Growth cabinet fungicide experiments

4.5.3.1 Introduction

In the 1982 and 1983 field trials (sections 4.5.1 and 4.5.2), Pro-Gro proved to significantly increase plant survival throughout the season (17% increase in 1982 and 70% in 1983) and yield (0.2% increase in 1982 and 125% in 1983 of fluid drilled Southport White Globe onions. Pro-Gro additions have been particularly effective when used in a smut infested area and under cold and humid weather conditions (Table 3).

It was decided to undertake fungicide inclusion experiments in a controlled environment in order to clarify the response of early seedling growth to the gel/fungicide combinations. Accordingly, the gel fungicide treatment was compared in one experiment to dry seeding, and in another a range of Pro-Gro concentrations added to the gel was tested for their suitability.

4.5.3.2 Materials and methods

The experiment took place from October 29 to December 17, 1982 (49 days), and was replicated in time between January 28 and March 18, 1983 (49 days).

Onion seeds cv. Southport White Globe were pregerminated as described in section 3.1.1. Laponite 508 gel was prepared at 15 $g l^{-1}$ and where appropriate, Pro-Gro fungicide was added to the gel powder prior to adding water . The basic rate for adding Pro-Gro to the gel (X1) was 0.16 $g\ l^{-1}$ (Table 33) and was calculated by reference to the standard rate used for dry seeds (25 $g\ kg^{-1}$ seeds; X1), the weight of onion seeds (250 g^{-1}) and the seed:gel ratio utilized (25 seeds 15

ml^{-1} gel). Three lower (0.016, 0.04 and 0.08 g l^{-1}) and 3 higher rates (0.4, 0.8 and 1.6 g l^{-1}), calculated from the standard (0.16 g l^{-1}) concentration (Table 33) were tested in the gel to determine at which concentration the product became either ineffective or phytotoxic. The dry seeds were dusted with Pro-Gro at 25 g kg^{-1} of seeds or left untreated for the control.

For each treatment, 25 seeds were distributed on five 10 cm rows along the short axis of each flat. Pregerminated seeds were placed individually into the gel, when the radicles were 2-3 mm long, while dry seeds were placed directly into the rows (section 3.2.1). All seeds and gels were covered with 1 cm of organic soil collected from a smut infested area of the Ste-Clotilde Research Station. Gel extrusion rate was 15 ml per 50 cm of rows, equivalent to that recommended by Fluid Drilling Ltd. (Anonymous 1980). The flats were watered daily as required.

The ten treatments (7 fluid drilled treatments + control; 1 dry seed treatment + control) were replicated 3 times and the flats completely randomized in the growth chamber. Environmental conditions have been described in section 3.2.1.

Time and percent emergence were taken for each flat. Survival and fresh weight (total and mean plant weight) were recorded after 49 days as described in section 3.2.2. In addition, the percentage of harvested plants showing smut at the end of the experiment was observed using the transparency technique utilized by Crête and Tartier (1973). The percentage of healthy plants, defined as surviving seedlings with normal development and absence of smut was also recorded.

In Experiment A, dry seeded and fluid drilled controls and standard Pro-Gro treatments were compared in a 2 X 2 factorial arrangement. An analysis of variance was performed for experiment 1 (1982) and its replicate in time: experiment 2 (1983) separately, and LSD (0.05) values calculated for all variables measured (Table A.14).

In Experiment B (Range of Pro-gro rates), pooled analyses of variance were done on the data of gel additive treatments of the two experiments, in a split-plot design in time (Table A.15). Variables for which significant differences were found between experiment 1 (1982) & 2 (1983) were further analysed in 2 separate experiments (Table A.16). Variables which showed no difference between the experiments were analysed using the averaged values of experiments 1 and 2. Regression curves were fitted to the response of plants to the increasing Pro-Gro concentration in the gel by the General Linear Models (GLM) procedure (Helwig 1978); (Table A.18). Because of the very high coefficient of variation (c.v.≥ 200) of the smut data analysis and the non significant differences among Pro-Gro rates for the percentage emergence, regression analyses were judged inaccurate and no regression curves were drawn. Means were thus compared by the LSD test.

TABLE 33. Rates of Pro-Gro used either as coated on dry seeds or incorporated in the gel in the growth cabinet experiments.

Application rate of Pro-Gro		
to dry seeds ($g\ kg^{-1}$)		
	0	(X 0)[1]
	25	(X 1)
to gel	($g\ l^{-1}$)	
	0	(X 0)
	0.016	(X 0.1)
	0.04	(X 0.25)
	0.08	(X 0.5)
	0.16	(X 1.0)
	0.4	(X 2.5)
	0.8	(X 5.0)
	1.6	(X10.0)

1. (X x): X the standard commercial rate of application.

4.5.3.3 <u>Results</u>

Experiment A : Fluid drilling vs. Dry seeding

<u>Emergence time</u>

Mean time to emergence was significantly reduced by fluid drilling compared to dry seeding in all cases (Table 34). While adding a standard rate of Pro-Gro significantly delayed emergence of fluid drilled seeds compared to the control in experiment 1, the dry seeded treatment was not significantly affected in both experiments.

<u>Percentage emergence</u>

The percentage of emergence was higher for fluid drilled than for the dry seeded control in experiment 1, but no significant differences were found between the seeding methods in the second experiment or when adding the fungicide (Table 34). While emergence of dry seeds was significantly increased by the addition of Pro-Gro, no significant effect of Pro-Gro was noted for the fluid drilled seeds (Table 34).

<u>Percentage survival</u>

Fluid drilling resulted in significantly higher survival rates after seven weeks than dry seeding in experiment 1, for both control and Pro-Gro treatments (Table 34). The addition of fungicide in the gel and to dry seeds led to significantly more surviving seedlings than their respective controls. On the other hand, no significant differences in survival were found between the treatments in experiment 2.

<u>Percentage healthy plants</u>

Neither the seeding method nor the use of Pro-Gro significantly affected the percentage of surviving plants showing normal growth (Table 34). Nevertheless, Pro-Gro treatments tended to give a greater proportion of normal healthy looking plants than did the controls for both fluid drilling and dry seeding.

No significant difference was observed in the percentage of plants showing smut symptoms (Table 34).

Total and mean plant weight

The trends for total and mean seedling weight results were similar (Table 34). Fluid drilling resulted in greater total weight and weight per plant than dry seeding for control and Pro-Gro treatments, although the differences were significant only for the first experiment. In both experiments, the addition of standard rate of Pro-Gro on dry seeds and in the gel showed a non significant decrease in weight after 49 days, compared to the controls.

TABLE 34. Effect of Pro-Gro rate on emergence, survival, health and weight of dry seeded and fluid drilled onion cv. Southport White Globe in growth experiments (Exp.) 1 & 2.

	Seeding method and fungicide treatment				
	DS[1] (X0)[2] control	DS (X1) 25 g kg^{-1}	FD[1] (X0) control	FD (X1) 0.16 g l^{-1}	LSD (0.05)
Emergence time (days)					
Exp.1	8.3	8.0	5.2	5.6	1.21
Exp.2	9.2	9.3	5.8	6.9	0.99
Percentage emergence (%)					
Exp.1	82.7	96.0	98.7	100.0	10.43
Exp.2	98.7	100.0	98.7	98.7	ns
Percentage survival (%)					
Exp.1	80.0	89.3	90.8	98.7	7.53
Exp.2	97.3	98.7	94.7	97.3	ns
Healthy plants (%)					
Exp.1	88.0	92.6	89.5	91.9	ns
Exp.2	78.0	82.4	77.6	79.4	ns
Percentage smut (%)					
Exp.1	0.0	0.0	4.5	0.0	ns
Exp.2	2.8	0.0	2.7	0.0	ns
Total plant weight (g flat^{-1})					
Exp.1	31.8	30.9	46.1	43.5	9.76
Exp.2	49.2	47.5	52.7	48.2	ns
Mean weight (g plant^{-1})					
Exp.1	1.58	1.39	2.04	1.76	0.46
Exp.2	2.02	1.92	2.22	1.98	ns

ns: non significant at the 5% level.
[1]. DS: Dry Seeding; FD: Fluid Drilling
[2]. (X x): X the standard commercial rate of application.

Experiment B: Range of Pro-Gro rates in the gel

Emergence time

Adding a range of Pro-Gro concentrations to the gel delayed emergence compared with the gel control (Figure 21a). In general, seedlings of experiment 1 emerged faster than those of experiment 2. The response curve of the first experiment showed that emergence was slower as Pro-Gro concentration increased, up to a rate of 1 g l^{-1}. Higher inclusion rates did not further delay emergence. In experiment 2, the effect was linear: as the rate of Pro-Gro in the gel increased, so did the time to emergence. For experiments 1 and 2, the use of 0.16 g l^{-1} Pro-Gro (standard rate) caused short delays of 0.25 and 0.45 days compared to the controls (Figure 21a).

Percentage emergence

The addition of 0.016 to 1.6 g Pro-Gro per liter of gel did not significantly affect the level of emergence of onion seedlings which ranged between 94.7 and 100% of the initial seed rate, and therefore no regression curves were drawn (Table A.15).

Percentage survival

Concentrations of 0.16 (X1) to 0.48 (X3) g Pro-Gro l^{-1} gel, estimated by regression analysis led to maximum seedling survival (between 96-97%) after 49 days (Figure 21b). The addition of 0.8 g l^{-1} (X5) of fungicide resulted in a plant stand as high as that of the control (94%) but further increases in the rate resulted in decreased seedling survival.

Percentage healthy plants

In both experiments, the percentage of healthy plants decreased with increasing rates of Pro-Gro in the gel (Figure 21c). However, the decrease was greater in experiment 2. A toxicity effect seemed to exist at concentrations above 0.8 g l^{-1} (X5) where up to 23 and 68% more plants showed disease or stunted growth (non-healthy plants) compared to the control in experiment 1 & 2, respectively. The use of the standard commercial rate of Pro-Gro in the gel resulted in a 3 and 6% decrease in healthy plants compared to the gel control in experiments 1 and 2, respectively.

Percentage smut

Smut occurrence (3.6%) was significantly greater in the gel control than in the Pro-Gro gel additives (Table A.17). It is possible that a certain proportion of seedlings did not emerge at all due to an attack of smut at an early stage. The addition of 0.5 X the standard rate and above resulted in the absence of smut on the plants at the end of the experiment.

Total plant weight

Total plant weight decreased linearly with increasing rate of Pro-Gro, with the addition of 1.6 g l^{-1} resulting in a 60% loss compared to the control (Figure 22a). The standard rate of Pro-Gro resulted in a reduction of 6% in total seedling weight.

Mean plant weight

Regression analysis showed a decreasing mean plant weight with increasing rate of fungicide to a rate of 1.2 g l^{-1}, after which mean weight did not decrease further (Figure 22b). The addition of 0.16 gl^{-1} (X1) Pro-Gro decreased plant weight by 8% compared to the gel control.

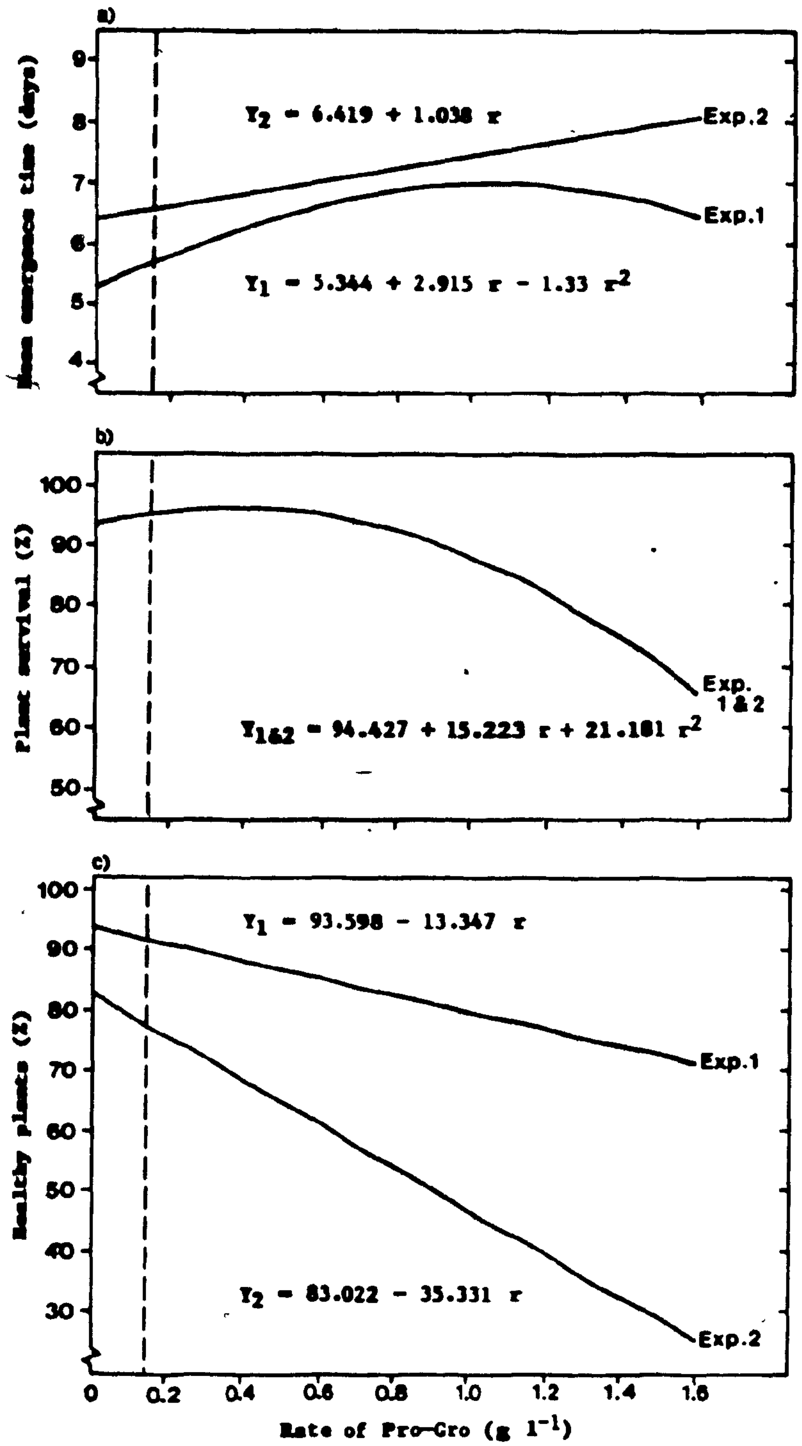


FIGURE 21. Regression curves showing the effect of Pro-Gro fungicide on a) mean emergence time, b) plant survival and c) percentage healthy plants of fluid drilled onion cv. Southport White Globe.
r: rate of Pro-Gro in the gel
Dotted lines: standard rate of Pro-Gro

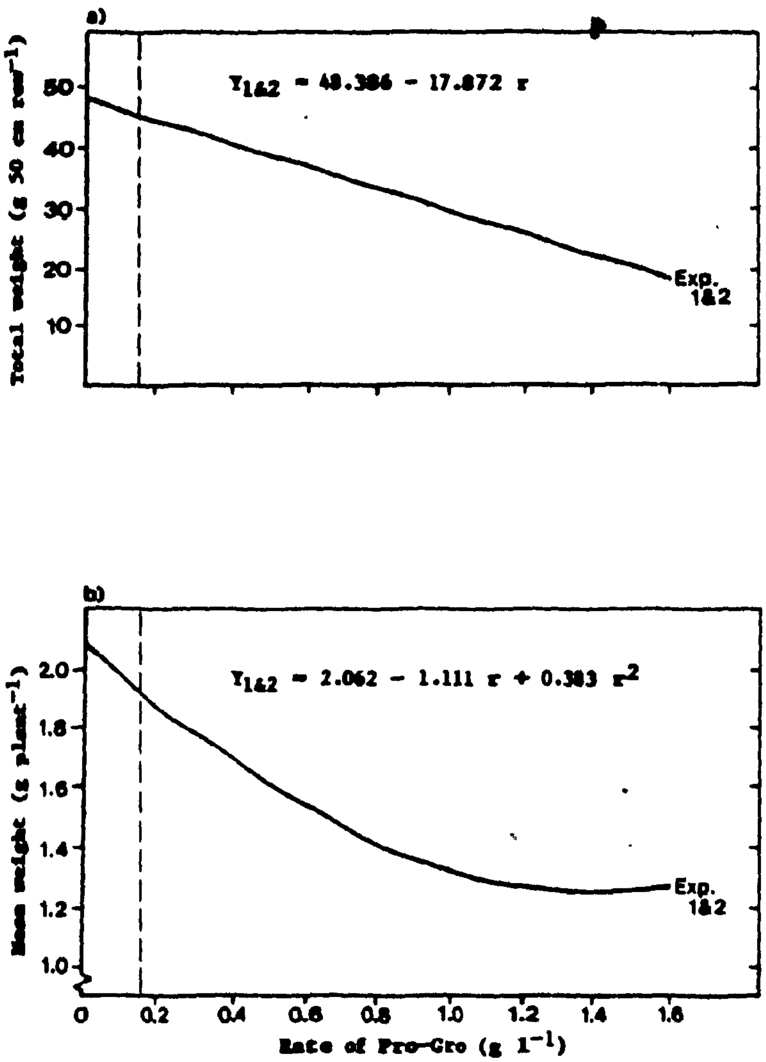


FIGURE 22. Regression curves showing the effect of Pro-Gro fungicide on a) total plant weight and b) mean weight of fluid drilled onion cv. Southport White Globe.
r: rate of Pro-Gro in the gel
Dotted lines: standard rate of Pro-Gro

4.5.3.4 Discussion

Fluid drilling exhibited an advantage over dry seeding in terms of time and percentage of emergence, survival, and plant weight (Table 34). The advantage was due mainly to the head start afforded by the pregermination of the seeds, reinforced by the selection of viable and optimally germinated seeds at sowing. Furthermore, the incorporation of a fungicide such as Pro-Gro enhanced the benefits of the fluid drill technique as it resulted in a higher survival, total and mean plant weight than the treated dry seeds.

Although Pro-Gro additions had positive effects on percentage emergence, survival and healthy plants for both seeding methods, there was a trend for the fungicide treatments to delay emergence and reduce plant weight compared to the controls in both experiments. This delay however, became non significant by the end of the season. Indeed, the Pro-Gro treated seeds would be expected to survive in greater proportions than the untreated seeds, consequently give higher final yields as has been reported by Crête and Tartier (1976).

Only a few plants were found to be infected by smut after 49 days, consequently, no significant control of the disease by Pro-Gro applications on dry seeds or in the gel was noted (Table 34). Although soil was taken from a contaminated field, the conditions of temperature and moisture in the growth chambers may have not permitted a sufficient development of the fungus to cause severe infection. However, the decrease in plant stand between emergence and final survival (Table 34) was greater in non-treated plants which may indicate that more seedlings died from smut after emergence when they were not protected.

Furthermore, among the four treatments, the fungicide gel additive led to the smallest plant loss from emergence to the end of the experiments. This could be due to the more direct and longer contact of the fungicide with the radicles thereby, affording protection during the critical infection period (15 days; Chupp ans Sherf, 1960).

Although most trends were similar for the two time experiments, emergence time in 1983 was reduced for the fluid drilled treatment. This difference was most probably due to the shorter radicles of the seeds in the second experiment which lenghtened the time to emergence thereby eliminating differences between fluid drilling and dry seeding.

The addition of Pro-Gro systemic fungicide to the gel did not affect emergence and growth of onion seedlings markedly when used up to the standard rate. Adverse effects were however observed at concentrations 5 to 10 times the standard. Percentage survival was increased by an addition of Pro-Gro up to 3 times the standard rate (Figure 21b). This confirmed the findings of Ghate and Phatak (1983) who concluded that chemical treatments did not significantly change emergence and growth rates of pepper seeds when applied with the gel at the rate up to 2.5 times recommended field rates. However, it was noted that concentrations of 0.1 to 0.25 times the standard rate did not give complete smut control and rates above the standard tended to produce toxic effects. Similarly, Entwistle and Munasinghe (1981) demonstrated that at only 0.25 and 0.5 of the standard rate, Iprodione incorporation into the gel proved adequate for controlling white rot and was well tolerated by the pregerminated onion seedling.

High concentrations of Pro-Gro delayed emergence, lowered plant survival, decreased percentage of healthy plants, and decreased plant weight (Figures 21 & 22). Two explanations were possible. Firstly, a phytotoxicity effect was observed as survival became progressively lower with increasing fungicide rates above 5 X the standard rate (Figure 21b). Secondly, it was noted that gels with Pro-Gro concentrations of 0.4 g l^{-1} (2.5 X the standard) and above formed hard strips around the seedlings. The physical barrier thus created could have accounted for some of the reduction in survival and growth afforded by the higher rates. Although, Ghate (1982) noted no major change in Laponite gel structure using Metalaxyl fungicide, but no specific studies have reported with Pro-Gro fungicide in the gel for onions grown on organic soil. Chevrier and Stewart (1985) reported that sodium alginate gel dessication caused entrapment of lettuce seedlings at 25% field capacity of organic soil. The same effect could be expected from Laponite gel, but since no moisture stress was experienced in the trials, it was more likely that gel/Pro-Gro interactions existed above a certain concentration of the product thereby causing a hardening of the gel, as well as toxicity to the plants.

V. GENERAL CONCLUSIONS

Production of onions suitable for dehydration was possible under the climatic conditions in the organic soil region of Quebec. The choice of cultivar appeared crucial. Genetic background and adaptation were largely responsible for production of large bulbs with a high dry matter content and elongated shape. However, environmental conditions markedly influenced cultivar performance. There appeared to be a significant relationship between bulb size and the reciprocal of dry matter content for all cultivars. Bulb shape index was found to be negatively correlated with mean bulb weight. Bulb shape, although related to cultivar, was influenced by climatic conditions particularly the temperature. Reducing the sowing rate to 35 seeds m^{-1} produced larger more commercially useful bulbs.

Cultivar response to fluid drilling in terms of plant stand and final yield was less than desirable. The problem appeared to arise from weather conditions prevailing at sowing, gel used, as well as from the lack of protection from soilborne fungi as the fungicide coating was washed away during the pregermination process. Several disadvantages of the most commonly used gels (Laponite 508 and 445) were noted in this study. The requirement of a high shear force to mix the gel with water would mean the use of specialized and costly equipment. The low field emergence observed with these gels most probably was caused by high pH and hardening of the carriers. Furthermore, although Laponite gels performed satisfactorily under controlled conditions even when uncovered, they appeared to react negatively under field conditions. From these trials, the most promising gel types were Agrigel and Water-Lock J550.

The trials indicated that gel additives served to protect and promote rapid growth of developing onion seedlings. The development of a complete drilling package including gel additives was feasible. The addition of endomycorrhiza and Pro-Gro fungicide appeared particularly promising. In this study, Pro-Gro addition to the gel produced seedlings with a hastened emergence, increased survival and plant weight, and controlled smut under controlled conditions when compared to the conventional seed dusting technique. Pro-Gro gel addition was best between one half and one times the standard rate. Higher concentrations adversely affected onion emergence and early growth, and lower concentrations did not control smut. It thus appeared that the very effective use of the small quantities of fungicide was due to the prolonged contact between the fungicide and seedlings.

The minimal response to Cytex may have been due to a gel type/Cytex interaction. Nevertheless, there was a tendency for the 2.5% rate to improve growth and yield over the gel control. It was possible that an increase in sample size or replicate number, or the use of another cultivar and gel type would prove more advantageous and hence more economic.

Although gel additive combination were promising, a number of modifications in the technique would be required before recommending the use of the fluid drilled system for dehydrating onions.

VI. FUTURE INVESTIGATIONS

Based on the results obtained in this study, several areas of research remain to be investigated to optimize the production of dehydrating onions using the fluid drilling technique:

1. Evaluation of new long-day cultivars.

2. Use of a control cultivar to obtain a reference curve of yield against density in order to render more accurate yield comparisons among cultivars under test.

3. A study on the effect of a more regular arrangement pattern on yield and bulb size distribution, by using a sowing rate of 35 seeds m^{-1} with an inter row spacing ranging from 20 to 45 cm.

4. Investigation of the possible interactions between preemergence herbicide and granular insecticide on the gel/seed system.

5. Testing of new low pH gel materials that would not harden for their compatibility with additives. Information would be required on additive effect on gel chemical and physical properties (viscosity and pH) and on the optimal rate of additives inclusion for plant growth and yield.

6. Evaluation of the effect of Pro-Gro and other protectants in combination with growth promoting substances such as Cytex to create a disease free micro environment and permit the full expression of the growth regulators.

7. Evaluation of a liquid formulation with the same 30% Carbathiin / 50% Thiram ratio as Pro-Gro to ensure a more even distribution in the gel and a better efficiency of the fungicide.

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APPENDIX TABLES

TABLE A.1 Analyses of variance for data of emergence, growth and yield of 8 onion cultivars sown by fluid drilling in a 1982 field trial.[1]

Measurement	Source	df	MS	F value
Emergence time	Block	3	2.54	2.90 ns
	Cultivar	7	2.13	2.43 ns
	Error	21	0.88	
Maturity time	Block	3	0.53	0.18 ns
	Cultivar	7	230.32	77.19 **
	Error	21	2.98	
Stand (harvest)	Block	3	24.96	2.90 ns
	Cultivar	7	14.21	1.65 ns
	Error	21	8.60	
Bulb weight	Block	3	592.94	3.74 *
	Cultivar	7	2947.13	18.60 **
	Error	21	158.47	
Bulb shape	Block	3	0.004	1.79 ns
	Cultivar	7	0.013	5.35 **
	Error	21	0.002	
Fresh yield	Block	3	143.53	5.58 **
	Cultivar	7	1095.66	42.60 **
	Error	21	25.72	
Dry matter yield	Block	3	4.62	4.77 *
	Cultivar	7	15.43	15.94 **
	Error	21	0.97	
Bulb dry matter(%)	Block	3	0.34	0.45 ns
	Cultivar	7	17.50	23.22 **
	Error	21	0.75	

* : significant at the 5% level
** : significant at the 1% level
ns : non significant
[1]. Data were analysed in a randomized complete block design

TABLE A.2 Analyses of variance for the data of emergence, growth and yield of 8 onion cultivars sown by dry seeding in a 1982 field trial.[1]

Measurement	Source	df	MS	F value
Emergence time	Block	3	5.46	5.30 **
	Cultivar	7	2.41	2.34 ns
	Error	21	1.03	
Maturity time	Block	3	4.50	0.74 ns
	Cultivar	7	209.07	34.17 **
	Error	21	6.12	
Stand (harvest)	Block	3	36.33	8.37 **
	Cultivar	7	47.29	10.90 **
	Error	21	4.34	
Bulb weight	Block	3	544.96	11.08 **
	Cultivar	7	1337.28	27.18 **
	Error	21	49.20	
Bulb shape	Block	3	0.004	0.92 ns
	Cultivar	7	0.018	3.76 **
	Error	21	0.005	
Fresh yield	Block	3	107.38	8.31 **
	Cultivar	7	1011.39	78.30 **
	Error	21	12.92	
Dry matter yield	Block	3	4.06	4.96 **
	Cultivar	7	13.14	16.05 **
	Error	21	0.82	
Bulb dry matter(%)	Block	3	1.10	0.64 ns
	Cultivar	7	16.58	9.61 **
	Error	21	1.72	

* : significant at the 5% level
** : significant at the 1% level
ns : non significant
[1]. Data were analysed in a randomized complete block design

TABLE A.3 Analyses of variance for the effect of sowing method on emergence, growth and yield data of 9 onion cultivars in a 1983 field trial.[1]

Source of variation	df	Emergence time MS	Emergence time F value	Maturity time MS	Maturity time F value
Cultivar	8	17.81	43.72 **	842.02	157.74 **
Sowing method	1	102.72	252.14 **	5.01	0.94 ns
CultivarXSowing	8	1.28	3.15 **	7.48	1.40 ns
Error	54	0.41		5.34	

Source of variation	df	Plant stand MS	Plant stand F value	Bulb weight MS	Bulb weight F value
Cultivar	8	26706.75	19.23 **	11028.98	88.30 **
Sowing method	1	14506.72	10.45 **	1535.50	12.29 **
CultivarXSowing	8	2768.78	1.99 ns	361.61	2.90 **
Error	54	1388.68		124.90	

Source of variation	df	Bulb shape MS	Bulb shape F value	Fresh yield MS	Fresh yield F value
Cultivar	8	0.050	11.63 **	2016.11	114.57 **
Sowing method	1	0.007	1.59 ns	199.00	11.31 **
CultivarXSowing	8	0.007	1.73 ns	18.24	1.04 ns
Error	54	0.004		17.60	

Source of variation	df	Dry matter yield MS	Dry matter yield F value	Bulb dry matter MS	Bulb dry matter F value
Cultivar	8	40.77	72.52 **	108.89	42.95 **
Sowing method	1	4.30	7.65 **	3.29	1.30 ns
CultivarXSowing	8	0.40	0.70 ns	1.37	0.54 ns
Error	54	0.56		2.54	

* : significant at the 5% level
** : significant at the 1% level
ns : non significant
[1]. Data were analysed from a 9 X 2 factorial arrangement in a completely randomized design

TABLE A.4 Analysis of variance for the effect of sowing method on emergence, growth and yield data of onion cv.Southport White Globe sown over 3 sowing dates in a 1982 field trial.[1]

Measurement and Source	df	Date 1 MS	Date 1 F value	Date 2 MS	Date 2 F value	Date 3 MS	Date 3 F value
Emergence time							
Block	3	0.33	0.33 ns	0.83	5.00 ns	0.46	0.58 ns
Sowing method	1	32.00	32.00 *	24.50	47.00 **	45.13	57.00 **
Error	3	1.00		0.17		0.79	
Stand(6 weeks)							
Block	3	1.81	5.43 ns	20.12	21.99 *	34.47	1234.91 **
Sowing method	1	733.45	210.66 **	29.65	32.40 **	213.21	7637.42 **
Error	3	3.48		0.92		0.03	
Stand(harvest)							
Block	3	13.05	0.55 ns	4.08	0.83 ns	7.89	3.62 ns
Sowing method	1	363.15	15.18 *	82.21	16.93 *	98.70	45.25 **
Error	3	23.92		4.92		2.18	
Bulb weight							
Block	3	55.52	0.20 ns	45.17	28.15 *	17.26	0.39 ns
Sowing method	1	4361.78	15.80 *	888.31	553.61 **	1860.50	42.55 **
Error	3	276.02		1.60		43.72	
Bulb diameter							
Block	3	4.99	0.24 ns	19.35	0.46 ns	10.89	0.96 ns
Sowing method	1	188.18	8.93 ns	175.78	4.21 ns	80.01	7.07 ns
Error	3	21.07		41.79		11.31	
Fresh yield							
Block	3	107.15	2.10 ns	42.33	2.31 ns	24.46	3.97 ns
Sowing method	1	168.36	3.30 ns	7.22	0.39 ns	3.92	0.64 ns
Error	3	51.00		18.33		6.15	
Dry matter yield							
Block	3	4.21	2.47 ns	0.97	1.19 ns	0.90	26.16 *
Sowing method	1	6.85	4.02 ns	0.66	0.81 ns	0.01	0.33 ns
Error	3	1.70		0.82		0.03	
Bulb dry matter(%)							
Block	3	0.07	0.20 ns	0.67	1.37 ns	0.57	0.48 ns
Sowing method	1	0.05	0.13 ns	7.41	15.09 *	0.41	0.35 ns
Error	3	0.34		0.49		1.18	

* : significant at the 5% level

** : significant at the 1% level

ns : non significant

[1]. Data for each sowing date were analysed in a separate randomized complete block design

TABLE A.5 Analyses of variance for the effect of date of sowing and sowing method on emergence, growth and yield data of onion cv. Southport White Globe in a 1983 field trial.[1]

Source of variation	df	Emergence time MS	F value	df	Maturity time[2] MS	F value
Block	3	0.38	1.42 ns	3	0.25	0.27 ns
Date	2	2.38	57.00 **	1	20.25	22.09 *
BlockXDate	6	0.04	0.16 ns	3	0.92	1.00 ns
Sowing method	1	51.04	193.42 **	1	2.25	2.45 ns
DateXSowing	2	0.54	2.05 ns	1	30.25	33.00 **
Error	9	0.26		6	0.92	

Source of variation	df	Stand(3 weeks) MS	F value	Stand(6 weeks) MS	F value	Stand(harvest) MS	Fvalue
Block	3	2.82	0.06 ns	1.79	0.13 ns	3.64	1.44 ns
Date	2	19.54	0.85 ns	45.64	0.99 ns	20.03	1.13 ns
BlockXDate	6	23.10	0.51 ns	46.30	3.24 ns	17.65	6.97 **
Sowing method	1	21.09	0.46 ns	77.04	5.39 *	9.63	3.80 ns
DateXSowing	2	3.38	0.07 ns	7.89	0.55 ns	46.43	18.33 **
Error	9	45.73		14.30		2.53	

Source of variation	df	Bulb weight MS	F value	Bulb diameter MS	F value
Block	3	86.16	1.55 ns	7.90	0.63 ns
Date	2	344.56	2.47 ns	8.66	0.79 ns
BlockXDate	6	139.76	2.51 ns	10.92	0.87 ns
Sowing method	1	76.68	1.38 ns	5.61	0.45 ns
DateXSowing	2	239.42	4.30 *	15.23	1.21 ns
Error	9	55.64		15.07	

Source of variation	df	Fresh yield MS	F value	Dry matter yield MS	F value	Bulb dry matter MS	F value
Block	3	50.40	3.35 ns	1.69	4.12 *	1.59	1.55 ns
Date	2	178.64	4.43 ns	4.69	7.78 *	2.66	3.07 ns
BlockXDate	6	40.35	2.68 ns	0.60	1.47 ns	0.86	0.84 ns
Sowing method	1	6.72	0.45 ns	0.05	0.12 ns	0.24	0.23 ns
DateXSowing	2	85.20	5.65 *	1.07	2.60 ns	0.80	0.78 ns
Error	9	15.07		0.41		1.03	

* : significant at the 5% level

** : significant at the 1% level

ns : non significant

[1]. Data were analysed from a split-plot layout in a randomized complete block design, where the main plot unit was the sowing date and the sub-plot unit, the sowing method

[2]. As maturity was not reached in plots of date 3, only data of dates 1 and 2 were analysed

TABLE A.6 Analyses of variance for the effect of sowing rate and cultivar on emergence, growth and yield data of white onions in a 1982 field trial.[1]

Source of variation	df	Emergence time MS	Emergence time F value	Maturity time MS	Maturity time F value
Block	3	0.11	0.22 ns	1.17	1.09 ns
Cultivar	1	2.67	5.22 *	20.17	18.91 **
Sowing rate	2	0.50	0.98 ns	13.54	12.70 **
Cultivar X Rate	2	0.11	0.33 ns	1.54	1.45 ns
Error	15	0.51		1.07	

Source of variation	df	Stand (harvest) MS	Stand (harvest) F value	Survival (%) MS	Survival (%) F value
Block	3	0.85	0.16 ns	4.29	0.16 ns
Cultivar	1	28.38	5.21 *	130.20	4.95 *
Sowing rate	2	254.75	46.73 **	219.49	8.35 *
Cultivar X Rate	2	2.27	0.42 ns	3.26	0.12 ns
Error	15	5.45		26.28	

Source of variation	df	Bulb weight MS	Bulb weight F value	Bulb diameter MS	Bulb diameter F value	Shape index MS	Shape index F value
Block	3	35.16	0.86 ns	45.61	3.58 *	0.001	0.39 ns
Cultivar	1	281.54	6.88 *	59.22	4.65 *	0.038	11.85 **
Sowing rate	2	1037.86	25.35 **	16.94	1.33 ns	0.002	0.53 ns
Cultivar X Rate	2	5.29	0.13 ns	59.68	4.69 *	0.003	0.89 ns
Error	15	40.93		23.42		0.003	

Source of variation	df	Fresh yield MS	Fresh yield F value	Dry matter yield MS	Dry matter yield F value	Bulb dry matter MS	Bulb dry matter F value
Block	3	12.24	0.51 ns	0.52	0.49 ns	8.01	7.51 **
Cultivar	1	31.74	1.33 ns	0.74	0.70 ns	13.35	12.52 **
Sowing rate	2	0.91	0.04 ns	0.15	0.14 ns	0.24	0.22 ns
Cultivar X Rate	2	4.19	0.17 ns	0.49	0.46 ns	2.90	2.72 ns
Error	15	23.94		1.05		1.07	

* : significant at the 5% level
** : significant at the 1% level
ns : non significant
[1]. Data were analysed from a 2 X 3 factorial arrangement within a randomized complete block design

TABLE A.7 Analyses of variance for the effect of sowing rate and cultivar on emergence, growth and yield data of white onions in a 1983 field trial.[1]

Source of variation	df	Emergence time MS	Emergence time F value	Maturity time MS	Maturity time F value
Block	3	0.11	0.49 ns	1.28	0.40 ns
Cultivar	1	7.03	30.10 **	16.53	5.19 *
Sowing rate	3	1.45	6.10 **	282.36	88.63 **
Cultivar X Rate	3	0.11	0.49 ns	2.70	0.85 ns
Error	21	0.23		3.19	

Source of variation	df	Stand(harvest) MS	Stand(harvest) F value	Survival (%) MS	Survival (%) F value
Block	3	32.22	8.53 **	226.58	10.56 **
Cultivar	1	60.78	16.08 **	272.03	12.67 **
Sowing rate	3	393.49	69.42 **	52.39	2.44 ns
Cultivar X Rate	3	23.64	4.17 *	44.15	2.06 ns
Error	21	3.78		21.46	

Source of variation	df	Bulb weight MS	Bulb weight F value	Bulb diameter MS	Bulb diameter F value	Shape index MS	Shape index F value
Block	3	121.78	1.35 ns	15.55	0.96 ns	0.013	1.50 ns
Cultivar	1	3812.83	42.16 **	159.31	9.82 **	0.006	0.78 ns
Sowing rate	3	1809.23	20.00 **	75.91	4.68 *	0.006	0.78 ns
Cultivar X Rate	3	289.14	3.20 *	18.69	1.15 ns	0.004	0.51 ns
Error	21	90.44		16.22		0.008	

Source of variation	df	Fresh yield MS	Fresh yield F value	Dry matter yield MS	Dry matter yield F value	Bulb dry matter MS	Bulb dry matter F value
Block	3	46.74	4.98 **	0.90	4.19 *	0.38	0.74 ns
Cultivar	1	263.93	28.10 **	0.41	1.88 ns	150.08	289.83 **
Sowing rate	3	44.90	4.78 *	2.05	9.53 **	1.20	2.31 ns
Cultivar X Rate	3	7.95	0.85 ns	0.35	1.64 ns	0.72	1.39 ns
Error	21	9.39		0.22		0.52	

* : significant at the 5% level
** : significant at the 1% level
ns : non significant
[1]. Data were analysed from a 2 X 4 factorial arrangement within a randomized complete block design

TABLE A.8 Analyses of variance for the effect of gel type and soil cover on emergence, survival and plant weight data of onion cv. Southport White Globe in a growth cabinet experiment.[1]

Source of variation	df	Emergence time MS	Emergence time F value	Emergence(%) MS	Emergence(%) F value	Survival(%) MS	Survival(%) F value
Gel	7	0.99	1.57 ns	666.54	3.73 **	910.00	4.38 *
Rep(gel)	24	0.63	1.13 ns	178.67	1.61 ns	207.97	1.22 ns
Cover	1	96.78	173.77 **	1736.11	15.69 **	15365.67	90.20 **
GelXCover	7	1.36	2.44 *	820.93	7.42 **	995.63	5.84 **
Error	24	0.56		110.68		170.36	

Source of variation	df	Total weight MS	Total weight F value	Mean weight MS	Mean weight F value
Gel	7	50.75	5.06 **	0.51	2.93 **
Rep(gel)	24	10.01	0.96 ns	0.17	1.14 ns
Cover	1	1750.11	167.43 **	5.13	33.95 **
GelXCover	7	278.73	3.81 **	0.25	1.69 ns
Error	24	10.45		0.15	

* : significant at the 5% level
** : significant at the 1% level
ns : non significant
[1]. Data were analysed from a split-plot layout in a completely randomized design, where the main plot unit was the gel type and the soil covering, the sub-plot unit

TABLE A.9 Analyses of variance for the effect of gel type on emergence, growth and yield data of onion cv. Southport White Globe in a 1983 field trial.[1]

Measurement	Source	df	MS	F value
Emergence time	Block	3	1.18	2.94 ns
	Gel type	6	0.99	2.47 ns
	Error	18	0.40	
Maturity time	Block	3	188.10	1.51 ns
	Gel type	6	353.57	2.85 *
	Error	18	124.21	
Stand (3 weeks)	Block	3	21.56	1.14 ns
	Gel type	6	33.54	1.77 ns
	Error	18	18.90	
Stand (harvest)	Block	3	4.54	1.54 ns
	Gel type	6	8.93	3.03 *
	Error	18	2.95	
Bulb weight	Block	3	121.40	0.83 ns
	Gel type	6	494.21	3.[illegible]8 *
	Error	18	146.24	
Fresh yield	Block	3	22.76	1.20 ns
	Gel type	6	76.89	4.05 **
	Error	18	18.99	

* : significant at the 5% level
** : significant at the 1% level
ns : not significant
[1]. Data were analysed in a randomized complete block design

TABLE A.10 Analyses of variance for the effect of gel additives on emergence, growth and yield data of cv. Southport White Globe in a 1982 preliminary field trial.[1]

Measurement	Source	df	MS	F value
Emergence	Block	3	3.67	5.00 *
	Treatment	5	13.20	18.00 **
	Error	15	0.73	
Maturity	Block	3	15.82	4.81 *
	Treatment	5	4.37	1.33 ns
	Error	15	3.29	
Stand (3 weeks)	Block	3	35.02	1.85 ns
	Treatment	5	86.02	4.54 *
	Error	15	18.95	
Stand (harvest)	Block	3	6.64	1.88 ns
	Treatment	5	29.96	8.40 **
	Error	15	3.54	
Bulb weight	Block	3	94.30	1.72 ns
	Treatment	5	188 60	3.43 *
	Error	15	54.92	
Fresh yield	Block	3	6.24	0.27 ns
	Treatment	5	8.90	0.39 ns
	Error	15	22.90	
Dry matter yield	Block	3	0.10	0.14 ns
	Treatment	5	0.32	0.42 ns
	Error	15	0.75	
Bulb dry matter(%)	Block	3	0.65	0.48 ns
	Treatment	5	0.85	0.63 ns
	Error	15	1.35	

* : significant at the 5% level
** : significant at the 1% level
ns : non significant
[1]. Data were analysed in a randomized complete block design

TABLE A.11 Analyses of variance for the effects of Cytex on emergence, growth and yield data of onion cv. Southport White Globe in a 1983 field trial.[1]

Measurement	Source	df	MS	F value
Emergence time	Block	3	0.28	1.00 ns
	Cytex rate	5	0.30	1.08 ns
	Error	15	0.28	
Maturity time	Block	3	144.44	1.60 ns
	Cytex rate	5	62.50	0.69 ns
	Error	15	90.28	
Stand (18 days)	Block	3	28.17	0.79 ns
	Cytex rate	5	30.58	0.85 ns
	Error	15	35.81	
Stand (harvest)	Block	3	10.44	1.01 ns
	Cytex rate	5	4.36	0.44 ns
	Error	15	10.37	
Bulb weight	Block	3	673.58	1.07 ns
	Cytex rate	5	987.36	1.56 ns
	Error	15	630.94	
Fresh yield	Block	3	41.77	1.01 ns
	Cytex rate	5	14.79	0.36 ns
	Error	15	41.72	

ns: non significant
[1]. Data were analysed in a randomized complete block design

TABLE A.12 Analyses of variance for the effect of fungicide and sowing method on emergence, growth and yield data of onion cv. Southport White Globe in a 1983 field trial.[1]

Source of variation	df	Emergence time MS	Emergence time F value	Maturity time MS	Maturity time F value	Bulb weight MS	Bulb weight F value
Block	3	0.01	0.01 ns	28.82	0.32 ns	298.36	2.52 ns
Fungicide	2	0.79	3.39 ns	912.50	10.18 **	74.45	0.63 ns
Sowing	1	37.50	60.71 **	234.38	2.61 ns	316.10	2.67 ns
Fungicide X Sowing	2	2.38	10.18 **	87.5	0.98 ns	450.70	3.80 *
Error	15	0.23		89.65		118.47	

Source of variation	df	Fresh yield MS	Fresh yield F value	Dry matter yield MS	Dry matter yield F value	Bulb dry matter MS	Bulb dry matter F value
Block	3	8.72	1.44 ns	0.22	1.74 ns	0.44	1.08 ns
Fungicide	2	109.49	18.05 **	2.53	19.09 **	0.68	1.69 ns
Sowing	1	176.58	29.11 **	4.25	33.42 **	2.04	5.00 *
Fungicide X Sowing	2	24.32	4.01 *	0.56	4.43 *	0.28	0.67 ns
Error	15	6.07		0.13		0.41	

Source of variation	df	% Smut(day 26) MS	% Smut(day 26) F value	% Smut(day 33) MS	% Smut(day 33) F value
Block	3	0.26	0.77 ns	86.68	0.70 ns
Fungicide	2	5100.42	15.11 **	238.45	1.93 ns
Sowing	1	1413.76	4.19 ns	267.50	2.16 ns
Fungicide X Sowing	2	98.78	0.29 ns	228.97	1.85 ns
Error	15	337.61		123.59	

* : significant at the 5% level
** : significant at the 1% level
ns : non significant
[1]. Data were analysed from a 3 X 2 factorial arrangement in a randomized complete block design

TABLE A.13 F ratios of analyses of variance for the effect of fungicide and sowing method on onion percentage survival data of the 1983 fungicide field trial.

Days after sowing	Block	Fungicide	Sowing method	Fungicide X Sowing
12	0.15 ns	0.81 ns	0.07 ns	5.40 **
15	2.26 ns	0.27 ns	2.79 ns	0.32 ns
18	0.99 ns	0.11 ns	0.65 ns	0.01 ns
21	0.27 ns	3.08 ns	6.75 *	1.75 ns
26	1.26 ns	0.37 ns	3.01 ns	3.88 ns
33	0.68 ns	3.98 *	1.43 ns	0.70 ns
48	2.20 ns	3.00 ns	0.05 ns	0.69 ns
59	4.89 *	7.01 **	9.41 **	2.23 ns
62	9.05 **	10.33 **	14.44 **	1.52 ns
76	5.27 *	7.09 **	9.07 **	0.85 ns
117	4.36 *	16.50 **	43.42 **	1.67 ns

* : significant at the 5% level
** : significant at the 1% level
ns : non significant

TABLE A.14 Analyses of variance for the effect of Pro-Gro fungicide and sowing method on emergence, growth and weight data of onion cv. Southport White Globe in growth cabinet experiments 1 & 2.[1]

Measurement and Source	df	Experiment 1		Experiment 2	
		MS	Fvalue	MS	Fvalue
Emergence time					
Sowing method	1	22.96	56.01 **	25.81	93.30 **
Pro-Gro rate	1	0.01	0.03 ns	1.08	3.90 ns
SowingXRate	1	0.48	1.17 ns	0.75	2.71 ns
Error	8	0.41		0.28	
Emergence (%)					
Sowing method	1	300.00	9.78 *	1.33	0.33 ns
Pro-Gro rate	1	161.33	5.26 ns	1.33	0.33 ns
SowingXRate	1	108.00	3.52 ns	1.33	0.33 ns
Error	8	30.67		4.00	
Survival (%)					
Sowing method	1	300.00	18.75 **	12.00	0.90 ns
Pro-Gro rate	1	225.33	14.08 **	12.00	0.90 ns
SowingXRate	1	1.33	0.08 ns	1.33	0.10 ns
Error	8	16.00		13.33	
Healthy (%)					
Sowing method	1	0.04	0.01 ns	8.50	0.43 ns
Pro-Gro rate	1	36.75	0.71 ns	28.52	1.44 ns
SowingXRate	1	3.63	0.07 ns	4.94	0.25 ns
Error	8	51.92		19.76	
Smut (%)					
Sowing method	1	15.50	3.00 ns	0.01	0.00 ns
Pro-Gro rate	1	15.50	3.00 ns	22.23	2.00 ns
SowingXRate	1	15.50	3.00 ns	0.01	0.00 ns
Error	8	5.17		11.12	
Total weight					
Sowing method	1	539.48	20.06 **	13.27	0.25 ns
Pro-Gro rate	1	167.35	9.64 ns	28.89	0.55 ns
SowingXRate	1	2.41	0.09 ns	5.17	0.10 ns
Error	8	26.89		52.26	
Mean weight					
Sowing method	1	0.52	8.84 *	0.05	0.63 ns
Pro-Gro rate	1	0.16	2.77 ns	0.09	1.12 ns
SowingXRate	1	0.01	0.11 ns	0.01	0.19 ns
Error	8	0.06		0.08	

* : significant at the 5% level
** : significant at the 1% level
ns : non significant
[1]. Data for each experiment were analysed from a separate 2 X 2 factorial layout in a completely randomized design

TABLE A.15 Pooled analyses of variance for the effect of Pro-Gro fungicide on emergence, growth and weight data of fluid drilled onion cv. Southport White Globe in growth cabinet experiments (Exp.) 1 & 2.[1]

Source of variation	df	Emergence time MS	Emergence time F value	Emergence (%) MS	Emergence (%) F value	Survival (%) MS	Survival (%) F value
Experiment	1	9.99	21.04 *	21.33	3.20 ns	5.33	0.20 ns
Replicate(Exp.)	4	0.47	2.35 ns	6.67	0.49 ns	27.33	1.31 ns
Pro-Gro rate	7	2.23	11.07 **	17.52	1.30 ns	716.95	34.37 **
RateXExp	7	0.29	1.42 ns	22.10	1.63 ns	85.33	4.09 **
Error	28	0.20		13.52		20.86	

Source of variation	df	Healthy (%) MS	Healthy (%) F value	Smut (%) MS	Smut (%) F value
Experiment	1	4370.08	39.45 **	1.93	0.42 ns
Replicate(Exp.)	4	110.78	2.12 ns	4.62	1.33 ns
Pro-Gro rate	7	1190.48	22.83 **	9.68	2.78 *
RateXExp	7	276.55	5.30 **	0.86	0.25 ns
Error	28	52.15		3.48	

Source of variation	df	Total weight MS	Total weight F value	Mean weight MS	Mean weight F value
Experiment	1	284.12	5.93 ns	0.34	2.45 ns
Replicate(Exp.)	4	47.88	3.02 *	0.14	3.71 *
Pro-Gro rate	7	623.98	39.36 **	0.61	16.56 **
RateXExp	7	60.15	3.79 **	0.05	1.42 ns
Error	28	15.85		0.04	

* : significant at the 5% level
** : significant at the 1% level
ns : non significant
[1]. Data were analysed from a split-plot arrangement in time of 2 completely randomized designs

TABLE A.16 Analyses of variance for the effect of Pro-Gro fungicide on emergence, growth and weight data of fluid drilled onion cv. Southport White Globe in growth cabinet experiments 1 & 2.[1]

Measurement and Source	df	Experiment 1 MS	Experiment 1 Fvalue	Experiment 2 MS	Experiment 2 Fvalue
Emergence time					
Pro-Gro rate	7	1.23	4.00 *	1.28	7.89 **
Error	16	0.31		0.16	
Emergence (%)					
Pro-Gro rate	7	36.57	1.89 ns	3.05	0.51 ns
Error	16	19.33		6.00	
Survival (%)					
Pro-Gro rate	7	173.33	5.65 **	628.95	49.65 **
Error	16	30.66		12.67	
Healthy (%)					
Pro-Gro rate	7	187.26	3.73 *	1279.76	18.63 **
Error	16	50.27		68.69	
Smut (%)					
Pro-Gro rate	7	7.59	1.94 ns	2.95	0.89 ns
Error	16	3.92		3.33	
Total weight					
Pro-Gro rate	7	167.35	13.57**	516.79	18.87 **
Error	16	18.27		41.74	
Mean weight					
Pro-Gro rate	7	0.19	5.06 **	0.48	7.72 **
Error	16	0.04		0.06	

* : significant at the 5% level
** : significant at the 1% level
ns : non significant
[1]. Data for each experiment were analysed in a separate completely randomized design

TABLE A.17 Effect of Pro-Gro rate on emergence, survival, health and weight of fluid drilled onion, in growth cabinet experiments (Exp.) 1 & 2.

Pro-Gro rate XStd ($g\ l^{-1}$)		Emergence time (days)		Emergence (%)		Survival (%)	
		Exp.1	Exp.2	Exp.1	Exp.2	Exp.1	Exp.2
X0	(0)	5.2	5.8	98.7	98.7	90.8	94.7
X0.1	(0.016)	5.1	6.5	98.7	98.7	92.0	97.3
X0.25	(0.04)	6.1	6.4	98.7	98.7	93.3	97.3
X0.5	(0.08)	5.5	6.7	97.3	97.3	94.7	97.3
X1	(0.16)	5.6	6.9	100.0	98.7	98.7	97.3
X2.5	(0.4)	6.3	7.0	100.0	100.0	94.7	98.7
X5	(0.8)	6.8	7.3	96.0	97.3	90.7	94.7
X10	(1.6)	6.6	8.0	89.3	100.0	73.3	56.0
LSD(0.05)		0.96	0.70	ns		5.40	

Progro rate XStd ($g\ l^{-1}$)		Healthy plants (%)		Smut (%)	
		Exp.1	Exp.2	Exp.1	Exp.2
X0	(0)	89.5	77.6	4.5	2.7
X0.1	(0.016)	93.1	85.0	1.3	1.3
X0.25	(0.04)	91.9	82.2	1.3	0.0
X0.5	(0.08)	94.5	87.5	0.0	0.0
X1	(0.16)	91.9	79.4	0.0	0.0
X2.5	(0.4)	92.9	67.6	0.0	0.0
X5	(0.8)	82.4	43.7	0.0	0.0
X10	(1.6)	71.2	31.7	0.0	0.0
LSD(0.05)		12.27	14.35	2.21	

Progro rate XStd ($g\ l^{-1}$)		Total weight ($g\ flat^{-1}$)		Mean weight ($g\ plant^{-1}$)	
		Exp.1	Exp.2	Exp.1	Exp.2
X0	(0)	46.1	52.7	2.04	2.22
X0.1	(0.016)	46.0	54.8	2.01	2.26
X0.25	(0.08)	38.9	48.3	1.67	1.97
X0.5	(0.04)	41.9	54.2	1.78	2.23
X1	(0.16)	43.5	48.2	1.76	1.98
X2.5	(0.4)	39.7	42.8	1.68	1.74
X5	(0.8)	31.5	34.0	1.38	1.44
X10	(1.6)	24.7	16.2	1.35	1.18
LSD(0.05)		4.71		0.23	

ns: non significant

TABLE A.18 Regression analyses for the effect of Pro-Gro rate on emergence, survival, health and weight of fluid drilled onions, in growth cabinet experiments (Exp.) 1 and 2.

Variable	Source	df	MS	F value	R^2	Effect	Regression equation
Emergence							
Exp.1	r	1	5.05	16.56 **	0.53	Q	Y=5.344+2.915r
	rxr	1	2.12	6.94 *			-1.331r²
	Error	21	0.31				
Exp.2	r	1	7.10	34.69 **	0.61	L	Y=6.419+1.038r
	Error	22	0.20				
Survival %							
	r	1	3907	131.62 **	0.79	Q	Y=94.427+15.223r
Exp.1&2	rxr	1	1071	36.10 **			-21.18r²
	Error	45	29.69				
Healthy %							
Exp.1	r	1	1173	27.42 **	0.55	L	Y=93.598-13.347r
	Error	22	42.80				
Exp.2	r	1	8222	98.58 **	0.82	L	Y=83.022-35.331r
	Error	22	83.41				
Total weight							
Exp.1&2	r	1	4208	129.00 **	0.74	L	Y=48.386-17.872r
	Error	46	32.62				
Mean weight							
Exp.1&2	r	1	3.63	62.60 **	0.60	Q	Y=2.062-1.111r
	rxr	1	0.35	6.03 *			+0.383r²
	Error	45	0.05				

r : rate of Progro
L : Linear effect
Q : Quadratic effect
*, ** : significant at the 5% and 1% level, respectively