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The Effects Of Seedbed Management On Soil Properties And Crop Growth For Canola And Flax

By

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled THE EFFECTS OF SEEDBED MANAGEMENT ON SOIL PROPERTIES AND CROP GROWTH FOR CANOLA AND FLAX submitted by MU REN in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in AGRICULTURAL ENGINEERING.

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Abstract

The experiments of seedbed preparation and seeding depth for small seed crops (canola and flax) were conducted at Ellerslie, Alberta over a three year period. Seedbed conditions for canola were also investigated in the central Alberta area in 1990, 1991 and 1992. In 1993, soil compaction experiments were carried out on silt loam, clay soil and sandy loam in three locations in Alberta.

Emergence and yield for both canola and flax were depressed with seeding depths greater than 30 mm. The emergence of canola and flax responded favourably to pre-seeding packing. The combination of pre-seeding and post-seeding packing improved the emergence and yield of canola and flax. A large proportion of aggregates < 4 mm in the seedbed led to better emergence of canola and flax.

A canola seedbed survey in the central Alberta area showed that during each growing season, the average of emergence counts for rapa varieties was higher than napus varieties, but the average yield for napus varieties was higher than rapa varieties. Aggregates larger than 9.5 mm had a negative relationship with yield while aggregates smaller than 4.76 mm had a positive effect on yield. Yield showed a general decreasing response to dry bulk density. As seeding depth increased, yield decreased.

Soil compaction affected the seedbed soil layer and the soil under the seedbed which in turn affected canola emergence and yield. Seed germination and emergence were dependent on seedbed conditions. Yield was depressed when the soil density was high and mechanical impedance was formed in the root zone although better emergence was obtained early in the growing season. Increasing compaction decreased the seedbed depth and increased the bulk density in the seedbed which promoted better germination and emergence. Canola yield decreased when soils were highly compacted with bulk density of the soil below the seedbed being in the range of 1.10-1.14 Mg/m^3 for silt loam and 1.58-1.68 Mg/m^3 for clay soil. Maximum yield was obtained when the soil below the seedbed was compacted to a bulk density of 1.10 Mg/m^3 for silt loam and 1.58 Mg/m^3 for clay soil. The results were not conclusive for sandy loam.

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List of Symbols, Nomenclature or Abbreviations

CO = control (without packing treatment).

D.B.D. = dry bulk density in the soil, Mg/m^3.

DO = dual rear tires with one pass in soil compaction treatment.

FP = five passes with packing implements or tractor tires.

H.D.Cult. = heavy duty cultivator.

M.C. = moisture content in the soil, % dry basis.

NP = no packing.

OP = one pass with packing implement or tractor tires.

OPP = one post seeding packing.

P.S.P. = pre-seeding packing.

SO = single rear tire with one pass in soil compaction treatment.

ST = single rear tire with three passes in soil compaction treatment.

S.T.Cult. = spring tooth cultivator.

TP = three passes with packing implements or tractor tires.

VAR. = variety.

1 INTRODUCTION

An ideal soil structure should facilitate rapid infiltration of showers and at the same time keep evaporation losses to a minimum, two requirements which are practically incompatible. In narrow row crops like small grains it will always be necessary to compromise between requirements of infiltration and evaporation properties of the seedbed. Infiltration properties have a priority in areas where heavy showers are likely, while evaporation control dominates in climates with a high probability of early drought and little risk of soil erosion (Heinonen, 1985).

The process of seedbed preparation is essential to good germination, emergence and yield of a crop. Different procedures of preparing a seedbed by using different tillage and packing implements will change the physical properties of the soil. Two purposes related to a seedbed are effective seed-soil contact and efficient evaporation control of the soil moisture.

The optimum seedbed produced by tillage and packing is subject to the combination of regional conditions such as aggregate size distribution, seedbed depth, seedbed compaction, soil moisture and climate. The objective of tillage is to create a pore size distribution that meets the plant requirements for water, air, temperature and non-limiting mechanical resistance (deJong, 1984). In general, smaller aggregates give better seed-soil contact and efficient evaporation control. It has been suggested that the mean aggregate size should be about 1/10 to 1/5 of the seed size to meet the optimum seed-soil contact (Hadas and Russo, 1974). The highest yield in a corn experiment was reported with 39 percent of soil granules smaller than 2 mm (Johnson and Taylor, 1960 as cited by Johnson and Buchele, 1961). The most efficient evaporation control is gained, when the aggregate size is in the range of 0.5-2 mm (Heinonen, 1979). An increase in granule size accelerated the drying rate of soil and decreased corn emergence (Johnson and Buchele, 1961). For small grain crops under dry weather conditions, good evaporation control and crop emergence were obtained in a firm seedbed which mainly consisted of aggregates smaller than 4 mm (Håkansson and Von Polgar, 1984).

Packing of seedbed soil is considered as a management method for seedbed preparation in different weather situations. Under dry weather conditions, compaction of soil will decrease evaporation and improve germination of seeds (Heinonen, 1985). If moisture conditions at the time of seeding are good, packing prior to seeding (pre-packing) is probably not needed. Compaction affects seed imbibition by altering the capillary vapour movement in the seedbed rather than increasing seed-soil contact (Rogers and Dubetz, 1980).

Factors such as seeding depth, seedbed depth, soil surface roughness, etc. affect emergence and yield of a crop. Seed placement is closely related to the emergence state of small seed crops. Seeding depth should be shallow so that the seed's energy is not expended before the seedling reaches the soil surface. Normally, yield decreases with increasing sowing depth. For spring-sown wheat, optimum yield occurred at a sowing depth of 51 mm (Anderson, 1975). Under Swedish conditions, experiments showed that the optimum seeding depth for barley and rapeseed were 50 mm and 20 mm respectively (Håkansson and Von Polgar. 1984). If soil slaking or crusting is expected, seed should be placed as shallow as possible in order to obtain good emergence (Håkansson and Von Polgar, 1979). For cereals, the evaporation protection was satisfactory if the seedbed was at least 40 mm deep and consisted of aggregates smaller than 4 mm (Håkansson and Von Polgar, 1984). In general, the rougher the soil surface, the greater the number of depressions for trapping and storing precipitation (Godwin, 1990).

Soil compaction induced by tractor tires causes changes in soil physical properties under the seedbed. Generally, increasing the degree of compaction affects crop root development and reduces the ability of plants to utilize water and nutrients in the soil. As the degree of compaction increased, it resulted in higher penetration resistance, lower air filled porosity, smaller daily temperature fluctuations and a greater accumulation of roots in the topsoil (Lipeil et al., 1991). Compacted soil retains more water in the upper layer of the soil than an uncompacted soil and is slow to dry out in the early growing season (Mcafee et al., 1989). The state of compaction of a plough layer is described as the degree of compactness which is defined as the ratio of the dry bulk density of the soil to the dry bulk density of the same soil under a standardized 200 kPa uniaxial compression test (Håkansson, 1990a).

When the degree of compactness exceeds 85%, soil aeration and penetrability become critical. Oxygen deficiency causes problems whenever aeration for a major part of the root zone remains critical for more than a very short period (Håkansson, 1992). To maximize yield, the optimum degree of compactness has been demonstrated in Sweden to be 78% for fall seeded rapeseed and 87% for fall seeded cereals (Henriksson et al., 1980). The use of dual rear wheels on the tractor with low inflation pressure of 50-60 kPa resulted in 6% higher yield than the standard wheel (Håkansson, 1990b).

The objectives of this study were (i) to determine the effects of different methods for preparing the seedbed for small seed crops (canola and flax), (ii) to assess seedbed conditions for canola in the central Alberta area, and (iii) to compare the effects of compaction by tractor tires on seedbed soil and the soil under the seedbed for canola crops.

2 METHODOLOGY

2.1 Experiment I: Seedbed Preparation Experiments for Canola and Flax

Three experiments were conducted to study the effects of pre-seeding tillage, pre-seeding packing and post-seeding packing on aggregate size, soil moisture, bulk density and crop response for canola (var. Tobin) and flax (var. Norlin). A fourth experiment was conducted to study the effects of seeding depth on emergence and yield of canola and flax.

2.1.1 Experimental Design

Each experiment was replicated four times in a randomized block design. All plots within an experiment were 6 m wide by 50 m long except for the seeding depth experiments in 1988, 1989 and 1990 which were 1.8 m wide by 13.5 m long. The experiments were repeated for three consecutive years 1988-90 for flax and 1989-91 for canola.

2.1.2 Tillage and Seeding Methods

Pre-Seeding Tillage Experiment (C1 & F1)

Four methods of pre-seeding tillage: vibrashank (Plate 1), heavy duty cultivator (Plate 2), spring tooth cultivator (Plate 3) and tandem disc (Plate 4) were utilized with two depths of tillage; 37.5 mm (shallow) and 100 mm (deep). Tillage was followed by harrowing and plots were seeded with a double disc press drill at a depth of 30 mm.

All plots were first harrowed then the appropriate tillage treatments were applied. Following tillage, all plots received a broadcast application of fertilizer then seeded according to the rates outlined in Tables 1 and 2.

Table 1. Fertilizer and seeding rates for canola experiments from 1989 to 1991

year	seeding rate	fertilizer application
1989	7.6 kg/ha	160 kg/ha 34-17-0 prior to seeding
1990	7.6 kg/ha	200 kg/ha 34-0-0-11 prior to seeding in all plots 45 kg/ha 11-51-0 with seed in C1 & C2 100 kg/ha 8-25-25 with seed in C3 & C4
1991	7.6 kg/ha	150 kg/ha 34-0-0-11 prior to seeding 65 kg/ha 11-51-0 with seed

Table 2. Fertilizer and seeding rates for flax experiments from 1988 to 1990

year	seeding rate	fertilizer application
1988	40 kg/ha	160 kg/ha 34-17-0 prior to seeding
1989	40 kg/ha	160 kg/ha 34-17-0 prior to seeding
1990	40 kg/ha	100 kg/ha 34-0-0-11 prior to seeding 45 kg/ha 11-51-0 with seed

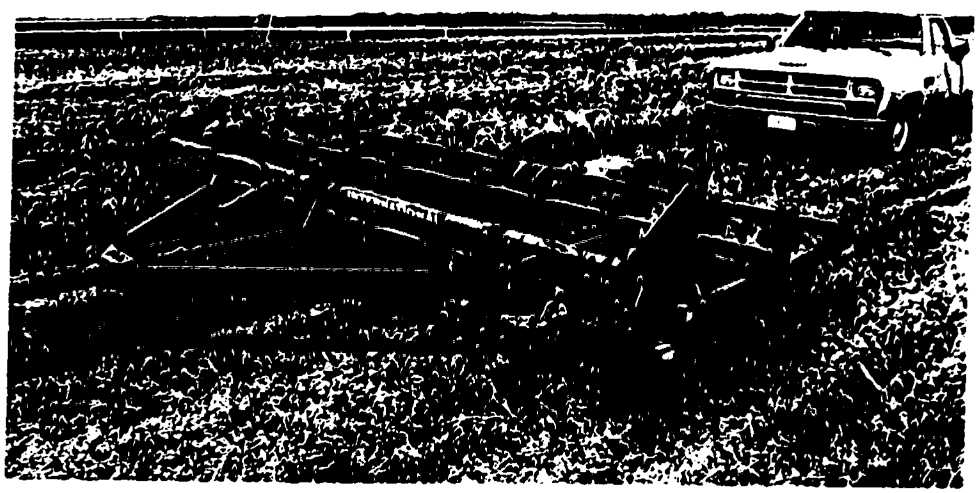


Plate 1. Vibrashank cultivator used in pre-seeding tillage treatment

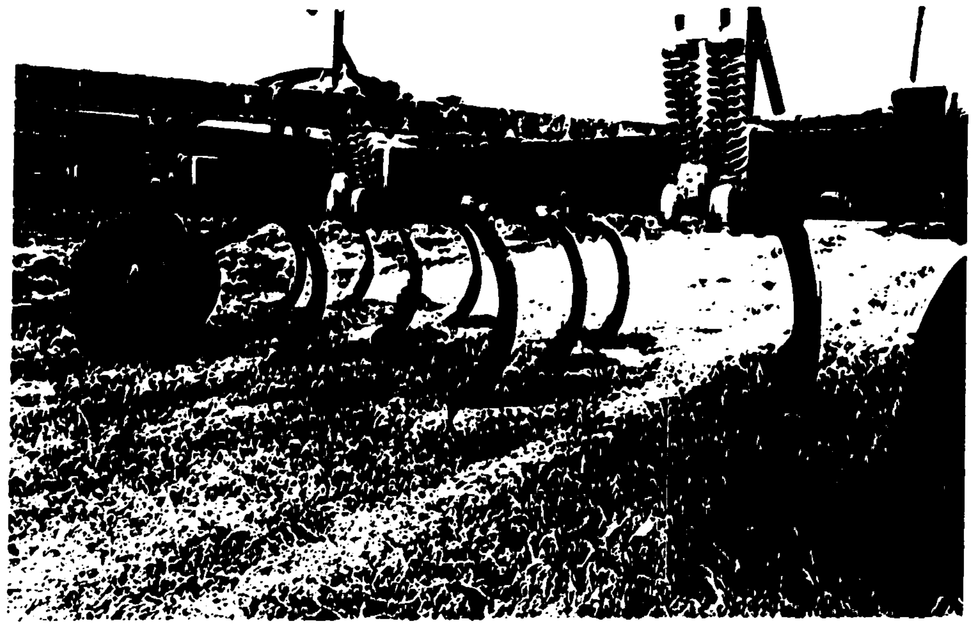


Plate 2. Heavy duty cultivator used in pre-seeding tillage treatment

Plate 3. Spring tooth cultivator used in pre-seeding tillage treatment

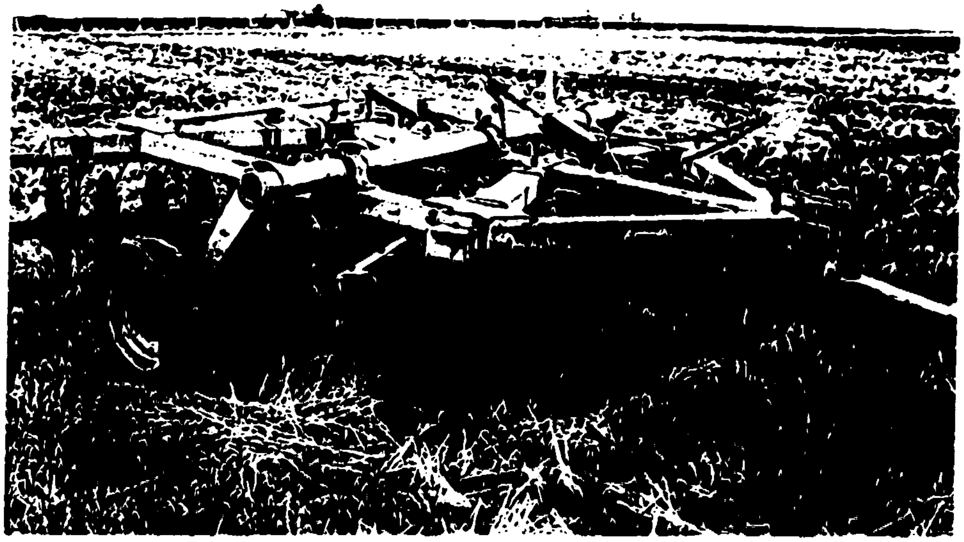


Plate 4. Tandem disc used in pre-seeding tillage treatment

Pre-Seeding Packing Experiment (C2 & F2)

All plots were cultivated at a depth of 150 mm in the previous fall. Before any other operations occurred in the spring, plots were harrowed. To simulate dry and moist field conditions, plots were vibrashanked at a depth of 75 mm either five days before (dry) or just before seeding (moist). Fertilizer was then applied at the appropriate rates (Tables 1 and 2). Each set of dry and moist plots was packed with one of four treatments: spiral coil (Plate 5), press wheels (Plate 6), rod weeder (Plate 7) or no packing. Plots were then seeded with a double disc press drill at a depth of 40 mm.

Post-Seeding Packing Experiment (C3 & F3)

All plots were first harrowed then vibrashanked to a depth of 75 mm. Prior to seeding, plots received either no packing or packing with spiral coil packers. Fertilizer was applied at rates recommended by Alberta Agriculture based on soil tests (Tables 1 and 2). After seeding at a depth of 40 mm with a double disc drill, plots received the same packing performed in the pre-seeding packing experiment.

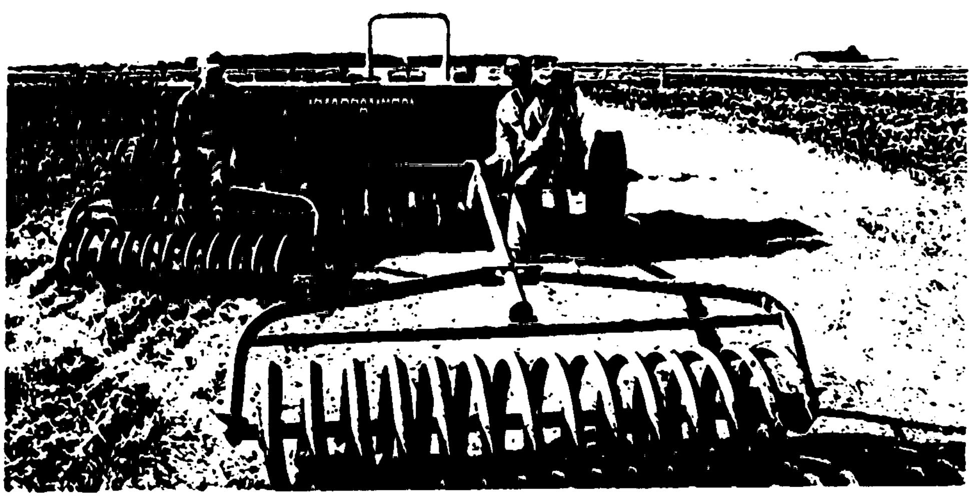


Plate 5. Spiral coil used in pre-seeding and post-seeding packing treatments

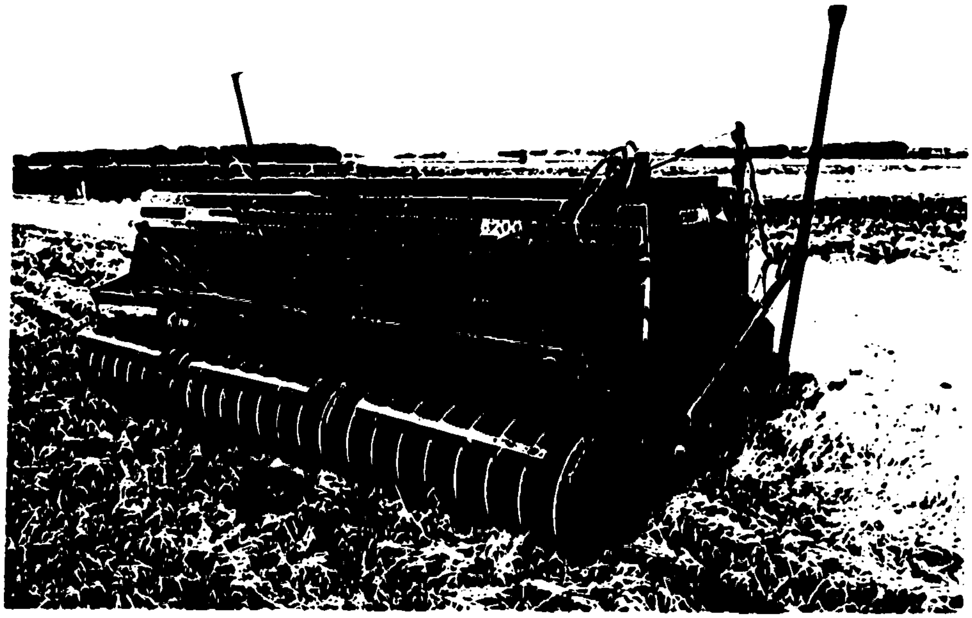


Plate 6. Press wheels used in pre-seeding and post-seeding packing treatments

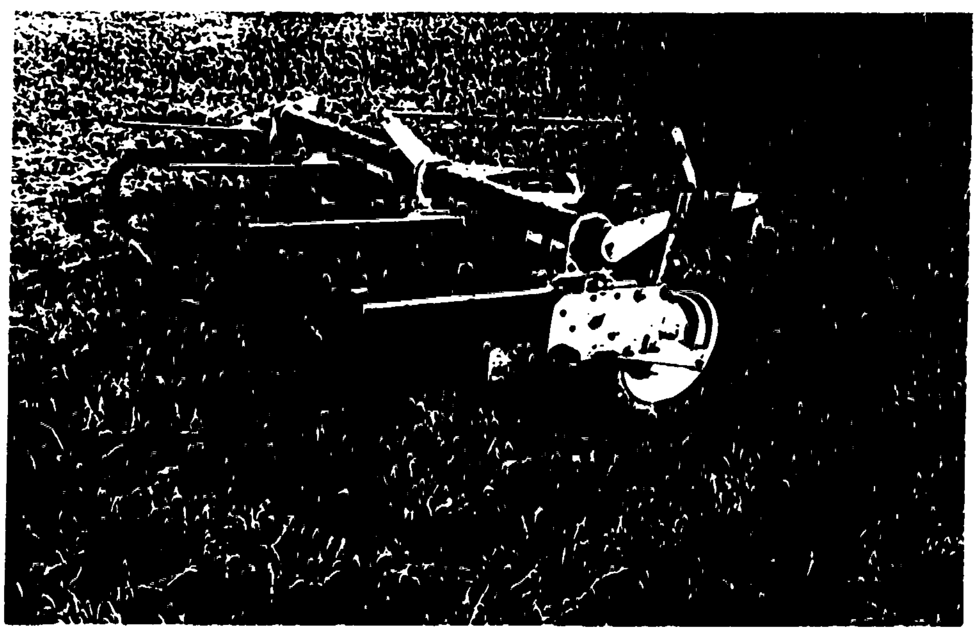


Plate 7. Rod weeder used in pre-seeding and post-seeding packing treatments

Seeding Depth Experiment (C4 & F4)

Before seeding, the plots were harrowed then cultivated using a vibrashank cultivator at depth of either 30 mm (shallow) or 100 mm (deep). Each set of shallow and deep tillage treatments was fertilized and then seeded at a depth of 10 mm, 30 mm, 50 mm or 70 mm with a plot seeder (Plate 8).

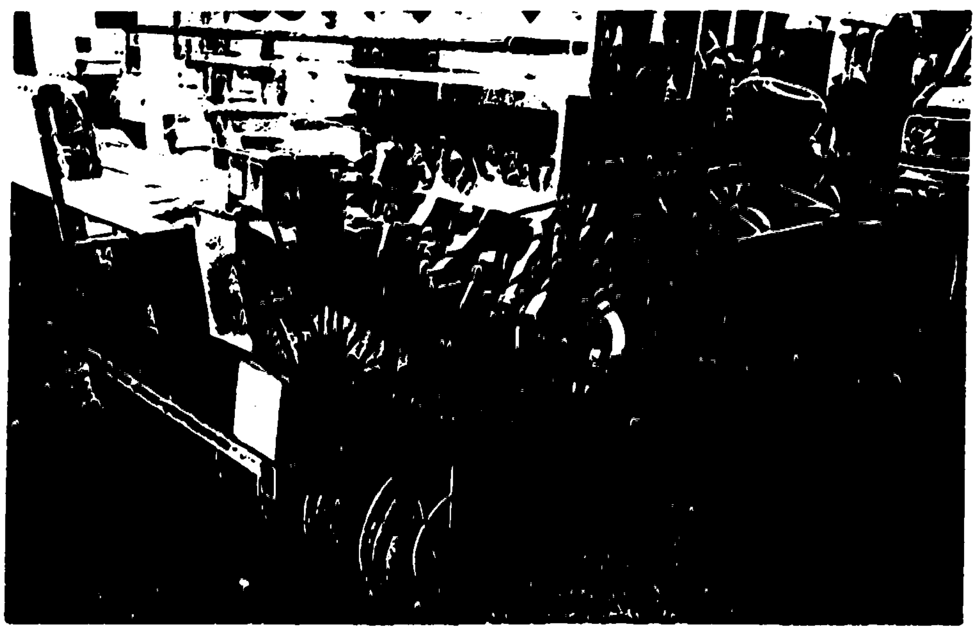


Plate 8. Plot seeder used in seeding depth experiment

2.1.3 Measurement of Seedbed and Crop Response

Aggregate Size Distribution

Aggregate size distribution was determined by gravimetric dry soil sieving. A 40 x 40 cm square was placed into the seedbed and the soil to seeding depth was collected with a flat bottomed scoop. Two samples were collected per plot at the first emergence count and later sieved in the laboratory. Sieve sizes were 19, 12.5, 8, 4, 2, 1, 0.5, 0.25 mm, and pan. The air dry mass of soil retained on each sieve was weighed and recorded. The mass of sample retained on each sieve-pan was expressed as a percentage of the total mass.

Soil Moisture and Bulk Density

Soil moisture and bulk density were determined before emergence counts using a Troxler Electronics Labs Ltd. Nuclear Gauge Model 3401. Density readings were taken every 5 cm down to 20 or 25 cm. Moisture readings were recorded simultaneously with bulk density. No less than 6 readings were taken for each plot. A computer program was written to convert the data into moisture and density values. To verify the Troxler readings, soil samples were taken at 5 and 10 cm depths for laboratory gravimetric moisture determination.

Penetration Resistance

Penetration resistance of the seedbed was measured using a soil cone penetrometer manufactured according to ASAE Standard S313.2 specifications and equipped with a paper trace. No less than eight observations to 30 cm were recorded for each plot before the first emergence counts were taken. The resistances recorded on the paper trace were averaged to obtain a penetration resistance profile for each plot.

Emergence Counts

Emergence counts were taken 30 days after seeding, however, some counts were taken at various times throughout the early part of growing season. A 1 m length was staked from six different rows in each plot. As a result emergence was consistently monitored in the same area on the plot. Each of the six rows were counted at each emergence sampling period. The results were then converted to a per square metre basis.

Yield Determination

At harvest, a 4 m swath was made down each plot. Once dry, each plot was harvested with a standard combine and the canola or flax from each plot was collected and weighed. Because of the small plot sizes for the seeding depth experiments in 1988, 1989 and 1990, only the four middle rows in each plot were hand cut, dried and then harvested with a stationary thresher. A subsample was taken from the weighed samples for moisture determination on a Motomco Model 919 Grain Moisture Meter. From these moisture measurements, yields for each plot were corrected to 10% wet basis to ensure all yields were compared at the same moisture level.

2.1.4 Statistical Analysis

All data, except penetration resistance, were subject to statistical analysis by the SAS General Linear Models ANOVA, DUNCAN'S MULTIPLE COMPARISON at the $\alpha = 0.05$ level (SAS Institute, 1985).

2.2 Experiment II: Seedbed Survey for Canola in the Central Alberta Area

Seedbed conditions for canola were investigated in the central Alberta area in 1990, 1991 and 1992. Canola varieties were rapa (Polish) and napus (Argentine). Seedbed characteristics measured were soil aggregate size distribution, bulk density, moisture content, seedbed surface roughness, seeding depth and seedbed depth. Emergence counts and yield were correlated with the seedbed characteristics by using linear regression.

2.2.1 Site Selection

Over three growing seasons (1990, 1991 and 1992), all seedbeds were chosen in close proximity to Edmonton with most being south, southwest and northeast of the city. The seedbeds were sampled as soon after seeding as possible. All seedbeds were sampled within two weeks after seeding.

2.2.2 Soil Classification

The Soil Survey of the Edmonton Sheet (Bowser et al., 1962), the Soil Survey of the Red Deer Sheet (Bowser et al., 1951) and the Alberta Soil Survey Report for Flagstaff (Alberta Agriculture, 1984) were used to determine the soil types at each site. Soils were predominately Chernozemic, except one which was Solonetzic. The soils were mostly Eluviated to Orthic black and had a loam, silt loam, silty clay loam, or sandy loam texture.

2.2.3 Tillage Practices

Producers were interviewed to determine the tillage practices employed at each site. Inquiries were made about the number and type of tillage operations used (fall tillage, spring tillage, fertilizer application, herbicide application, seeding, and pre- or post- seeding packing operations) and the type of crop in the previous year.

2.2.4 Seedbed Characteristics and Crop Response

Seedbed characteristics were determined using equipment similar to that used in Swedish experiments by Kritz (1976, 1983). A list of equipment can be found in Appendix C. Measurements for the following seedbed characteristics were replicated three times.

Aggregate Size Distribution

Aggregate size distribution was determined by volumetric soil sieving. A 25 x 40 cm wing was attached to the 40 x 40 cm square and the soil was divided into layers by a flat bottomed scoop. The top 2 cm was sieved as one layer and the remainder of the seedbed was divided into two layers not less than 2 cm in depth each. In seedbeds less than 3 cm deep only the top layer was sieved and in seedbeds less than 5 cm deep only the top two layers were sieved. Each layer was sieved manually in the field. Sieve sizes were 9.5, 4.76, 2, 1 mm, and pan. The volume of soil retained on each sieve was measured in a graduated cylinder and recorded. The proportion of sample retained on each sieve-pan was expressed as a percentage of the total volume.

Bulk Density and Moisture Content

Soil bulk density and moisture were determined using a Troxler Electronics Labs Ltd. Nuclear Gauge Model 3401. Density readings were taken every 5 cm down to 20 or 25 cm. Moisture readings were recorded simultaneously with density. A computer program was written to convert the data into moisture and density values. To verify the Troxler readings, soil samples were taken at each layer for laboratory gravimetric moisture determination.

Seedbed Surface Roughness

A 40 x 40 cm square frame was pressed into the bottom of the seedbed with the top parallel to the soil surface. A straight edge was placed across the frame as a reference and measurements were taken to the highest and lowest point of the soil surface within the frame. The difference between these measurements was the maximum height variation (surface roughness) in the seedbed surface.

Seeding Depth

Seeding depth was determined by pulling the plants at the time of emergence counting. The distance from the change in root colour (green to white) to the decrease in root diameter (indicative of microscopic root hairs) was measured as the seeding depth. Eight plants within each frame were used to determine the average seeding depth.

Seedbed Depth

The soil to the bottom of the tilled layer within the frame was scooped into a calibrated pail and the average seedbed depth was read from the pail.

Emergence Counts

Emergence counts were taken about 30 days after seeding. A 1 m^2 frame was randomly placed in the field and the canola plants in the frame were counted. No less than seven observations were made to determine plant density in each field.

Investigation of Crop Growing State

All the crops were inspected during the middle of the growing season (around July 25) to compare cleanliness, disease, crop height, crop density and percent flower.

Yield Determination

To determine yield at each site, samples were taken either just prior to or just after swathing. At sites where the crop was still standing, ten 1 m^2 samples were cut and bagged separately and tagged. The number of stems per m^2 were also counted. At sites where swathing had already taken place, the plant density was determined by counting cut stems within a 1 m^2 area at 10 locations then averaged. Ten samples of plants equivalent to the average of plants per square metre were obtained from the swath, bagged separately and tagged. All samples were hung to dry and later threshed. Yield levels were converted to equivalent yields at 10% moisture content on a wet basis.

2.3 Experiment III: Soil Compaction Experiment for Canola

To evaluate the effects of soil compaction caused by tractor tires on different types of soil, three compaction experiments with canola were conducted in 1993 at three locations (Ellerslie, Rycroft and Stettler). Soils at Ellerslie, Rycroft and Stettler were silt loam, clay and sandy loam respectively.

2.3.1 Experimental Design

A completely randomized block design was used at each of the three locations.

At Ellerslie, plot treatments were accomplished by using a CASE 7130 tractor with a single tire one pass (SO), single tire three passes (ST), dual tires one pass (DO) and control (CO). In order to obtain a suitable seedbed, a shallow cultivation was done on the plots after compaction treatments. Plots were seeded perpendicular with a double disc press drill.

At Rycroft, the compaction treatment was done by using the packing press wheels attached to the seed drill. The treatments were one pre-packing (OP), three pre-packings (TP), five pre-packings (FP), no pre-packing (NP) and one post packing (OPP). There were no tillage operations after packing. Canola was seeded with a hoe press drill.

At Stettler, the soil compaction was conducted by using a JOHN DEERE 4020 tractor with single tires. The treatments were one pass (OP), three passes (TP), five passes (FP) and control (CO). There were no tillage operations after compaction. Canola was seeded immediately after the compaction treatment with a hoe press drill.

The parameters of the tractor, seeding rates and fertilizer application rates are listed in Table 3.

2.3.2 Measurement of Soil Properties and Crop Response

To maintain the sampling under similar conditions, all sampling spots were covered with a plastic sheet. At Ellerslie, plots were covered immediately after seeding and soil samples were taken at the time of crop flowering. Soils sampled were divided into three layers; seedbed layer, top layer and bottom layer in the soil under the seedbed. At Rycroft and Stettler, plots were covered and soil samples were taken at the time of emergence. Soils sampled were divided into two layers; seedbed layer and the layer below the seedbed.

Table 3. Canola varieties, seeding rates, fertilizer application and tractors used in soil compaction experiments

	Ellerslie	Rycroft*	Stettler
Canola variety	Colt (Rapa)	Bounty (Napus)	Hyola 401 (Napus)
Seeding rate	7.7 kg/ha	9 kg/ha	6.7 kg/ha
Fertilizer application	11-51-0 67 kg/ha	90-45-0-11 kg/ha	56-28-34-22 kg/ha
Tractor used for compaction			
Type of tractor	CASE 7130	J D 4050	J D 4020
Axle load			
Front wheel	3292 kg	1656 kg	1279 kg
Rear wheel	7047 kg	4545 kg	5120 kg
Tire pressure			
Front wheel	150 kPa (with single tire) 75 kPa (with dual tires)	275 kPa	276 kPa
Rear wheel	150 kPa (with single tire) 50 kPa (with dual tires)	85 kPa	138 kPa

* Packing treatment was done by using press wheels attached to the seed drill. The total weight of the seed drill was about 1500 kg.

Soil Texture and Organic Matter

Soil samples were taken to determine the soil texture and the organic matter content in the laboratory. Soils were classified into three types: silt loam (Ellerslie, 21.9% clay), clay (Rycroft, 53.3%

clay) and sandy loam (Stettler, 13.7% clay) (APPENDIX A). The organic matter content was obtained (APPENDIX B) by multiplying the organic C concentration by 1.724. The Dry Combustion Method was used to measure the organic C concentration in the soil samples. The organic matter contents were 9.87% (silt loam), 8.29% (clay) and 6.01% (sandy loam).

Seedbed Depth

A 50x50x30 cm steel frame was pounded into the soil. A straight edge was put on the upper edge of the frame and heights from top of the frame to the surface of different layers were measured and recorded. Seedbed depth was obtained by subtracting the height from the top of the frame to the soil surface from the height from the top of frame to the bottom of the seedbed layer. Sixteen readings were taken for each layer and averaged.

Bulk Density and Soil Moisture Content

The soil in each layer was scooped into a pail and weighted. Soil bulk density was calculated by dividing the weight of the soil with the volume of the layers. Soil samples in each layer were also taken to determine moisture content. Dry bulk density was calculated for each sample.

Penetration Resistance

A soil cone penetrometer CP10 manufactured by Rimik PTY Ltd. was used to measure penetration resistance. Three samples were taken in each plot. Penetrometer readings were recorded at the depth of every 1.5 cm from the surface of the soil down to 45 cm.

Emergence Counts

At Ellerslie, plant density was measured instead of emergence count. Five samples were taken from each plot by using a 1 m^2 frame in the field. At Rycroft, emergence counts were averaged for each treatment. At Stettler, emergence counts were taken and averaged for each plot.

Yield Determination

At harvest time, the canola plots were swathed and then combined after drying for a period of time. Canola seeds for each plot were collected and weighted on a scale in the field. Seed samples were also taken to determine the moisture content.

2.3.3 Statistical Analysis

All data, except penetration resistance, were subject to statistical analysis by the SAS General Linear Models ANOVA, DUNCAN'S MULTIPLE COMPARISON Procedures at the $\alpha = 0.05$ level (SAS Institute, 1985).

3 RESULTS AND DISCUSSION

3.1 Experiment I: Seedbed Preparation Experiments for Canola and Flax

Because of the large amount of data accumulated over three years with four different experiments, each experiment was treated separately. For pre-seeding tillage (C1 & F1), pre-seeding packing (C2 & F2) and post-seeding packing (C3 & F3) experiments, canola emergence and yield were analyzed with treatments as well as seedbed characteristics since these experiments relate specifically to altering seedbed properties. The seeding depth experiment (C4 & F4)) was treated differently since yield and emergence are most likely influenced by depth of seed placement rather than seedbed preparation itself.

Since the sample numbers were not equal and some data were missing, the means listed in years in some tables are not equal to the average of the means from each year.

3.1.1 Canola Results

In a general overview, 1989 and 1990 emergence and yields were relatively lower than the 1991 values. In 1990, spring soil moisture was low which resulted in poor emergence.

3.1.1.1 Seedbed Soil Parameters

Seedbed Soil Moisture

Soil moisture varied between years with 1990 being lower than 1989 and 1991. In 1990, lack of moisture during emergence and throughout the growing season depressed emergence and yield. In 1991, moisture was high at emergence and throughout the growing season which resulted in higher emergence and yield than the other two crop years.

The pre-seeding tillage experiment showed that differences in tillage implements did not give any significant moisture savings but shallow tillage did have significantly more moisture in the top 10 cm versus deep tillage (Table 4). Some differences were noted in 1990 but were not consistent in all years.

Table 4. Seedbed moisture content (%)* in pre-seeding tillage experiment (C1) for canola

Treatment	1989	1990	1991**	Years
Vibrashank Shallow	33.3a	28.9b	-	31.8a
Vibrashank Deep	30.8a	31.9a	-	31.1a
H.D. Cult. Shallow	32.3a	29.4ab	-	31.3a
H.D. Cult. Deep	31.2a	30.1ab	-	30.9a
S.T. Cult. Shallow	32.8a	28.0b	-	31.2a
S.T. Cult. Deep	30.9a	28.3b	-	30.0a
Tandem Disk Shallow	32.2a	30.0ab	-	31.4a
Tandem Disk Deep	30.9a	28.3b	-	30.0a
Implements				
Vibrashank	32.0a	30.4a	-	31.5a
H.D. Cult.	31.7a	29.7ab	-	31.1a
S.T. Cult.	31.8a	28.1ab	-	30.6a
Tandem Disk	31.5a	29.1b	-	30.7a
Tillage Depth				
Shallow	32.6a	29.0a	-	31.4a
Deep	30.9b	29.6a	-	30.5b

Table 5. Seedbed moisture content (%)* in pre-seeding packing experiment (C2) for canola

Treatment	1989	1990	1991	Years
Spiral Coil Dry	33.7a	25.7a	37.1a	31.4a
Spiral Coil Moist	34.2a	24.8a	35.1a	29.9ab
Press Wheels Dry	34.0a	25.3a	36.4a	30.8ab
Press Wheels Moist	33.6a	24.8a	33.7a	29.2b
Rod Weeder Dry	33.7a	25.1a	35.5a	30.3ab
Rod Weeder Moist	37.4a	25.2a	35.7a	30.4ab
No Packing Dry	33.5a	24.6a	36.8a	30.7ab
No Packing Moist	33.7a	25.1a	36.5a	30.8ab
Implements				
Spiral Coil	34.0a	25.3a	36.1a	30.7a
Press Wheel	33.8a	25.0a	35.1a	30.0a
Rod Weeder	35.6a	25.1a	35.6a	30.4a
No Packing	33.6a	24.9a	36.6a	30.8a
Moisture condition				
Dry	33.7a	25.2a	36.5a	30.8a
Moist	34.7a	25.0a	35.2a	30.1a

* values followed by same letter in a column are not significantly different at the $\alpha = 0.05$ level.
** Data in this column are not available.

Table 6. Seedbed moisture content (%)* in post-seeding packing experiment (C3) for canola

Treatment	1989	1990	1991	Years
Spiral Coil no P.S.P.	32.2d	23.8c	38.8a	31.3ab
Spiral Coil with P.S.P.	33.9cd	24.8bc	37.6a	31.2ab
Press Wheels no P.S.P.	35.2b	26.2abc	39.0a	32.6a
Press Wheels with P.S.P.	37.6a	25.8abc	34.3a	30.1b
Rod Weeder no P.S.P.	30.8d	26.9ab	38.5a	32.7a
Rod Weeder with P.S.P.	31.0d	27.7a	37.8a	31.1ab
No Packing no P.S.P.	32.9bcd	27.6a	36.8a	30.6ab
No Packing with P.S.P.	34.8b	26.7ab	35.4a	31.0ab
Implements				
Spiral Coil	33.1b	24.3b	38.2a	31.3a
Press Wheel	36.4a	26.0a	36.7a	31.3a
Rod Weeder	30.9c	27.3a	38.3a	32.0a
No Packing	33.9b	27.1a	35.8a	30.8a
Packing condition				
No P.S.P.	32.8b	26.1a	38.5a	31.9a
P.S.P.	34.3a	26.2a	36.1b	30.8a

* values followed by same letter in a column are not significantly different at the α = 0.05 level.

Significant differences in moisture were noted in the data among years for the pre-seeding packing experiment (Table 5). The spiral coil dry treatment had significantly higher soil moisture than the press wheel moist treatment. No significant differences were found among other treatments. The comparison of implements did not show any significant differences over years.

Post-seeding packing had an effect on seedbed moisture (Table 6). Some significant differences were observed in 1989 and 1990. Over years, the press wheel and the rod weeder with no pre-seeding packing treatments had significantly higher moisture content than the press wheel with pre-seeding packing treatment. There were no significant differences between packing implements and no packing. However, all packing implements had a higher moisture content than those with no packing. Pre-seeding packing did not increase the moisture content in the seedbed.

Bulk Density

Pre-seeding tillage had an effect on bulk density in the seedbed soil (Table 7). Over years, the spring tooth cultivator with shallow depth of tillage treatment had a significantly higher bulk density than the vibrashank deep, spring tooth cultivator deep and the tandem disc treatments. This result was supported by the statistical analysis of the data from implements and tillage depth.

Pre-seeding packing treatments had significant effects on bulk density compared to no packing. This is reflected in the bulk density values of Table 8. Data over years indicated that treatments with packers had significantly higher bulk density than no packing. Reviewing breakdowns by implements, packing induced significantly higher bulk density than no packing while the press wheel had the highest bulk density.

Similar statistical results were achieved for bulk density in post-seeding packing experiments (Table 9). Data in years showed that the bulk densities in packing with no pre-seeding packing and pre-seeding packing were significantly higher than that in no packing plots. The press wheel with pre-seeding

Table 7. Seedbed bulk density (Mg/m^3)* in pre-seeding tillage experiment (C1) for canola

Treatment	1989	1990	1991**	Years
Vibrashank Shallow	0.97ab	1.01ab	-	0.98ab
Vibrashank Deep	0.93c	0.98b	-	0.95c
H.D. Cult. Shallow	0.96abc	1.01a	-	0.98abc
H.D. Cult. Deep	0.93c	1.08a	-	0.98abc
S.T. Cult. Shallow	0.99a	1.05ab	-	1.01a
S.T. Cult. Deep	0.94bc	1.03ab	-	0.97bc
Tandem Disk Shallow	0.95bc	0.99b	-	0.96bc
Tandem Disk Deep	0.94bc	1.04ab	-	0.97bc
Implements				
Vibrashank	0.95a	0.99a	-	0.96b
H.D. Cult.	0.94a	1.05a	-	0.98ab
S.T. Cult.	0.96a	1.04a	-	0.99a
Tandem Disk	0.94a	1.01a	-	0.97ab
Tillage Depth				
Shallow	0.97a	1.01a	-	0.98a
Deep	0.93b	1.03a	-	0.97b

* values followed by same letter in a column are not significantly different at the α = 0.05 level.
** Data in this column are not available.

Table 8. Seedbed bulk density (Mg/m^3)* in pre-seeding packing experiment (C2) for canola

Treatment	1989	1990	1991	Years
Spiral Coil Dry	0.97a	1.04a	1.01a	1.03a
Spiral Coil Moist	0.94a	1.05a	1.01a	1.03a
Press Wheels Dry	0.97a	1.05a	1.00ab	1.03a
Press Wheels Moist	0.91a	1.06a	1.02a	1.04a
Rod Weeder Dry	0.96a	1.05a	1.01a	1.03a
Rod Weeder Moist	0.98a	1.05a	0.99ab	1.02a
No Packing Dry	0.94a	1.03a	0.93c	0.98b
No Packing Moist	0.91a	1.02a	0.95bc	0.99b
Implements				
Spiral Coil	0.96a	1.04ab	1.01a	1.03a
Press Wheel	0.94a	1.05a	1.01a	1.03a
Rod Weeder	0.97a	1.05a	1.00a	1.03a
No Packing	0.92a	1.02b	0.94b	0.98b
Moisture condition				
Dry	0.96a	1.04a	0.99a	1.01a
Moist	0.93a	1.04a	0.99a	1.02a

Table 9. Seedbed bulk density (Mg/m^3)* in post-seeding packing experiment (C3) for canola

Treatment	1989	1990	1991	Years
Spiral Coil no P.S.P.	0.93ab	1.00b	0.98b	0.99b
Spiral Coil with P.S.P.	0.95ab	1.04a	0.99ab	1.02a
Press Wheels no P.S.P.	0.96a	1.00b	0.95bc	0.98b
Press Wheels with P.S.P.	0.96a	1.06a	1.03a	1.04a
Rod Weeder no P.S.P.	0.91b	1.00b	0.97b	0.99b
Rod Weeder with P.S.P.	0.94ab	1.06a	0.97b	1.03a
No Packing no P.S.P.	0.95ab	0.95c	0.91c	0.94c
No Packing with P.S.P.	0.93ab	0.98bc	0.98ab	0.98b
Implements				
Spiral Coil	0.94b	1.02a	0.98a	1.00a
Press Wheel	0.96a	1.03a	0.99a	1.01a
Rod Weeder	0.93b	1.03a	0.97a	1.00a
No Packing	0.94b	0.97b	0.96a	0.96b
Packing condition				
No P.S.P.	0.94a	0.99b	0.96b	0.97b
P.S.P.	0.95a	1.03a	0.99a	1.02a

* values followed by same letter in a column are not significantly different at the α = 0.05 level.

packing treatment yielded the highest bulk density while the treatment with no pre-seeding and no post-seeding packing had the lowest bulk density. Differences were found between implements and pre-seeding packing conditions. The packers and pre-seeding packing significantly increased bulk density in the seedbed.

Aggregate Size Distribution (<4 mm)

Aggregate size distribution in the pre-seeding tillage experiment showed some significant differences between treatments (Table 10). The tandem disc had a significantly lower proportion of aggregates smaller than 4 mm compared to the other tillage implements. In the comparison of treatments vibrashank with deep tillage had significantly higher small aggregates than the heavy duty cultivator deep and tandem disc shallow treatments but was not significantly different from the spring tooth cultivator with both shallow and deep tillage treatments.

Aggregate size distribution generally was not significantly different among treatments in pre-seeding packing experiments over years (Table 11). The press wheel dry and moist treatments significantly disintegrated the soil aggregates in the seedbed. The differences between packing implements were not significant. The rod weeder had the least effect on aggregates. The dry condition during packing treatments enhanced aggregates (< 4 mm) in the seedbed although there was no significant difference comparing to the moist condition.

Statistical results for the post-seeding packing experiment showed some significant differences (Table 12). The press wheel with pre-seeding packing and the rod weeder with both no pre-seeding packing and pre-seeding packing treatments yielded significantly higher aggregates (< 4 mm) in the seedbed than no packing with no pre-seeding packing. The results for implements indicated that there were significant differences between rod weeder and no packing, but no significant differences between the packers. The highest proportion of aggregates < 4 mm in the post-seeding packing was produced by the rod weeder which produced the lowest proportion of aggregates < 4 mm in the pre-seeding packing experiment.

Table 10. Aggregates (< 4 mm) in seedbed (%)* in pre-seeding tillage experiment (C1) for canola

Treatment	1989	1990	1991	Years
Vibrashank Shallow	60.5a	65.1a	55.5bc	59.9abc
Vibrashank Deep	66.7a	63.1ab	60.3ab	63.4a
H.D. Cult. Shallow	66.7a	62.1abc	56.2abc	61.6abc
H.D. Cult. Deep	60.7a	62.5ab	50.2d	57.4bc
S.T. Cult. Shallow	65.8a	62.0abc	58.7abc	62.2ab
S.T. Cult. Deep	64.4a	60.1abc	61.2a	62.1ab
Tandem Disk Shallow	61.9a	53.9c	54.7cd	57.1c
Tandem Disk Deep	61.8a	56.3bc	57.0abc	58.5abc
Implements				
Vibrashank	63.6a	64.1a	57.9ab	61.6a
H.D. Cult.	63.7a	62.3a	53.2c	59.5ab
S.T. Cult.	65.1a	61.0a	59.9a	62.1a
Tandem Disk	61.8a	55.1b	55.8bc	57.8b
Tillage Depth				
Shallow	63.7a	60.8a	56.2a	60.2a
Deep	63.4a	60.5a	57.1a	60.3a

Table 11. Aggregates (< 4 mm) in seedbed (%)* in pre-seeding packing experiment (C2) for canola

Treatment	1989	1990	1991	Years
Spiral Coil Dry	75.0a	76.2ab	70.1ab	73.6a
Spiral Coil Moist	77.7a	78.6ab	62.9b	72.5a
Press Wheels Dry	75.2a	81.8a	69.8ab	75.0a
Press Wheels Moist	75.2a	78.7ab	73.6a	75.6a
Rod Weeder Dry	69.6a	78.6ab	72.8ab	73.2a
Rod Weeder Moist	69.9a	74.4b	69.3ab	70.9a
No Packing Dry	75.6a	79.5ab	64.0ab	72.4a
No Packing Moist	71.7a	75.4b	71.0ab	72.5a
Implements				
Spiral Coil	76.3a	77.4a	66.5a	73.0a
Press Wheel	75.2a	80.2a	71.7a	75.3a
Rod Weeder	69.8a	76.5a	71.1a	72.1a
No Packing	73.6a	77.4a	67.5a	72.4a
Moisture condition				
Dry	73.9a	79.0a	69.2a	73.6a
Moist	73.6a	76.8a	69.2a	72.9a

* values followed by same letter in a column are not significantly different at the $\alpha = 0.05$ level.

Table 12. Aggregates (< 4 mm) in seedbed (%)* in post-seeding packing experiment (C3) for canola

Treatment	1989	1990	1991	Years
Spiral Coil no P.S.P.	79.8a	76.6a	74.1a	76.8ab
Spiral Coil with P.S.P.	80.0a	75.7a	73.0a	76.3ab
Press Wheels no P.S.P.	79.0a	76.7a	74.8a	76.9ab
Press Wheels with P.S.P.	80.4a	77.4a	76.4a	78.1a
Rod Weeder no P.S.P.	80.1a	80.9a	72.9a	77.7a
Rod Weeder with P.S.P.	82.2a	80.3a	73.3a	78.4a
No Packing no P.S.P.	71.2b	74.7a	74.0a	73.2b
No Packing with P.S.P.	79.[illegible]a	76.9a	73.7a	76.7ab
Implements				
Spiral Coil	79.9ab	76.2b	73.5a	76.6ab
Press Wheel	79.7ab	77.1ab	75.6a	77.5ab
Rod Weeder	81.1a	80.6a	73.1a	78.1a
No Packing	75.4b	75.8b	73.8a	74.9b
Packing condition				
No P.S.P.	77.6a	77.2a	73.9a	76.1a
P.S.P.	80.5a	77.6a	74.1a	77.4a

* values followed by same letter in a column are not significantly different at the $\alpha = 0.05$ level.

3.1.1.2 Crop Response

In a general overview, emergence and yields in 1989 and 1990 were relatively lower than the 1991 values. In 1989, a late spring snowstorm damaged the emerging canola crop in experiment C4. This hampered crop emergence and weed competition resulted. In 1990, spring soil moisture was low which resulted in poor emergence.

Pre-Seeding Tillage Experiment (C1)

The overall analysis by years showed that the shallow tilled disc treatment was superior to the deep tilled disc, vibrashank and heavy duty cultivator treatments in terms of emergence (Table 13). The comparison between implements and tillage depth revealed significant emergence differences. The heavy duty cultivator showed significantly lower emergence versus spring tooth and tandem disc tillage implements and shallow tillage had lower emergence than deep tillage over years.

In 1990 the shallow vibrashank treatment had significantly higher yields than the deep heavy duty cultivator and shallow spring tooth cultivator treatments (Table 14). In 1990, one replicate of the shallow spring tooth cultivator treatment was severely infested with weeds which reduced treatment average. In 1991 the yield results were nearly opposite with the spring tooth cultivator treatment superior to the vibrashank treatment and the heavy duty cultivator treatment. Over years, the analysis revealed a yield advantage for the deep spring tooth cultivator treatment over the shallow spring tooth cultivator and deep heavy duty cultivator treatments. In a breakdown by implement, the 1990 and 1991 data showed conflicting results. The vibrashank and tandem disc had a yield advantage over both cultivator implements. In 1991 the spring tooth cultivator had a significant yield advantage over all implements. However, neither of the trends persisted over years.

Table 13. Canola emergence (plants/m^2)* in pre-seeding tillage experiment (C1)

Treatment	1989	1990	1991	Years
Vibrashank Shallow	124a	83a	273bc	161bc
Vibrashank Deep	126a	77a	268bcd	157bc
H.D. Cult. Shallow	131a	85a	256cd	154bc
H.D. Cult. Deep	112a	76a	234d	140c
S.T. Cult. Shallow	114a	101a	302ab	175ab
S.T. Cult. Deep	122a	87a	296ab	172ab
Tandem Disk Shallow	126a	87a	326a	185a
Tandem Disk Deep	126a	89a	272bc	162bc
Implements				
Vibrashank	125a	80a	290b	159ab
H.D. Cult.	121a	81a	245c	147b
S.T. Cult.	118a	94a	299a	173a
Tandem Disk	126a	88a	299a	173a
Tillage Depth				
Shallow	124a	89a	289a	169a
Deep	121a	82a	267b	158b

* values followed by same letter in a column are not significantly different at the α = 0.05 level.

Table 14. Canola yield (kg/ha)* in pre-seeding tillage experiment (C1)

Treatment	1989	1990	1991	Years
Vibrashank Shallow	800a	1121a	1419c	1113ab
Vibrashank Deep	786a	1027ab	1529abc	1114ab
H.D. Cult. Shallow	762a	998ab	1497abc	1086ab
H.D. Cult. Deep	819a	921b	1418c	1053b
S.T. Cult. Shallow	821a	753c	1602ab	1058b
S.T. Cult. Deep	814a	1004ab	1630a	1150a
Tandem Disk Shallow	741a	1102a	1483bc	1109ab
Tandem Disk Deep	714a	1067ab	1477bc	1086ab
Implements				
Vibrashank	793a	1074a	1474b	1114a
H.D. Cult.	791a	960b	1457b	1069a
S.T. Cult.	817a	879b	1616a	1104a
Tandem Disk	727a	1085a	1480b	1097a
Tillage Depth				
Shallow	781a	993a	1500a	1092a
Deep	783a	1005a	1513a	1100a

* values followed by same letter in a column are not significantly different at the $\alpha = 0.05$ level.

Pre-Seeding Packing (C2)

Pre-seeding packing showed consistent effects on canola emergence (Table 15), although there was varying significance between packing treatments within each year. Over years, all packing treatments had significantly higher emergence than no packing. Between packing treatments, the rod weeder dry and moist treatments showed significantly lower emergence than the spiral coil dry treatment. The effects of implements clearly showed significant differences which were similar to the results from treatment comparison. In 1990, no packing and the rod weeder packing on dry soil conditions had significantly lower emergence than spiral coil packing on moist and dry soil conditions. Since 1990 was a dry year, the spiral coil and press wheel treatment were able to create conditions to draw moisture up to the seedbed for the canola seed to utilize. The reason for lower emergence for the rod weeder treatment was possibly the soil disturbance induced by rod weeder packing which disrupted soil surface sealing that packers such as the spiral coil and press wheel provided. In 1991, the no packing treatments showed significantly lower emergence than the packing treatments. The lowest emergence with no packing was reflected by the bulk density data in Table 8 and Table 11 which shows no packing to have the lowest bulk density and aggregates (< 4 mm) in the seedbed.

Significant yield differences were only between packers and control in the pre-seeding packing experiment in each year and over years (Table 16). No packing on dry soil conditions resulted in a significantly lower yield than other treatments. There were no significant differences between packing treatments while the press wheel on moist conditions had the highest yield. When yield data are analyzed by implement, no implement held a significant yield advantage but no packing did have significantly lower yields. The press wheel and the spiral coil had more influence on yield than the rod weeder. Yield differences were basically in line with emergence results.

Table 15. Canola emergence (plants/m^2)* in pre-seeding packing experiment (C2)

Treatment	1989	1990	1991	Years
Spiral Coil Dry	176a	79ab	264ab	193a
Spiral Coil Moist	172ab	84a	225c	171b
Press Wheels Dry	160abc	74abc	243abc	175ab
Press Wheels Moist	159abc	73abc	261ab	181ab
Rod Weeder Dry	141c	54c	273a	171b
Rod Weeder Moist	150c	64abc	239bc	161b
No Packing Dry	162abc	32d	164d	125c
No Packing Moist	152bc	59bc	154d	126c
Implements				
Spiral Coil	174a	82a	245a	182a
Press Wheel	159b	74ab	252a	178ab
Rod Weeder	146b	59bc	256a	166b
No Packing	157b	46c	159b	125c
Moisture condition				
Dry	160a	60a	236a	166a
Moist	158a	70a	220b	160a

* values followed by same letter in a column are not significantly different at the α = 0.05 level.

Table 16. Canola yield (kg/ha)* in pre-seeding packing experiment (C2)

Treatment	1989	1990	1991	Years
Spiral Coil Dry	962ab	1125a	1684a	1257a
Spiral Coil Moist	944ab	1132a	1656a	1244a
Press Wheels Dry	978a	1101a	1701a	1260a
Press Wheels Moist	952ab	1143a	1756a	1284a
Rod Weeder Dry	956ab	1064a	1672a	1231a
Rod Weeder Moist	999a	1011ab	1702a	1237a
No Packing Dry	913b	910b	1623a	1149b
No Packing Moist	949ab	1029ab	1684a	1221a
Implements				
Spiral Coil	953ab	1129a	1670a	1250a
Press Wheel	965ab	1122a	1728a	1272a
Rod Weeder	977a	1037ab	1687a	1234a
No Packing	931b	969b	1654a	1185b
Moisture condition				
Dry	952a	1050a	1670a	1224a
Moist	961a	1079a	1699a	1246a

* values followed by same letter in a column are not significantly different at the α = 0.05 level.

Post-Seeding Packing (C3)

Post-seeding packing resulted in varied degree of emergence differences between treatments in 1990, 1991 and over years (Table 17). Over years, the press wheels and the spiral coil with pre-seeding packing treatments had significantly higher emergence than other packing treatments. By looking at breakdowns of implements and packing conditions, the rod weeder had significantly lower emergence than the spiral coil and the press wheels and the combination of pre and post-seeding packing resulted in significantly higher emergence than post-seeding packing alone. Data from each individual year and years showed that the rod weeder with no pre-seeding packing treatment had lower emergence than all other packing treatments. A possible reason for this was lower bulk density in the rod weeder treatments without pre-seeding packing. This suggests rod weeder packing after seeding with no pre-seeding packing was ineffective in increasing the seedbed bulk density enough to obtain good canola emergence.

For the post-seeding packing experiment, the advantage of emergence did not translate directly into a yield gain (Table 18). Over years, the pre-seeding packed rod weeder treatment had a significantly higher yield than the spiral coil packers with no pre-seeding packing treatment and controls. When comparing the effects between implements in the post-seeding packing, the rod weeder was found to be superior to both the spiral coil and press wheel considering canola yield. Since bulk density was measured in the seedbed soil, it was possible that higher bulk density occurred below the seedbed for the treatments with press wheel and spiral coil. Canola root development may have been limited leading to low yield under these conditions. The combination of pre and post-seeding packing had an yield advantage over post-seeding packing alone.

Table 17. Canola emergence (plants/m^2)* in post-seeding packing experiment (C3)

Treatment	1989	1990	1991	Years
Spiral Coil no P.S.P.	160a	162c	225abc	188bcd
Spiral Coil with P.S.P.	168a	211a	237a	210a
Press Wheels no P.S.P.	158a	179bc	202cd	183cd
Press Wheels with P.S.P.	166a	226a	239a	214a
Rod Weeder no P.S.P.	147a	131d	187d	161e
Rod Weeder with P.S.P.	161a	206ab	231ab	205ab
No Packing no P.S.P.	160a	151cd	208bcd	175de
No Packing with P.S.P.	167a	199ab	220abc	198abc
Implements				
Spiral Coil	164a	187ab	231a	199a
Press Wheel	162a	202a	220ab	199a
Rod Weeder	154a	168b	209b	183b
No Packing	164a	175b	214ab	186b
Packing condition				
No P.S.P.	156a	156b	206b	177b
P.S.P.	166a	211a	232a	207a

* values followed by same letter in a column are not significantly different at the α = 0.05 level.

Table 18. Canola yield (kg/ha)* in post-seeding packing experiment (C3)

Treatment	1989	1990	1991	Years
Spiral Coil no P.S.P.	831b	867ab	1542bc	1080bc
Spiral Coil with P.S.P.	844ab	866ab	1617abc	1109ab
Press Wheels no P.S.P.	841ab	825ab	1623ab	1096abc
Press Wheels with P.S.P.	843ab	927a	1615abc	1128ab
Rod Weeder no P.S.P.	869ab	843ab	1654a	1122ab
Rod Weeder with P.S.P.	869ab	914ab	1628ab	1137a
No Packing no P.S.P.	894a	824ab	1534c	1084bc
No Packing with P.S.P.	834b	811b	1531c	1059c
Implements				
Spiral Coil	837a	866a	1580bc	1094bc
Press Wheel	842a	876a	1619ab	1112ab
Rod Weeder	869a	879a	1641a	1129a
No Packing	864a	818a	1532c	1071c
Packing condition				
No P.S.P.	859a	840a	1588a	1095a
P.S.P.	848a	880a	1598a	1108a

* values followed by same letter in a column are not significantly different at the α = 0.05 level.

Seeding Depth (C4)

The most consistent results were found with the seeding depth experiments. Each year showed some variation with seeding depth and tillage depth on emergence but basically emergence decreased with increasing seeding depth each year (Table 19). This result was best expressed in the analysis over years which showed emergence to be significantly different in every treatment seeded greater than 30 mm in depth. In comparing seeding depth alone, emergence decreased with a seeding depth greater than 30 mm every year and over years. The 10 and 30 mm seeding depths differed significantly in 1989, 1991 and over years. Emergence was found to be superior for shallow tillage over deep tillage in 1990, 1991 and over years.

Treatment comparisons of yield with seeding depth were similar to those with emergence only the differences were not as distinct. In 1989, 10 mm deep tilled treatment was significantly better than 70 mm deep tilled treatment (Table 20). In 1990, yield of canola seeded at the 70 mm was significantly less than all other treatments. In 1991, canola seeded at the 70 mm depth in a deep seedbed yielded lower than almost all treatments. Over years, virtually all canola seeded greater than 30 mm in depth had depressed yields regardless of seedbed depth. Statistical results for seeding depth showed clearly that increasing seeding depth greater than 30 mm resulted in significantly depressed yields with each 20 mm increment. Unlike emergence, shallow tillage did not give better yield than deep tillage. Deep tillage had better yields but the difference was not significant.

Table 19. Canola emergence (plants/m^2)* in seeding depth experiment (C4)

Treatment	1989	1990	1991	Years
10 mm Shallow	91c	150a	97c	90c
10 mm Deep	102b	124b	116b	91c
30 mm Shallow	114a	147a	144a	124a
30 mm Deep	122a	119b	117b	110b
50 mm Shallow	84cd	126b	100bc	94c
50 mm Deep	80d	72c	72d	69d
70 mm Shallow	49e	73c	45e	48e
70 mm Deep	28f	37d	36e	28f
Seeding Depth				
10 mm	96b	137a	107b	91b
30 mm	118a	133a	130a	117a
50 mm	82c	99b	86c	82c
70 mm	38d	55c	40d	38d
Tillage Depth				
Shallow	84a	124a	96a	89a
Deep	83a	88b	85b	75b

* values followed by same letter in a column are not significantly different at the α = 0.05 level.

Table 20. Canola yield (kg/ha)* in seeding depth experiment (C4)

Treatment	1989	1990	1991	Years
10 mm Shallow	959ab	873ab	1367a	1066ab
10 mm Deep	1084a	949a	1301ab	1111ab
30 mm Shallow	951ab	962a	1376a	1096ab
30 mm Deep	1071a	955a	1470a	1165a
50 mm Shallow	995a	728ab	1347a	1023b
50 mm Deep	996a	767ab	1379a	1047ab
70 mm Shallow	899ab	481c	1271ab	884c
70 mm Deep	759b	398c	1107b	755d
Seeding Depth				
10 mm	1021a	911a	1334a	1089ab
30 mm	1011a	959a	1423a	1131a
50 mm	995a	747b	1363a	1035b
70 mm	829b	440c	1189b	819c
Tillage Depth				
Shallow	951a	761a	1340a	1017a
Deep	978a	767a	1314a	1020a

* values followed by same letter in a column are not significantly different at the α = 0.05 level.

3.1.2 Flax Results

3.1.2.1 Seedbed Soil Parameters

Seedbed Soil Moisture

Over years, soil moisture in the pre-seeding tillage experiment was significantly different among implements (Table 21). The spring tooth cultivator and vibrashank treatments had significantly higher moisture content than the heavy duty cultivator. The shallow tillage was more effective in keeping the moisture in the seedbed than the deep tillage. The interaction of tillage implements and tillage depth indicated that the spring tooth cultivator with shallow depth of tillage treatment had significantly higher moisture content than the vibrashank and the spring tooth cultivator with deep tillage depth treatments and the heavy duty cultivator with both of shallow and deep tillage depth treatments. In 1989 a spring snowstorm fell on the emerging flax crop in experiments F1 and F4 which delayed growth and allowed

Table 21. Seedbed moisture content (%)* in pre-seeding tillage experiment (F1) for flax

Treatment	1988	1989	1990**	Years
Vibrashank Shallow	22.8ab	33.2a	-	28.0ab
Vibrashank Deep	23.0ab	30.4abc	-	26.7bcd
H.D. Cult. Shallow	21.8b	31.5abc	-	26.6bcd
H.D. Cult. Deep	22.4b	29.6c	-	25.2d
S.T. Cult. Shallow	24.7a	33.3a	-	30.0a
S.T. Cult. Deep	22.3b	29.8bc	-	26.1cd
Tandem Disk Shallow	22.1b	31.0abc	-	26.5bcd
Tandem Disk Deep	23.3ab	32.2ab	-	27.7abc
Implements				
Vibrashank	22.9a	31.8a	-	27.4a
H.D. Cult.	22.1a	30.1a	-	26.1b
S.T. Cult.	23.5a	31.5a	-	27.5a
Tandem Disk	22.7a	31.6a	-	27.1ab
Tillage Depth				
Shallow	22.8a	32.2a	-	27.5a
Deep	22.8a	30.3b	-	26.5b

Table 22. Seedbed moisture content (%)* in pre-seeding packing experiment (F2) for flax

Treatment	1988	1989	1990**	Years
Spiral Coil Dry	21.1a	30.0b	-	26.2ab
Spiral Coil Moist	19.9a	30.8ab	-	26.1ab
Press Wheels Dry	20.7a	29.5b	-	25.7b
Press Wheels Moist	20.7a	29.8b	-	25.9ab
Rod Weeder Dry	20.5a	28.9b	-	25.3b
Rod Weeder Moist	20.9a	32.1a	-	27.3a
No Packing Dry	18.9a	29.7b	-	25.0b
No Packing Moist	18.9a	30.8ab	-	25.7b
Implements				
Spiral Coil	20.5a	30.4a	-	26.1a
Press Wheel	20.7a	29.7a	-	25.8a
Rod Weeder	20.7a	30.5a	-	26.3a
No Packing	18.9b	30.2a	-	25.3a
Moisture condition				
Dry	20.3a	29.5b	-	25.6b
Moist	20.1a	30.9a	-	26.3a

* values followed by same letter in a column are not significantly different at the α = 0.05 level.
** Data in this column are not available.

Table 23. Seedbed moisture content (%)* in post-seeding packing experiment (F3) for flax

Treatment	1988	1989	1990**	Years
Spiral Coil no P.S.P.	20.5c	31.2ab	-	26.6b
Spiral Coil with P.S.P.	22.4abc	32.5a	-	28.2a
Press Wheels no P.S.P.	22.8ab	31.9a	-	28.0ab
Press Wheels with P.S.P.	21.8bc	33.1a	-	28.3a
Rod Weeder no P.S.P.	23.1ab	29.0b	-	26.5b
Rod Weeder with P.S.P.	24.4a	32.6a	-	29.1a
No Packing no P.S.P.	22.6ab	31.6a	-	27.7ab
No Packing with P.S.P.	21.7bc	32.3a	-	27.7ab
Implements				
Spiral Coil	21.4b	31.8ab	-	27.4a
Press Wheel	22.3b	32.5a	-	28.1a
Rod Weeder	23.8a	30.8b	-	27.8a
No Packing	22.2b	31.9ab	-	27.7a
Packing condition				
No P.S.P.	22.3a	30.9	-	27.2b
P.S.P.	22.6a	32.6a	-	28.3a

* values followed by same letter in a column are not significantly different at the α = 0.05 level.
** Data in this column are not available.

weeds to compete with the flax. This event is evidenced by the high emergence and low yield data for F1 and F4 in 1989 compared to the results for F1 and F4 in 1988 and 1990. The low moisture values in 1988 were attributed to a lack of early season moisture. The low moisture was only temporary as late spring precipitation brought moisture reserves up.

Seedbed soil moisture over years in the pre-seeding packing experiment did not show any significant differences among implements (Table 22). However, some significant differences appeared among treatments. The rod weeder treatment on moist soil conditions had significantly higher soil moisture than the press wheel and the rod weeder on dry conditions and no packing treatments. The breakdowns by soil moisture conditions indicated that seedbed management with moist conditions was significantly effective at retaining higher seedbed soil moisture than that with dry conditions. Though there were no significant differences between implements, no packing still showed the lowest moisture which was related to the data in 1988 when the no packing had a significantly lower moisture than all the packing implements.

Table 23 lists moisture results in the post-seeding packing experiment. Data over years showed some significant differences between treatments. All packing treatments with pre-seeding packing had significantly higher soil moisture than packing with no pre-seeding packing. This was confirmed by the comparison between packing conditions. No significant differences were found between implements and no packing.

Bulk Density

The pre-seeding tillage experiment did not show any significant differences in bulk density in 1988 and over years (Table 24). Only in 1989 were statistical significances noted in the comparisons of tillage depth and treatments. The bulk density in the seedbed with shallow tillage was significantly higher than that with deep tillage.

Over years, no packing did have significantly lower bulk density than packing on dry soil conditions for the pre-seeding experiment (Table 25). Packing treatments on moist soil conditions did not significantly alter bulk density compared to the no packing treatment. The consequences above were reflected by the analysis of soil moisture conditions in which the bulk density under dry soil conditions was significantly higher than that under moist soil conditions. The effects of packing implements on bulk density were obvious due to the significant differences between the spiral coil and the press wheel and no packing. The rod weeder had the lowest bulk density of all packing implements but still higher than no packing.

Over years, the no packing treatment with no pre-seeding packing had significantly lower bulk density than packing treatments with pre-seeding packing (Table 26). This was supported by the results of packing conditions which indicated a significantly higher bulk density for pre-seeding packing than that for no pre-seeding packing conditions. The bulk density from the comparison between implements was significantly higher with press wheel than that with rod weeder and no packing. The result for rod weeder was similar to that from the pre-seeding packing experiment.

Aggregate Size Distribution (< 4 mm)

Aggregate size distribution did not show any significant differences in the pre-seeding tillage experiment in each year and over years (Table 27). However, the spring tooth cultivator had the highest proportion of aggregates smaller than 4 mm in the seedbed compared to other implements.

Aggregate size distribution in the pre-seeding packing experiment generally did not show significant differences between treatments, implements and soil moisture conditions in 1989, 1990 and years (Table 28). The no packing treatment had the lowest value of aggregates smaller than 4 mm. Significant differences were only found in 1988. The rod weeder treatment on dry conditions had a significantly higher proportion of aggregates (< 4 mm) than the spiral coil on moist conditions.

Post-seeding packing treatments significantly reduced large aggregates in the seedbed soil (Table 29). The analysis for implements showed that the press wheel had a significantly higher proportion of aggregates < 4 mm than no packing. No significant differences were observed between packers while the press wheels had the highest proportion of small aggregates (< 4 mm). The results in the comparison of treatments showed some non-significant differences. The no packing treatment with no pre-seeding packing had the lowest proportion of aggregates smaller than 4 mm.

Table 24. Seedbed bulk density (Mg/m^3)* in pre-seeding tillage experiment (F1) for flax

Treatment	1988	1989	1990**	Years
Vibrashank Shallow	0.93a	0.93ab	-	0.93a
Vibrashank Deep	0.92a	0.89bc	-	0.90a
H.D. Cult. Shallow	0.90a	0.94a	-	0.92a
H.D. Cult. Deep	0.94a	0.87c	-	0.91a
S.T. Cult. Shallow	0.91a	0.91abc	-	0.91a
S.T. Cult. Deep	0.92a	0.89abc	-	0.91a
Tandem Disk Shallow	0.93a	0.89bc	-	0.91a
Tandem Disk Deep	0.92a	0.88bc	-	0.90a
Implements				
Vibrashank	0.93a	0.91a	-	0.92a
H.D. Cult.	0.92a	0.91a	-	0.91a
S.T. Cult.	0.92a	0.90a	-	0.91a
Tandem Disk	0.92a	0.89a	-	0.91a
Tillage Depth				
Shallow	0.92a	0.92a	-	0.92a
Deep	0.93a	0.88b	-	0.91a

Table 25. Seedbed bulk density (Mg/m^3)* in pre-seeding packing experiment (F2) for flax

Treatment	1988	1989	1990**	Years
Spiral Coil Dry	0.99a	0.98ab	-	0.98ab
Spiral Coil Moist	0.97abc	0.97ab	-	0.97bcd
Press Wheels Dry	0.98ab	1.01a	-	0.99a
Press Wheels Moist	0.95bcd	0.97ab	-	0.96bcd
Rod Weeder Dry	0.96abcd	0.99ab	-	0.97abc
Rod Weeder Moist	0.94cb	0.97b	-	0.95cd
No Packing Dry	0.95bcd	0.97b	-	0.96bcd
No Packing Moist	0.93d	0.96b	-	0.95d
Implements				
Spiral Coil	0.98a	0.97a	-	0.98a
Press Wheel	0.97ab	0.99a	-	0.98a
Rod Weeder	0.95b	0.98a	-	0.96ab
No Packing	0.94c	0.96a	-	0.95b
Moisture condition				
Dry	0.97a	0.98a	-	0.98a
Moist	0.95b	0.97b	-	0.96b

* values followed by same letter in a column are not significantly different at the α = 0.05 level.
** Data in this column are not available.

Table 26. Seedbed bulk density (Mg/m^3)* in post-seeding packing experiment (F3) for flax

Treatment	1988	1989	1990**	Years
Spiral Coil no P.S.P.	0.94a	0.96cd	-	0.95bc
Spiral Coil with P.S.P.	0.94a	0.99bcd	-	0.97ab
Press Wheels no P.S.P.	0.93a	0.99bcd	-	0.96abc
Press Wheels with P.S.P.	0.93a	1.03a	-	0.99a
Rod Weeder no P.S.P.	0.92a	0.97cd	-	0.94bc
Rod Weeder with P.S.P.	0.92a	1.01ab	-	0.97ab
No Packing no P.S.P.	0.91a	0.96d	-	0.97c
No Packing with P.S.P.	0.92a	1.00bc	-	0.96abc
Implements				
Spiral Coil	0.94a	0.98b	-	0.96ab
Press Wheel	0.93a	1.01a	-	0.98a
Rod Weeder	0.92a	0.99b	-	0.96b
No Packing	0.91a	0.98b	-	0.95b
Packing condition				
No P.S.P.	0.92a	0.97b	-	0.95b
P.S.P.	0.93a	1.01a	-	0.97a

Table 27. Aggregates (< 4 mm) in seedbed (%)* in pre-seeding tillage experiment (F1) for flax

Treatment	1988	1989	1990	Years
Vibrashank Shallow	75.6a	62.1a	58.8a	66.2a
Vibrashank Deep	76.3a	67.1a	59.6a	67.9a
H.D. Cult. Shallow	75.5a	68.9a	59.7a	67.7a
H.D. Cult. Deep	74.2a	61.4a	57.9a	65.6a
S.T. Cult. Shallow	75.8a	68.1a	63.5a	69.5a
S.T. Cult. Deep	75.2a	69.3a	61.7a	68.2a
Tandem Disk Shallow	78.3a	67.0a	60.2a	68.9a
Tandem Disk Deep	74.0a	65.2a	60.0a	66.2a
Implements				
Vibrashank	75.9a	64.6a	59.2a	67.0a
H.D. Cult.	74.8a	65.2a	58.8a	66.6a
S.T. Cult.	75.5a	68.7a	62.6a	68.9a
Tandem Disk	76.2a	66.1a	60.1a	67.6a
Tillage Depth				
Shallow	76.3a	66.5a	60.5a	68.1a
Deep	74.9a	65.8a	59.8a	67.0a

* values followed by same letter in a column are not significantly different at the $\alpha = 0.05$ level.
** Data in this column are not available.

Table 28. Aggregates (< 4 mm) in seedbed (%)* in pre-seeding packing experiment (F2) for flax

Treatment	1988	1989	1990	Years
Spiral Coil Dry	75.4ab	67.2a	70.3a	71.1a
Spiral Coil Moist	69.8b	64.4a	70.6a	70.9a
Press Wheels Dry	74.3ab	66.9a	71.0a	71.0a
Press Wheels Moist	72.9ab	71.9a	74.5a	72.1a
Rod Weeder Dry	75.9a	69.6a	70.6a	72.5a
Rod Weeder Moist	71.7ab	68.0a	71.9a	70.7a
No Packing Dry	73.4ab	64.1a	68.9a	70.1a
No Packing Moist	71.8ab	68.2a	68.5a	69.0a
Implements				
Spiral Coil	72.6a	65.8a	70.4a	71.0a
Press Wheel	73.6a	69.4a	72.8a	71.6a
Rod Weeder	73.8a	68.7a	71.2a	71.6a
No Packing	72.6a	66.1a	68.7a	69.5a
Moisture condition				
Dry	74.8a	66.8a	70.2a	71.1a
Moist	71.5b	68.1a	71.4a	70.7a

Table 29. Aggregates (< 4 mm) in seedbed (%)* in post-seeding packing experiment (F3) for flax

Treatment	1988	1989	1990	Years
Spiral Coil no P.S.P.	74.3ab	70.8a	68.8ab	71.5a
Spiral Coil with P.S.P.	74.2ab	67.5a	70.0ab	70.2a
Press Wheels no P.S.P.	73.5ab	68.9a	74.4a	71.9a
Press Wheels with P.S.P.	76.8ab	69.2a	67.7ab	71.9a
Rod Weeder no P.S.P.	72.7ab	70.3a	72.8ab	71.0a
Rod Weeder with P.S.P.	73.3ab	67.8a	71.5ab	70.6a
No Packing no P.S.P.	77.2a	63.3b	65.3b	68.4a
No Packing with P.S.P.	71.5b	68.5a	70.9ab	70.1a
Implements				
Spiral Coil	74.3a	69.1a	69.4a	70.8ab
Press Wheel	75.1a	69.0a	71.0a	71.9a
Rod Weeder	73.0a	69.1a	72.1a	70.8ab
No Packing	74.3a	65.6b	68.3a	69.2b
Packing condition				
No P.S.P.	74.4a	68.3a	70.5a	70.7a
P.S.P.	73.9a	68.2a	70.0a	70.7a

* values followed by same letter in a column are not significantly different at the $\alpha = 0.05$ level.

3.1.2.2 Crop Response

Pre-Seeding Tillage Experiment (F1)

Emergence and yield were quite variable between years. The pre-seeding tillage experiment showed no significant emergence response to tillage treatment in 1988. However, In 1989 and 1990 some significant differences were found in the comparisons of treatments, implements and tillage depth. The final analysis over years showed that the spring tooth cultivator treatments, shallow vibrashank and shallow heavy duty cultivator treatments had significantly higher emergence than the rest (Table 30). Comparing the tillage implements, the significantly highest emergence was noted with the spring tooth cultivator. Shallow tillage induced significantly higher emergence than deep tillage.

Table 30. Flax emergence (plants/m^2)* in pre-seeding tillage experiment (F1)

Treatment	1988	1989	1990	Years
Vibrashank Shallow	393a	624a	226b	418a
Vibrashank Deep	346a	540d	124c	335c
H.D. Cult. Shallow	400a	634a	217b	420a
H.D. Cult. Deep	361a	562bcd	172bc	366bc
S.T. Cult. Shallow	383a	615ab	292a	440a
S.T. Cult. Deep	396a	605abc	288a	436a
Tandem Disk Shallow	354a	545cd	176bc	359bc
Tandem Disk Deep	390a	575abcd	163c	373b
Implements				
Vibrashank	369a	582ab	175b	376bc
H.D. Cult.	381a	598ab	195b	393b
S.T. Cult.	390a	610a	290a	438a
Tandem Disk	372a	560b	169b	366c
Tillage Depth				
Shallow	383a	604a	228a	409a
Deep	373a	570b	187b	377b

* values followed by same letter in a column are not significantly different at the α = 0.05 level.

Yields demonstrated even less of a response to tillage with no significance in 1988 and 1989 except in 1990 when shallow tillage was shown to be superior to deep tillage and the spring tooth cultivator had significantly higher yield than the heavy duty cultivator which was similar to the results over years (Table 31). When combined into years, the deep heavy duty cultivator treatment was inferior to both spring tooth cultivator treatments.

Table 31. Flax yield (kg/ha)* in pre-seeding tillage experiment (F1)

Treatment	1988	1989	1990	Years
Vibrashank Shallow	2551a	718a	1994a	1754ab
Vibrashank Deep	2550a	711a	1784a	1682ab
H.D. Cult. Shallow	2511a	775a	1881a	1722ab
H.D. Cult. Deep	2489a	678a	1774a	1647b
S.T. Cult. Shallow	2529a	757a	2066a	1784a
S.T. Cult. Deep	2510a	792a	2024a	1775a
Tandem Disk Shallow	2516a	653a	1969a	1713ab
Tandem Disk Deep	2601a	697a	1792a	1688ab
Implements				
Vibrashank	2551a	714a	1889ab	1718ab
H.D. Cult.	2500a	726a	1828b	1685b
S.T. Cult.	2520a	774a	2045a	1780a
Tandem Disk	2558a	675a	1893ab	1701ab
Tillage Depth				
Shallow	2527a	726a	1978a	1743a
Deep	2537a	719b	1847b	1698a

* values followed by same letter in a column are not significantly different at the $\alpha = 0.05$ level.

Pre-Seeding Packing (F2)

Combining data into years in the pre-seeding packing experiment, the no packing and rod weeder packing in moist conditions had significantly lower emergence than all other packing treatments (Table 32). The significant differences between implements from high to low were in the order of press wheel, spiral coil, rod weeder and no packing. Packing under dry conditions fared better than packing under moist conditions.

The only noted difference in the pre-seeding packing experiment was a significantly lower yield in the no pre-seeding packing treatment in moist conditions versus press wheel packing in dry conditions in the 1990 crop year (Table 33).

Post-Seeding Packing Experiment (F3)

Emergence response varied between years in the post-seeding packing experiment (Table 34). Data in comparison between implements in 1988 and 1990 showed higher emergence with no packing. The results in 1989 and over years revealed that significantly higher emergence was produced by no packing. The comparison between treatments suggested emergence for treatments with pre-seeding packing was higher than that with no pre-seeding packing. This is supported by the analysis of packing conditions in years data.

Table 32. Flax emergence (plants/m^2)* in pre-seeding packing experiment (F2)

Treatment	1989	1990	1991	Years
Spiral Coil Dry	368a	548abcd	348b	432b
Spiral Coil Moist	346a	509d	352b	413bc
Press Wheels Dry	359a	583ab	417a	472a
Press Wheels Moist	339a	554abc	346b	428b
Rod Weeder Dry	323a	544bcd	294c	400cd
Rod Weeder Moist	348a	538cd	240d	381de
No Packing Dry	354a	517cd	165e	344f
No Packing Moist	328a	588a	135e	355ef
Implements				
Spiral Coil	357a	528b	350b	423b
Press Wheel	349a	568a	381a	450a
Rod Weeder	336a	541ab	267c	390c
No Packing	341a	552ab	150d	349d
Moisture condition				
Dry	351a	548a	306a	412a
Moist	340a	547a	268b	394b

* values followed by same letter in a column are not significantly different at the α = 0.05 level.

Table 33. Flax yield (kg/ha)* in pre-seeding packing experiment (F2)

Treatment	1988	1989	1990	Years
Spiral Coil Dry	2321a	1360a	1989ab	1892a
Spiral Coil Moist	2425a	1448a	2064ab	1979a
Press Wheels Dry	2464a	1291a	2175a	1977a
Press Wheels Moist	2359a	1428a	2130ab	1972a
Rod Weeder Dry	2398a	1398a	2111ab	1969a
Rod Weeder Moist	2444a	1370a	2079ab	1964a
No Packing Dry	2419a	1360a	2093ab	1957a
No Packing Moist	2451a	1481a	1969b	1967a
Implements				
Spiral Coil	2373a	1404a	2027a	1935a
Press Wheel	2412a	1359a	2153a	1974a
Rod Weeder	2421a	1384a	2095a	1967a
No Packing	2435a	1420a	2031a	1962a
Moisture condition				
Dry	2400a	1352a	2092a	1948a
Moist	2420a	1432a	2061a	1971a

Table 34. Flax emergence (plants/m^2)* in post-seeding packing experiment (F3)

Treatment	1988	1989	1990	Years
Spiral Coil no P.S.P.	371a	513b	239c	375cd
Spiral Coil with P.S.P.	341ab	478b	362a	404ab
Press Wheels no P.S.P.	335ab	506b	223c	359d
Press Wheels with P.S.P.	347ab	502b	350a	410ab
Rod Weeder no P.S.P.	340ab	510b	243c	369cd
Rod Weeder with P.S.P.	312b	495b	307b	383bcd
No Packing no P.S.P.	361ab	559a	226c	386bc
No Packing with P.S.P.	330ab	505b	378a	419a
Implements				
Spiral Coil	356a	495b	301a	390ab
Press Wheel	341a	504ab	287a	384b
Rod Weeder	326a	502ab	275a	376b
No Packing	345a	532a	302a	403a
Packing condition				
No P.S.P.	352a	522a	233b	372b
P.S.P.	332a	495b	349a	404a

* values followed by same letter in a column are not significantly different at the α = 0.05 level.

Table 35. Flax yield (kg/ha)* in post-seeding packing experiment (F3)

Treatment	1988	1989	1990	Years
Spiral Coil no P.S.P.	2322a	1116bc	1843abc	1760a
Spiral Coil with P.S.P.	2287a	1078bc	1855abc	1740a
Press Wheels no P.S.P.	2226a	1108bc	1699abc	1677a
Press Wheels with P.S.P.	2202a	1116bc	1896abc	1738a
Rod Weeder no P.S.P.	2156a	1149abc	1888abc	1731a
Rod Weeder with P.S.P.	2265a	1169ab	1950a	1795a
No Packing no P.S.P.	2348a	1241a	1672c	1754a
No Packing with P.S.P.	2168a	1057c	1943ab	1722a
Implements				
Spiral Coil	2304a	1097a	1849a	1750a
Press Wheel	2214a	1112a	1797a	1708a
Rod Weeder	2210a	1159a	1919a	1763a
No Packing	2258a	1149a	1808a	1738a
Packing condition				
No P.S.P.	2263a	1153a	1775b	1731a
P.S.P.	2230a	1105b	1911a	1749a

* values followed by same letter in a column are not significantly different at the α = 0.05 level.

There were no significant differences in yield in the post-seeding packing experiment over years but some significant differences between treatments were noted in 1989 and 1990 (Table 35). In 1989, the similar effect to emergence was again noted with yield for the control with no pre-seeding packing treatment but not for the control with pre-seeding packing treatment which had significantly lower yield. In 1990, the yield from the no packing treatment with no pre-seeding packing was significantly lower than the yield from the no packing and the rod weeder with pre-seeding packing treatments. Over years, pre-seeding packing had higher yield than no pre-seeding packing which was similar to the results of the emergence data.

Overall, significant differences noted in emergence in the pre-seeding packing and post-seeding packing experiments did not translate into significant yield differences in the three years of data. Two possibilities are considered as follows:

One, moisture was a limiting factor in only one instance (spring 1988). For emergence differences to be a factor, the plant must be under moisture stress for a long period of time. This will force the plant to search for moisture. In this situation, the various seedbed preparation methods used may show differences in moisture retention by the seedbed.

Two, Ellerslie silt loam soil is of high quality with good tilth, moisture retention and organic matter. This may have lead to an averaging effect which may have masked the differences being investigated.

In comparing the results from Table 35 with those from Table 33, a slight depression in yield is noted in the post-seeding packing experiment versus the pre-seeding packing experiment. This suggests packing is beneficial in some cases but a threshold may be reached where packing may be detrimental.

Seeding Depth Experiment (F4)

The most consistent experiment over years was the seeding depth experiment. Table 36 illustrates the importance of shallow seeding depth to promote good flax emergence. In 1988 and 1989, emergence dropped off when seed was placed below the depth of 50 mm. In 1990 and overall, emergence dropped off significantly when flax was seeded below a 10 mm depth. Another factor which seems to affect emergence is tillage depth as shallow tillage had significantly better emergence than deep tillage. This is most likely due to the fact that when the plot was tilled shallow and seeded deep, the flax seed was placed into firmer untilled soil. This suggests flax emergence is more effective when the seed is placed in a firm seedbed.

Yield results in the seeding depth experiment were similar to those for emergence with some differences. Within years yield dropped significantly when the seeding depth was greater than 30 mm (Table 37). The difference is that the yield was typically highest at the 30 mm seeding depth which was not the case with emergence. The yield advantage which was created with shallow tillage over deep tillage was significant only in the 1990 crop year.

Table 36. Flax emergence (plants/m^2)* in seeding depth experiment (F4)

Treatment	1988	1989	1990	Years
10 mm Shallow	312a	413ab	294b	353a
10 mm Deep	302a	395b	324a	359a
30 mm Shallow	308a	421a	262c	341ab
30 mm Deep	281a	392bc	255c	324b
50 mm Shallow	234b	369cd	220d	294c
50 mm Deep	207b	356d	166e	261d
70 mm Shallow	90c	300e	126f	213e
70 mm Deep	80c	242f	45g	144f
Seeding Depth				
10 mm	307a	404a	309a	356a
30 mm	294a	406a	259b	332b
50 mm	220b	362b	193c	278c
70 mm	85c	271c	86d	178d
Tillage Depth				
Shallow	236a	376a	225a	301a
Deep	218b	346b	198b	272b

Table 37. Flax yield (kg/ha)* in seeding depth experiment (F4)

Treatment	1988	1989	1990	Years
10 mm Shallow	1687b	716ab	2205a	1536ab
10 mm Deep	1894ab	743a	2272a	1636a
30 mm Shallow	1936a	812a	2200a	1649a
30 mm Deep	2010a	685abc	2152ab	1616a
50 mm Shallow	1842ab	693abc	1962bc	1499b
50 mm Deep	1860ab	687abc	1845c	1461b
70 mm Shallow	1083c	535bc	1770c	1130c
70 mm Deep	989c	493c	1260d	914d
Seeding Depth				
10 mm	1790b	730a	2238a	1586a
30 mm	1973a	748a	2176a	1632a
50 mm	1851ab	690a	1903b	1481b
70 mm	1036c	514b	1515c	1022c
Tillage Depth				
Shallow	1637a	689a	2034a	1453a
Deep	1688a	652a	1882b	1407a

* values followed by same letter in a column are not significantly different at the α = 0.05 level.

3.1.3 Seedbed Characteristics and Crop Response

Aggregates

Canola emergence showed a trend in aggregate size distribution as illustrated in Figures 1, 2 and 3. The correlations were quite low (R^2 < 0.15) for pre-seeding tillage, pre-seeding packing and post-seeding packing experiments due to the spread in emergence data in the lower proportion range. However, a general trend of increasing emergence with an increase in the proportion of aggregates smaller than 4 mm at seed depth is noted.

Canola yield in 1989 and 1990 increased when the proportion of aggregates smaller than 4 mm increased in the pre-seeding tillage experiment but not in 1991. In the pre-seeding packing experiment canola yield followed the same trends as emergence. In the post-seeding packing experiment the correlation lines between canola yield and aggregates were flat. All three experiments on canola had low correlation (R^2 < 0.1) between aggregate size distribution and crop yield.

Flax emergence decreased in 1988 and 1989 as the proportion of small aggregates increased in the pre-seeding experiment (Figure 4), but increased in 1990. Flax emergence had decreasing trends as the proportion of small aggregates increased in both pre and post-seeding packing experiment in 1989 (Figures 5 and 6). In 1988 and 1990, the emergence data was quite spread around the correlation lines but tended to increase with higher percentage of aggregates < 4 mm. Emergence data in each year revealed low correlation coefficients (R^2 < 0.15).

Flax yield for the pre-seeding tillage experiment had an increasing trend with an increase in small aggregates in the seedbed for all years. The highest correlation was obtained with 1990 data (R^2 = 0.29). Flax yield was negatively related to small aggregates in the seedbed in the pre-seeding packing experiment. Yield in 1988 for the post-seeding packing experiment had an increasing trend with a higher correlation (R^2 = 0.52) while yield in 1989 and 1990 did not respond to the proportion of small aggregates.

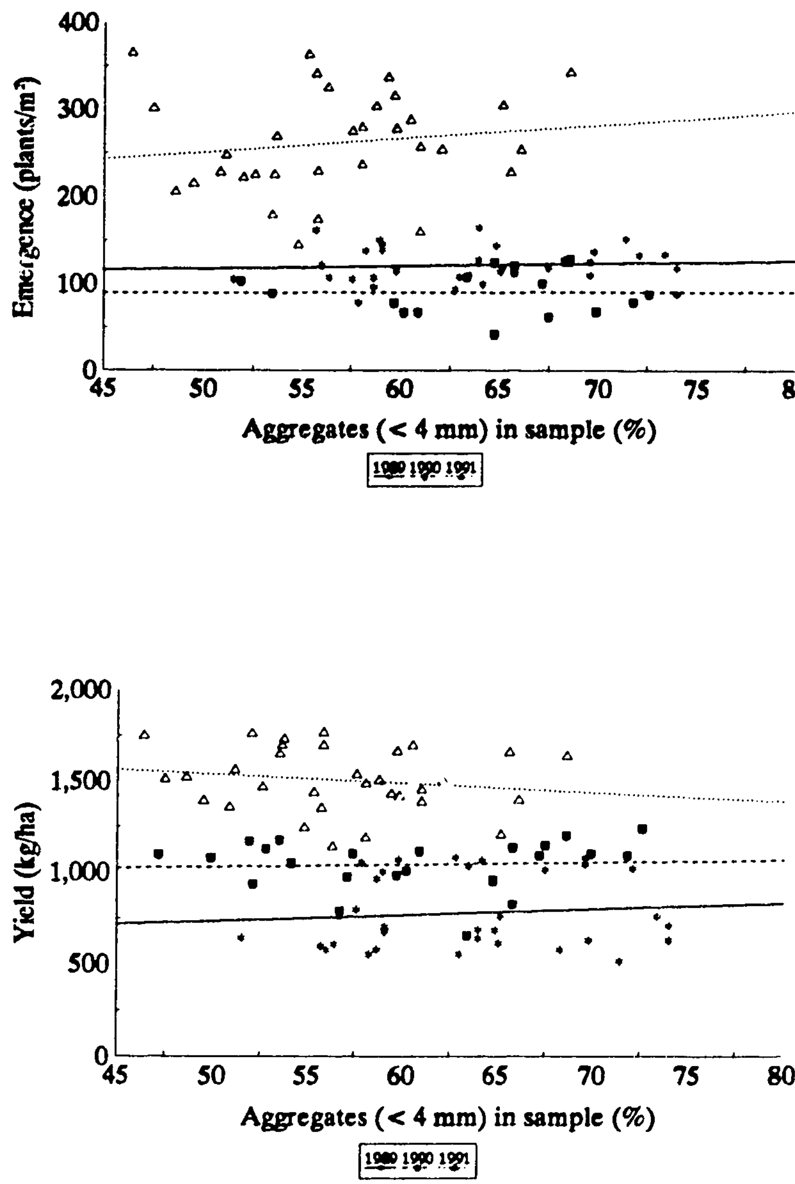
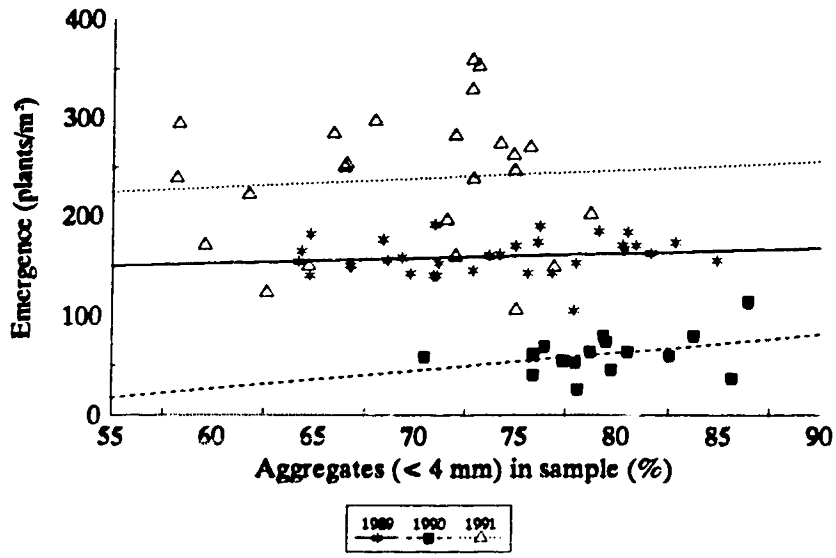


Figure 1. Canola emergence and yield as functions of aggregates in pre-seeding tillage experiment



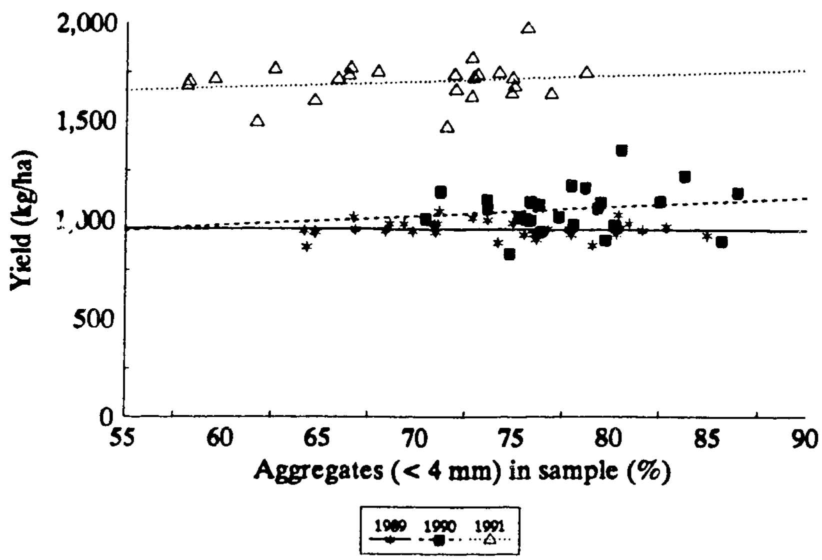
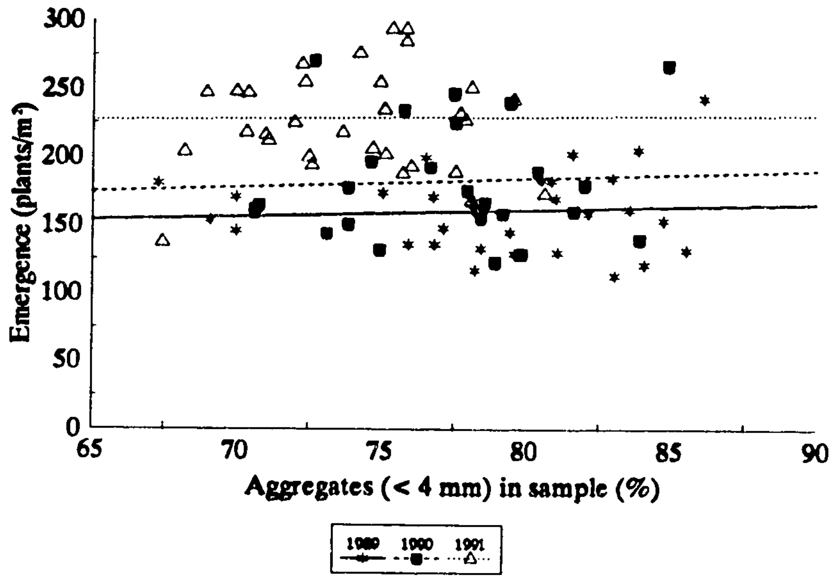


Figure 2. Canola emergence and yield as functions of aggregates in pre-seeding packing experiment



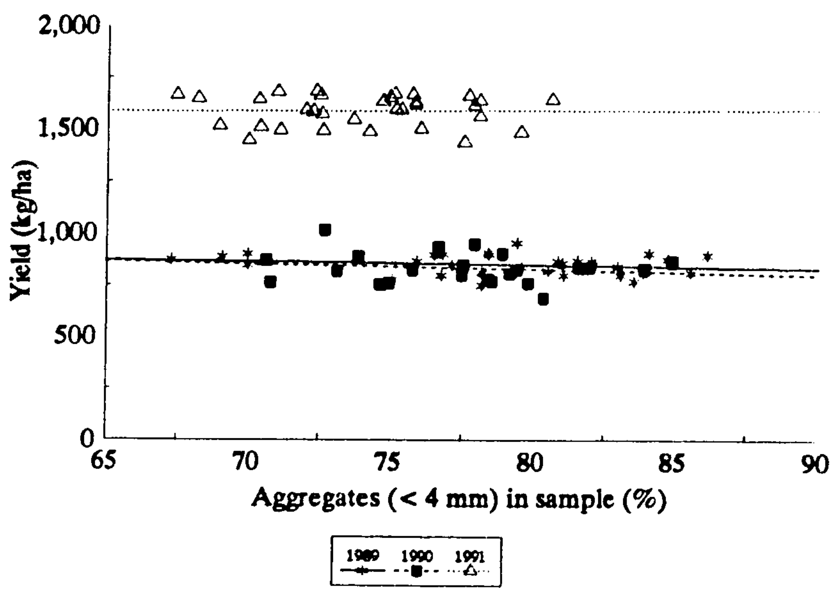


Figure 3. Canola emergence and yield as functions of aggregates in post-seeding packing experiment

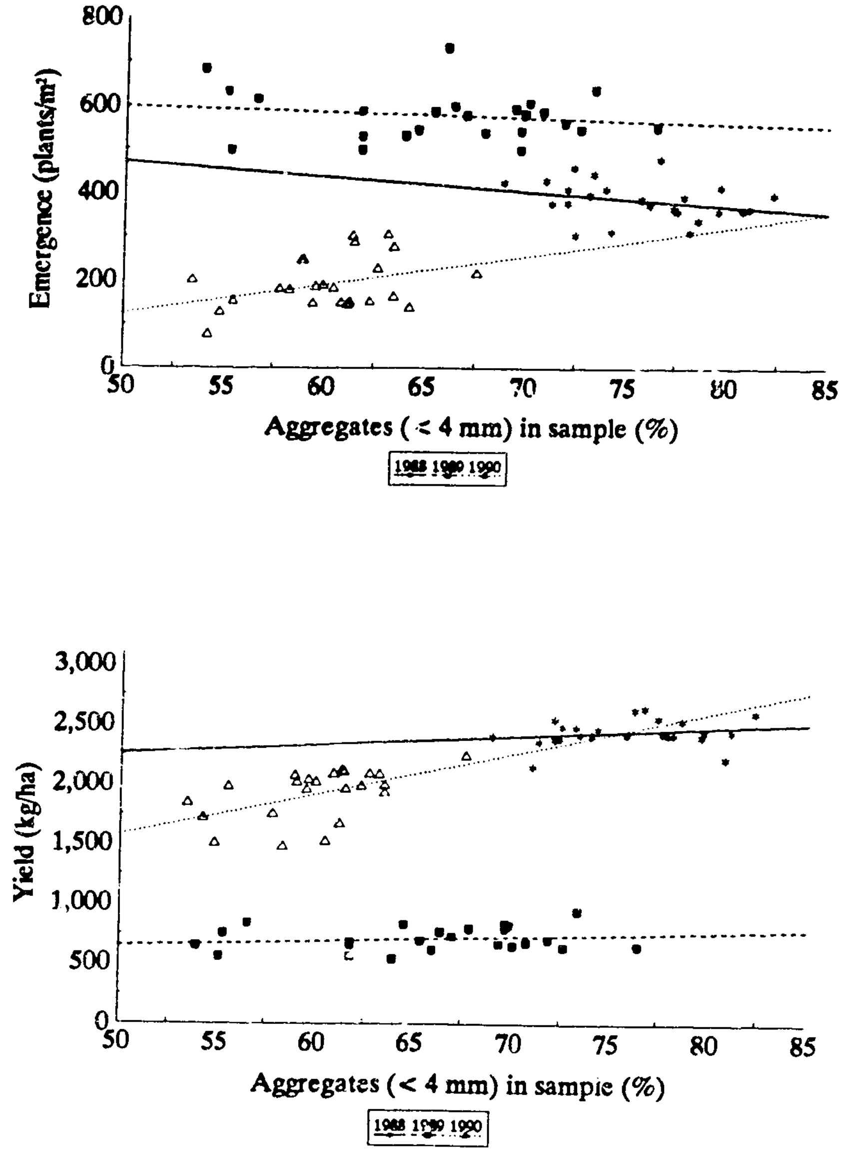


Figure 4. Flax emergence and yield as functions of aggregates in pre-seeding tillage experiment

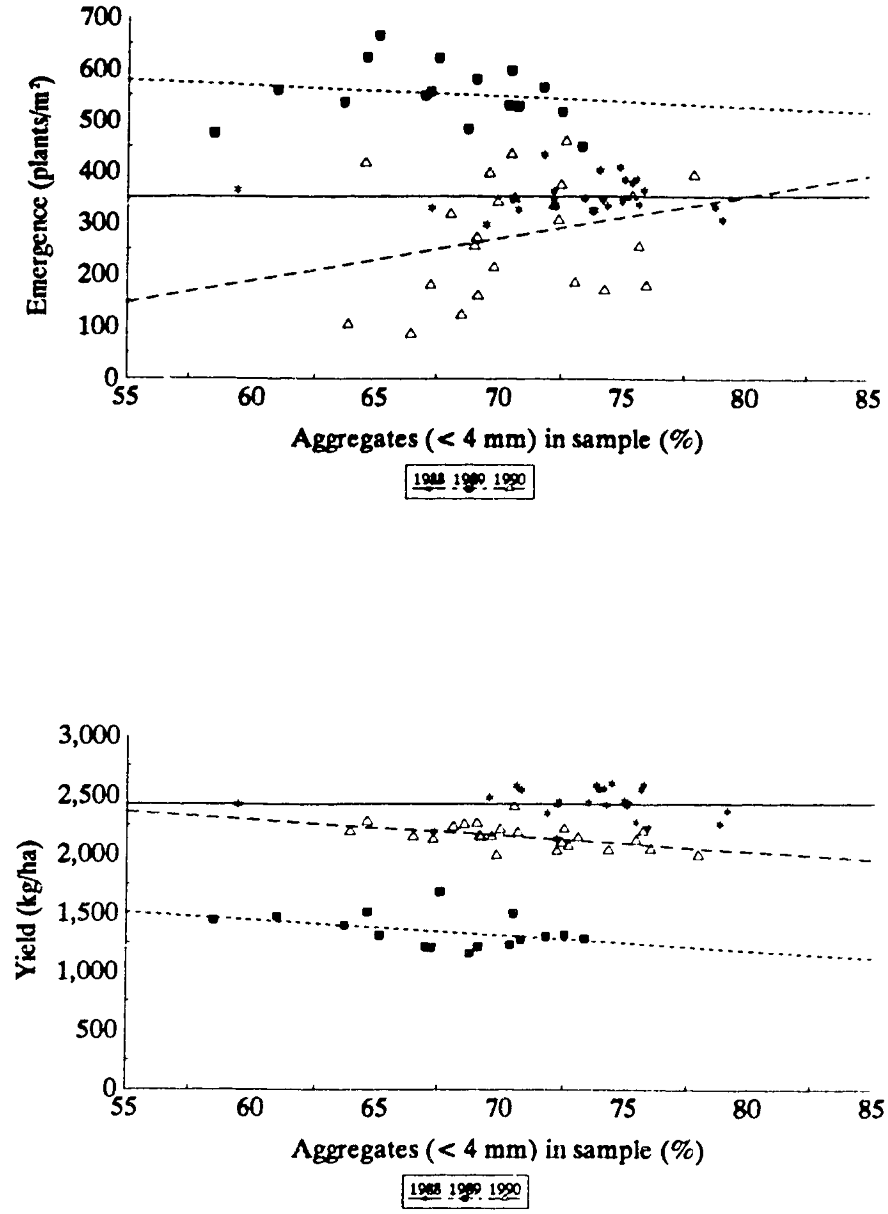
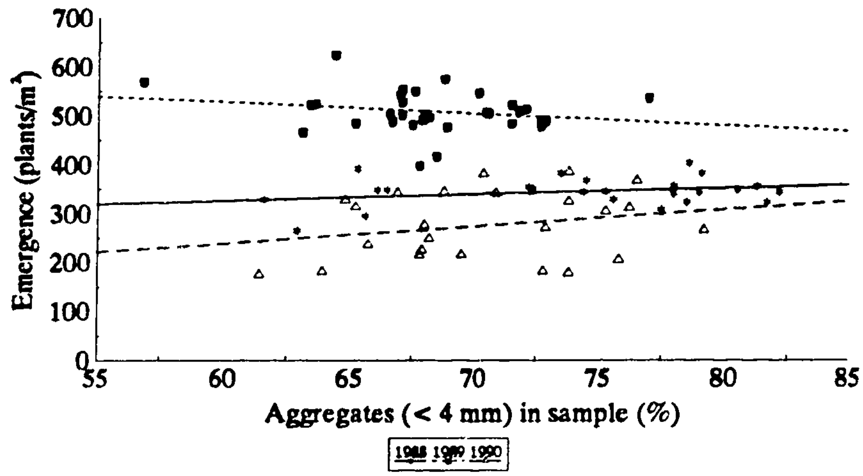


Figure 5. Flax emergence and yield as functions of aggregates in pre-seeding packing experiment



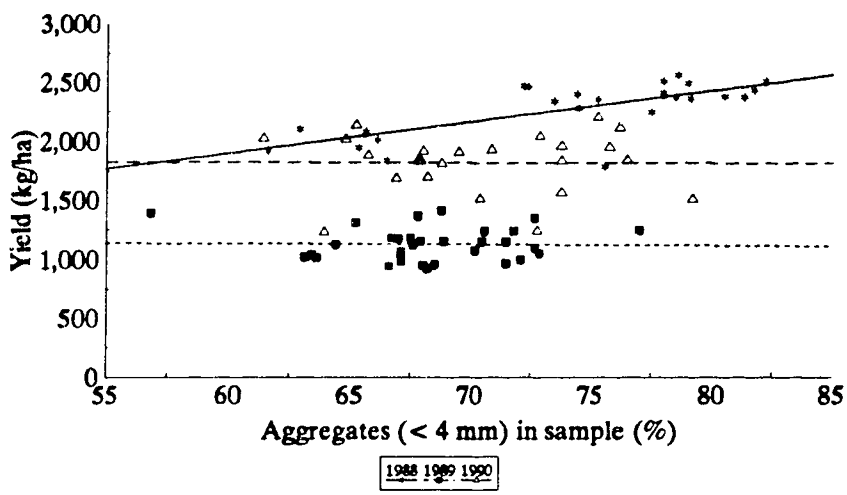
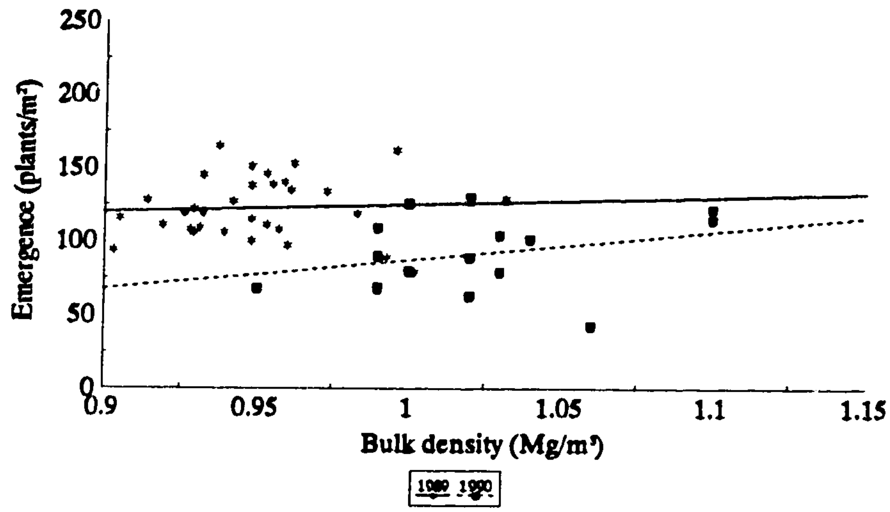


Figure 6. Flax emergence and yield as functions of aggregates in post-seeding packing experiment

Bulk Density

Figures 7, 8 and 9 show the relationship between canola emergence and yield and seedbed bulk density. For the pre-seeding tillage experiment, canola emergence increased with an increase in bulk density while canola yield had a decreasing trend. But correlations were very low ($R^2 < 0.1$). It was obvious that canola responded to bulk density with increases in both emergence and yield as bulk density increased in pre-seeding and post-seeding packing experiments. Higher correlation coefficients for canola emergence were noted in 1991 pre-seeding packing ($R^2 = 0.67$) and in 1990 pre-seeding and post-seeding packing ($R^2 = 0.21$). Canola yield only in post-seeding packing showed higher correlation ($R^2 = 0.37$ in 1990 and $R^2 = 0.3$ in 1991).

Compared to the results of canola, flax had some different responses to bulk density in the seedbed preparation experiments (Figures 10, 11 and 12). Flax emergence and yield in 1988 had an decreasing tendency while increasing correlation lines between flax emergence and yield and bulk density were found in 1989 for the pre-seeding tillage experiment. In the pre-seeding packing trial, flax yield decreased with an increase in bulk density while emergence increased. For both emergence and yield, correlation coefficients were very low ($R^2 < 0.1$). In post-seeding packing experiment, one year (1988) had an increasing trend and another year (1989) had a flat or slight decreasing line in emergence and yield when bulk density increased. Flax yield data in 1988 for the post-seeding packing had the highest correlation ($R^2 = 0.31$).



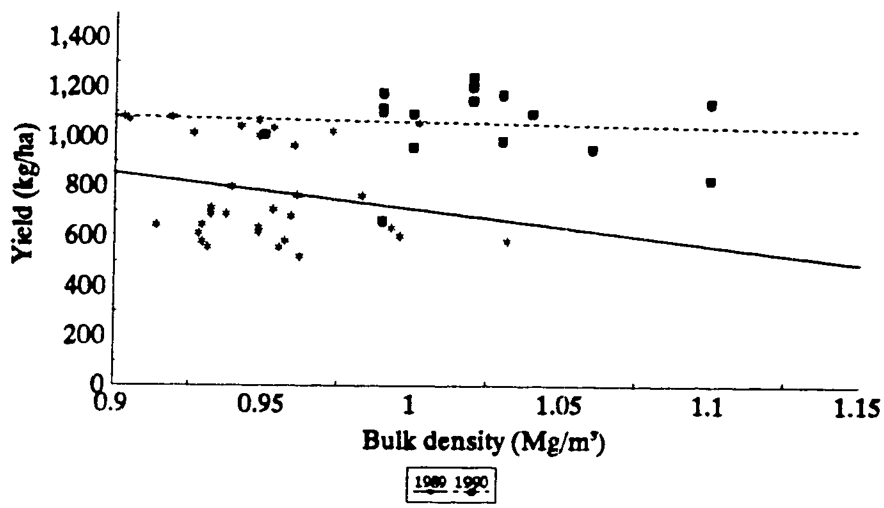
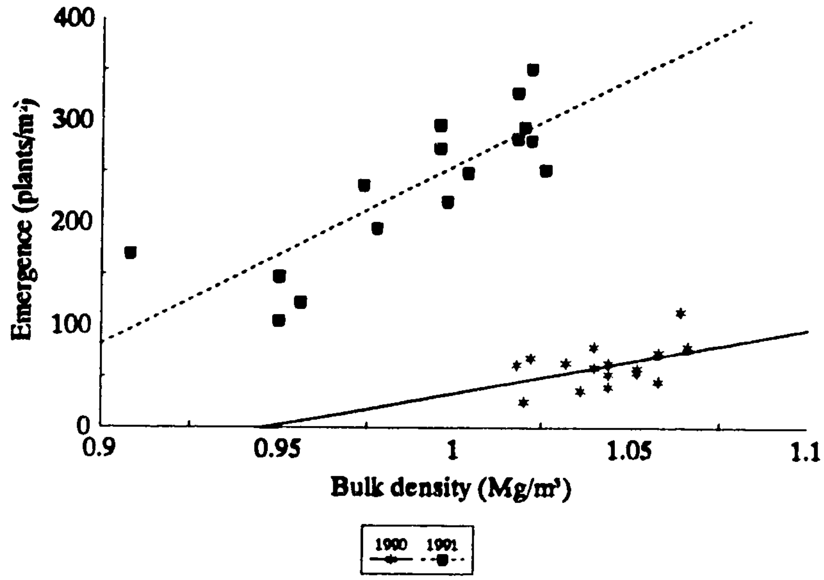


Figure 7. Canola emergence and yield as functions of bulk density in pre-seeding tillage experiment



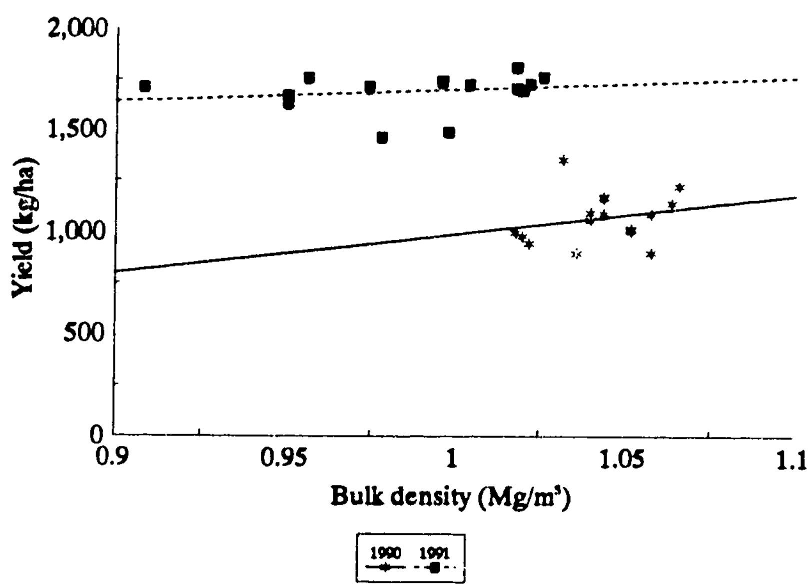


Figure 8. Canola emergence and yield as functions of bulk density in pre-seeding packing experiment

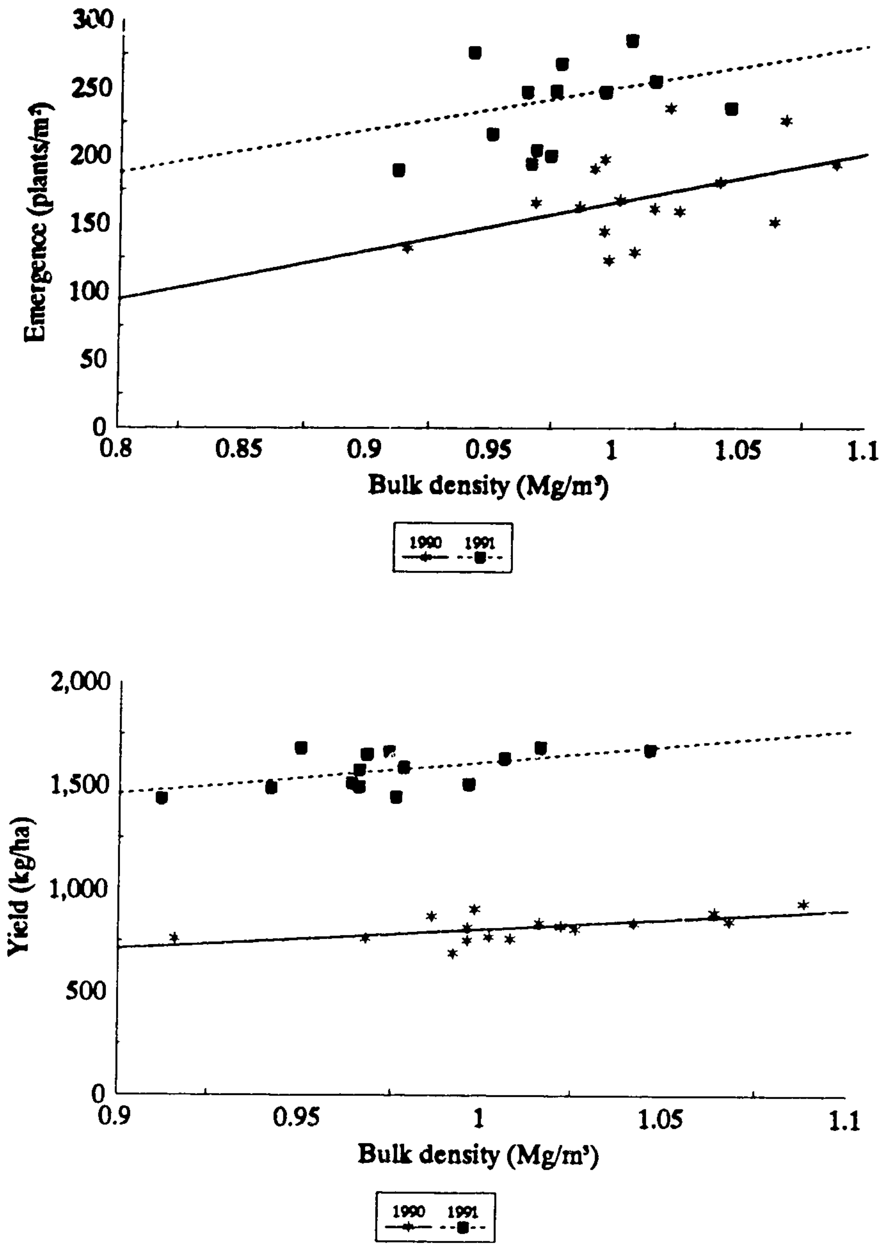
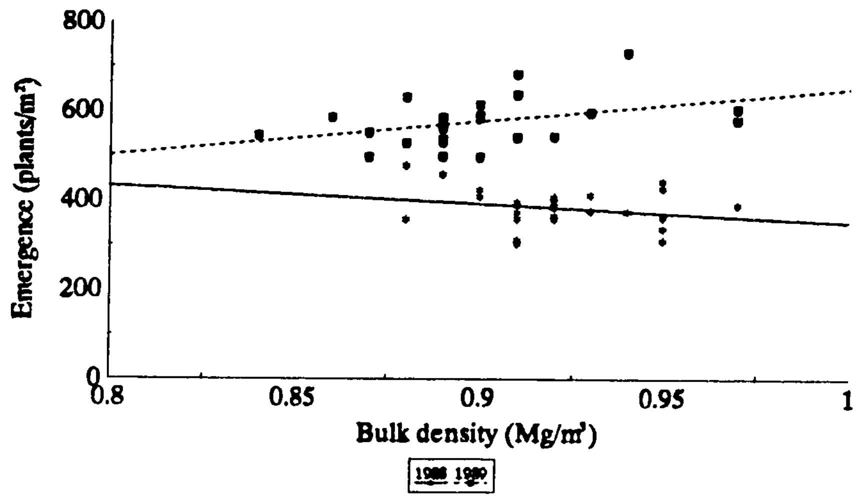


Figure 9. Canola emergence and yield as functions of bulk density in post-seeding packing experiment



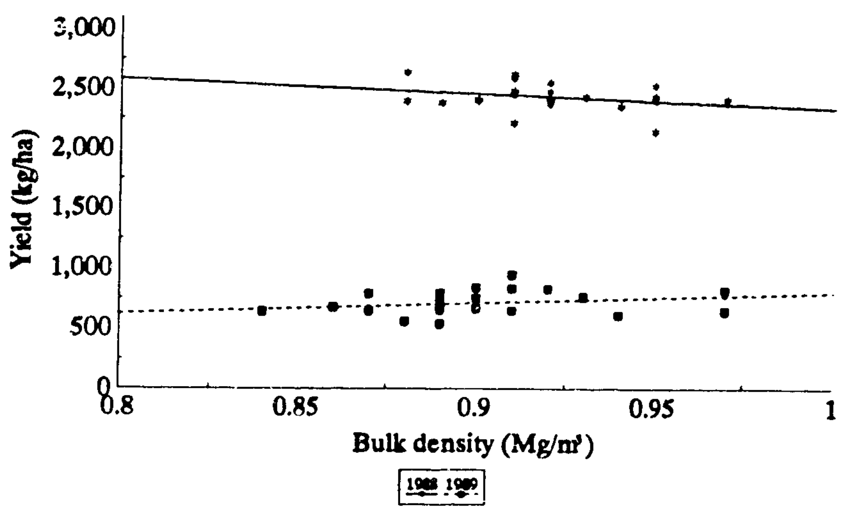
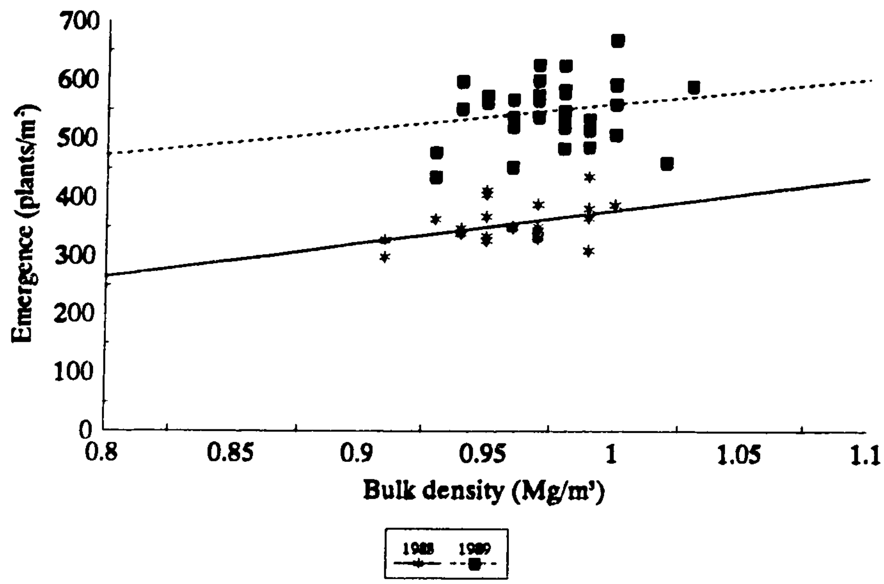


Figure 10. Flax emergence and yield as functions of bulk density in pre-seeding tillage experiment



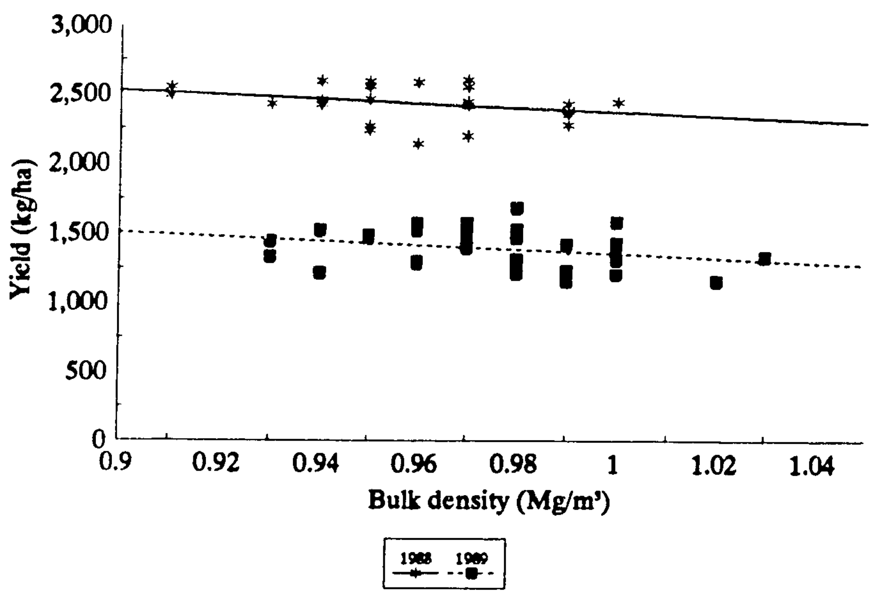


Figure 11. Flax emergence and yield as functions of bulk density in pre-seeding packing experiment

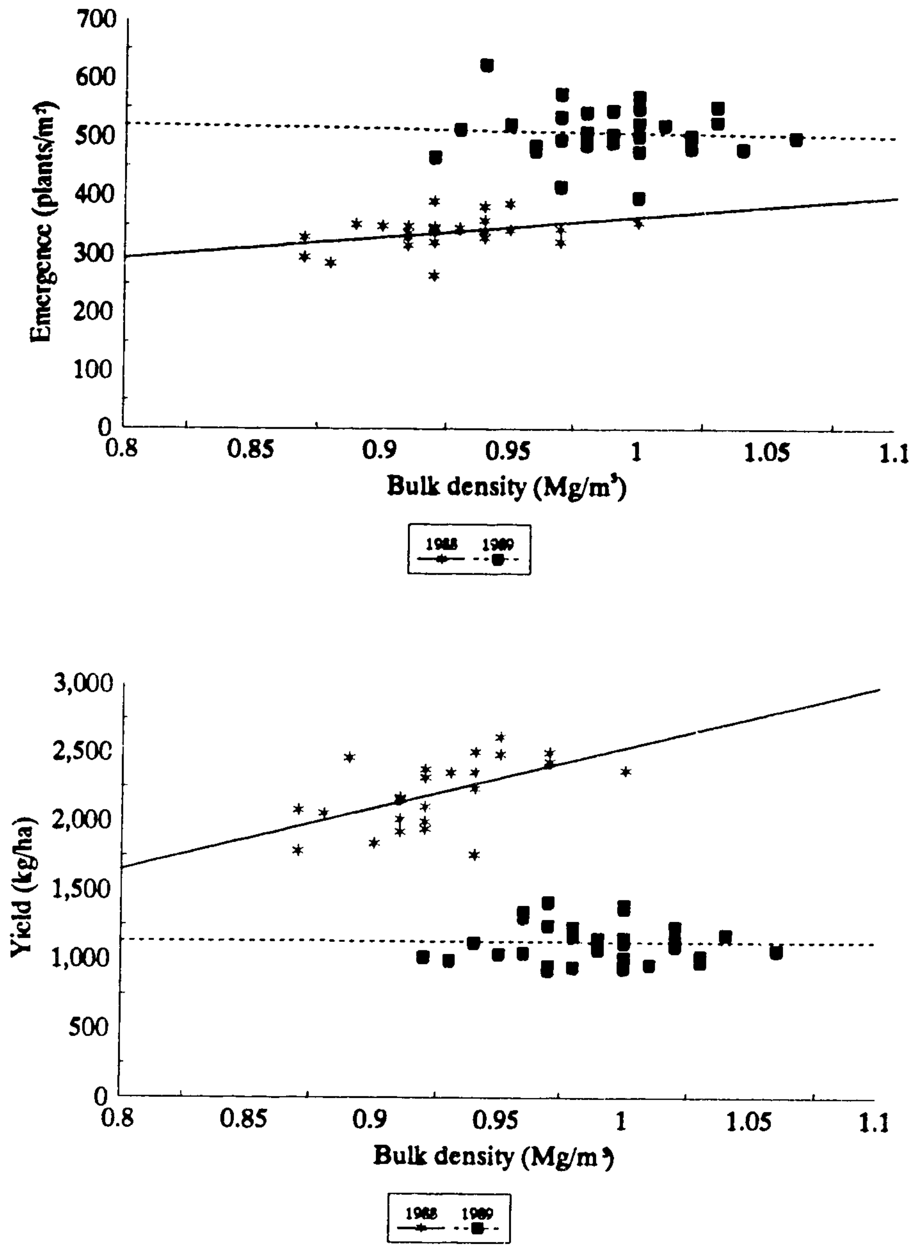


Figure 12. Flax emergence and yield as functions of bulk density in post-seeding packing experiment

3.1.4 Summary

The completed experiments of the pre-seeding tillage, pre-seeding packing, post-seeding packing and seeding depth show the importance of seedbed preparation and management on emergence and yield for small seed crops such as canola and flax.

Canola and flax will grow best if the seedbed is firm. This will allow for quick and uniform emergence against weed competition. A high proportion of aggregates < 4 mm at seeding depth will promote better seed-soil contact. This will result in optimum moisture transfer which in turn will lead to faster emergence and plant development. Emergence and yield for both canola and flax were depressed with seeding depths greater than 30 mm. Emergence of canola and flax respond favourably to pre-seeding packing. Pre-seeding packing is not as effective as the combination of pre and post-seeding packing in improving canola emergence. In terms of canola yield, pre-seeding packing is more beneficial than post-seeding packing. Flax does not respond to pre-seeding and post-seeding packing as much as canola with respect to improvement of yield.

3.2 Experiment II: Seedbed Survey for Canola in the Central Alberta Area

3.2.1 Sites and Canola Varieties

In 1990, 21 seedbeds on 14 farms were surveyed. Seventeen sites were rapa varieties and 4 sites were napus varieties. In 1991, the survey was expanded to 31 seedbeds on 21 farms. Fifteen sites contained the rapa variety while 16 sites had napus crops. In the 1992 growing season, 22 seedbeds on 16 farms and 2 seedbeds on the Ellerslie Research Station, University of Alberta were surveyed. Of the 24 sites surveyed, napus varieties were grown on 18 sites and rapa varieties were grown on 6 sites.

3.2.2 Tillage and Seeding Practices

In 1990, six of twenty-one sites had been summerfallowed the previous year. The others typically received one or two deep tillage passes in the fall. At two of the fields, nitrogen had been applied and in two other sites herbicides were incorporated in the fall. Spring tillage typically consisted of one or two shallow cultivations required for weed control, incorporation of herbicides, or nitrogen application. An air seeder was used at 12 of the fields, a double disk press drill at 5 of the sites, and a hoe drill at 4 locations. Seven fields received pre-seeding packing and all but 2 fields received post-seeding packing. The two fields that were not packed were harrowed after seeding.

In 1991, ten of the fields were summerfallowed and one no-till site was chem-fallowed. Twenty seven sites received at least one fall tillage operation. Eleven of 27 fields received fall fertilizer and/or herbicide application. Eighteen sites underwent spring tillage before seeding which consisted mainly of one or two cultivator passes at a depth of no more than 10 cm. The remaining fields were either cultivated at seeding time with an air seeder or direct drilled. Thirteen sites received a pre-seeding packing and 24 sites received a post-seeding packing operation. The most common seeder used was an air seeder which comprised 16 sites. Three sites were direct drilled. Seed broadcast and incorporation was utilized on 7 fields. Two sites were seeded with a double disc press drill and 3 sites were seeded with a hoe drill.

In 1992, 2 fields were summerfallow the previous growing season. Twenty three sites received at least one fall tillage operation and one site did not receive fall tillage. Tillage operations were mainly by heavy duty cultivator, vibrashank or double disc; in one instance fall ploughing was done. Five of the 24 sites received fall fertilizer and/or herbicide application. In spring seedbed preparation, all sites underwent tillage before seeding which mainly consisting of one or two passes of a field cultivator. Twenty sites received some form of pre-seeding packing treatment. Packing implements were mainly harrows attached to the cultivators. Twenty one sites received post-seeding packing which was accomplished by using harrows, harrowpackers and press wheels on seeders. An air seeder was used in 13 sites. Five sites were seeded with a double disc press drill and two sites were seeded with a hoe drill. Four sites utilized seed broadcast and incorporation operations. Fertilizer was applied on 22 fields and 16 fields received herbicide treatment.

3.2.3 Emergence Counts

Emergence counts varied widely (Tables 38, 39 and 40). In 1990, for rapa varieties, emergence counts ranged from 26 to 177 with an average of 86 plants/m^2 while napus had 60 to 105 with an average of 77 plants/m^2. In 1991, the 15 day emergence was higher for the rapa varieties than the napus varieties. By harvest, plant density for napus crops increased and decreased for rapa crops. Irrespective of this fact, the rapa crops still averaged a higher plant density at harvest. Both species were near the maximum-yield plant density outlined in the Alberta Agriculture publication, 'Canola Production in Alberta'. In 1992, overall, emergence counts varied from 58 to 187 plants/m^2 with an average of 120 plants/m^2. For rapa crops, the average emergence was 132 plants/m^2 which was higher than napus varieties with an average emergence of 116 plants/m^2.

The differences in plant densities are only arbitrary since canola can alter its' yield per plant if the plant densities are too high or low (Canola Council of Canada, 1984).

3.2.4 Crop Growing State

The survey over three years showed that most fields were in the 75 to 100% bloom stage. Six sites were in 65 to 75% bloom stage while only one site was less than 65% bloom. Canopy heights ranged from 0.7 to 1.6 m, averaging 1.1 m. Crop density varied from low to high. Low densities were attributed to late seeding dates and hot, dry mid-summer weather. Crop uniformity was quite variable from poor to excellent with some sites showing drowned out spots due to heavy early season rains. Thirty two percent of fields showed signs of weeds above the canopy. Twenty two percent of sites showed staghead or white rust.

Table 38. Summary of collected data from canola survey in 1990

Seedbed Data	Minimum	Maximum	Average
Seedbed Temperature (°C)	10	19	11
Surface Height Variation (cm)	1.5	5.7	3.3
Seedbed Depth (cm)	1.0	8.2	4.0
Seeding Depth (cm)	1.0	3.5	1.8
Aggregate Distribution (%vol)			
Top Layer (0-2 cm)			
> 9.5 mm	5%	46%	20%
4.76 - 9.5 mm	13%	26%	18%
< 4.76 mm	40%	80%	60%
Second Layer (2-4 cm)			
> 9.5 mm	2%	37%	11%
4.76 - 9.5 mm	11%	33%	20%
< 4.76 mm	46%	86%	69%
Soil Bulk Density (Mg/m^3)	1.04	1.34	1.17
Moisture Content (% dry basis)	21	39	29
Penetration Resistance (MPa)			
@ 5 cm soil depth	0.28	1.25	0.65
@ 10 cm soil depth	0.44	1.43	0.93
@ 20 cm soil depth	0.73	1.42	1.14

Crop Data		Minimum	Maximum	Average
30 Day Emergence	Rapa	26	177	86
($plants/m^2$)	Napus	60	105	77
Survey Yield (kg/ha)	Rapa	940	2690	1658
	Napus	1750	3050	2298
Producer Yield (kg/ha)	Rapa	448	2410	1536
	Napus	1401	2803	2175

Table 39. Summary of collected data from canola survey in 1991

Seedbed Data		Minimum	Maximum	Average
Seedbed Temperature (^oC)		11	21	15
Surface Height Variation (cm)		1.3	8.3	5.0
Seedbed Depth (cm)		1.3	7.0	3.5
Seeding Depth (cm)		1.1	3.1	2.1
Vegetative Cover (%)		0	53	18.2
Aggregate Distribution (%vol)				
Top Layer (0-2 cm)				
> 9.5 mm		3%	49%	17%
4.76 - 9.5 mm		3%	19%	15%
< 4.76 mm		36%	93%	68%
Second Layer (2-4 cm)				
> 9.5 mm		3%	28%	12%
4.76 - 9.5 mm		8%	27%	16%
< 4.76 mm		54%	88%	72%
Soil Bulk Density (Mg/m^3)		0.99	1.46	1.15
Moisture Content (% dry basis)		10.1	41.4	26.8
Moisture Content Below Seed (% dry basis)		10.1	42.7	30.1
Field Capacity (% dry basis)		7.9	44.5	31.7
Wilting Point (% dry basis)		4.2	22.7	15.0
Organic Matter (% dry basis)		1.6	11.9	7.2
Penetration Resistance (MPa)				
@ 5 cm soil depth		0.25	1.39	0.68
@ 10 cm soil depth		0.40	1.59	1.02
@ 20 cm soil depth		0.69	1.60	1.22
Crop Data		Minimum	Maximum	Average
30 Day Emergence ($plants/m^2$)	Rapa	11	174	116
	Napus	22	123	79
Plant Density @ Harvest ($plants/m^2$)	Rapa	35	142	107
	Napus	55	142	90
Survey Yield (kg/ha)	Rapa	778	2444	1829
	Napus	958	2796	2011
Producer Yield (kg/ha)	Rapa	1120	2241	1726
	Napus	952	2801	2105

Table 40. Summary of collected data from canola survey in 1992

Seedbed Data	Minimum	Maximum	Average
Seedbed Temperature (°C)	6	18	13
Surface Height Variation (cm)	2.3	5.0	3.8
Seedbed Depth (cm)	4.4	8.2	5.9
Seeding Depth (cm)	1.2	3.0	2.1
Aggregate Distribution (%vol)			
Top Layer (0-2 cm)			
> 9.5 mm	8%	34%	20%
4.76-9.5 mm	8%	16%	13%
< 4.76 mm	54%	83%	67%
Second Layer (2-4 cm)			
> 9.5 mm	5%	23%	14%
4.76-9.5 mm	9%	19%	14%
< 4.76 mm	63%	86%	73%
Soil Bulk Density (Mg/m^3)	0.97	1.19	1.07
Moisture Content (% dry basis)	19.1	29.8	23.9
Penetration Resistance (MPa)			
@ 5 cm soil depth	0.39	1.36	0.67
@ 10 cm soil depth	0.64	1.56	1.06
@ 20 cm soil depth	0.96	1.59	1.32

Crop Data		Minimum	Maximum	Average
30 Day Emergence	Rapa	58	187	132
(plants/m^2)	Napus	59	169	116
Survey Yield (kg/ha)	Rapa	1545	3116	2215
	Napus	1489	2810	2229
Producer Yield (kg/ha)	Rapa	1626	2635	1887
	Napus	1009	2410	1767

3.2.5 Yield Determination

In 1990, overall, yield ranged from 940 to 3050 kg/ha, averaging 1786 kg/ha (Tables 38, 39 and 40). For rapa, yields were in range of 940 to 2690 kg/ha with an average of 1658 kg/ha while napus varieties had yields ranging from 1750 to 3050 kg/ha with an average of 2298 kg/ha. The yield for one field was not used for data analysis because it was unacceptably high: 4300 kg/ha. In 1991, rapa varieties had a yield ranging from 778 to 2444 kg/ha with an average yield of 1289 kg/ha. Napus varieties yielded from 958 to 2796 kg/ha with an average yield of 2011 kg/ha. Yield data in 1992 had the following breakdown: rapa varieties with an average of 2215 kg/ha and napus varieties with an average of 2229 kg/ha. Overall, average yield was 2225 kg/ha. Napus varieties had higher yield than rapa varieties.

For both species, the maximum and minimum yields varied from low to high, partially due to regional moisture conditions. Pests and crop disease (due to high early season moisture), armyworms and reported cases of sclerotinia contributed to yield depressions.

3.2.6 Correlation between Seedbed Characteristics and Crop Response

Aggregates

Seedbed properties were analyzed for rapa and napus varieties based on the data in each year because weather conditions were different between years. Yield and emergence were each correlated with aggregate size distribution, bulk density, seeding depth, seedbed depth and surface roughness.

In most cases, canola yield and emergence responded negatively to an increase in aggregates larger than 9.5 mm in the seedbed soil (Figure 13 and Figure 14). There were large variations between years and varieties. For rapa varieties, emergence showed a decreasing trend with an increase in proportion of larger aggregates (>9.5 mm) in the seedbed. The highest correlation ($R^2 = 0.46$) was found in the emergence data in 1991. A decreasing line ($R^2 = 0.26$) for yield in 1990 paralleled the decreasing emergence count. Emergence data in 1992 did not follow the same trend. However, yield had a slight decrease with an increase in proportion of aggregates larger than 9.5 mm. Both correlations for emergence and yield were low (R^2 = 0.11 and R^2 = 0.0006). For napus varieties, only 1990 emergence data indicated a decrease with an increase in large aggregates (> 9.5 mm) in the soil. The survey in both 1991 and 1992 did not show decreasing trends of emergence for napus. Yield results from each year had a decreasing tendency but all correlations were very low (R^2 < 0.15).

Conversely, as shown in Figure 15 and Figure 16, increasing proportion of aggregates smaller than 4.76 mm in the seedbed generally resulted in increases in canola yield. Emergence was quite variable. Increasing lines were noted with emergence data of 1990 and 1991 rapa and 1990 napus. Negative correlations were found between emergence and aggregates (< 4.76 mm) in 1992 for both rapa and napus and in 1991 for napus. Emergence for rapa varieties in 1990 and 1991 had higher correlations (R^2 = 0.23 and R^2 = 0.37). The correlation between yield and aggregates (< 4.76 mm) in 1990 was the highest (R^2 = 0.43) while the rest were low (R^2 < 0.1). For napus varieties, data in 1990 had higher correlation (yield R^2 = 0.53, emergence R^2 = 0.6) though fewer seedbeds were investigated. Others showed even low correlations.

The changes in canola emergence and yield with the changes in seedbed aggregate size distribution can be attributed to the fact that an increase in aggregates smaller than 4.76 mm or a decrease in aggregates larger than 9.5 mm will increase seed-soil contact and evaporation control in the early time of seed emergence and benefit canola growth throughout whole crop season. A decrease in emergence was not always followed by a decrease in yield. Since canola has the ability to compensate itself through the growing season, the yield still showed an increasing trend.

Bulk Density

Bulk density representing the state of packing on the seedbed had conflicting effects on canola yield (Figure 17 and Figure 18). Yield showed a general decreasing response to bulk density for both rapa and napus varieties in 1990 and 1991. However, yields in 1992 showed increasing trends. In 1990 and 1991 canola seedbeds surveyed for rapa varieties were in the higher range of density from 1 to 1.26 Mg/m^3. In this range, canola yields showed decreasing responses but correlation coefficients were very low (R^2 < 0.15). In 1992, the bulk density was in the low range from 0.97 to 1.14 Mg/m^3 in which canola had an increasing yield corresponding to an increase in bulk density (R^2 = 0.82). Comparing the results of napus to that of rapa, 1990 and 1991 seedbed for napus had the higher bulk density (1.04-1.46 Mg/m^3). In this range napus yield showed similar results to rapa and the 1990 napus yield had a higher negative correlation with R^2 = 0.44. Again in 1992 bulk density data were collected in a low range from 1.02 to 1.19 Mg/m^3 in which canola yield showed an increasing response (R^2 = 0.15). Canola yield was the highest when the bulk density was around 1.15 Mg/m^3 except for 1991 rapa. This might be explained by the fact that there is an optimum degree of compaction. The correlation for canola emergence versus bulk density for rapa and napus varieties appeared quite low in most cases. Only 1990 napus had a decreasing emergence line with a higher correlation coefficient (R^2 = 0.45).

Seeding Depth

The effects of seeding depth on canola emergence and yield were variable. As shown in Figure 19, 1990 and 1991 rapa varieties had decreasing emergence and yield with increases in seeding depth but the correlations were low (R^2 < 0.3). In 1992, canola had an increasing trend in emergence and yield and the correlation coefficient of emergence was higher (R^2 = 0.51). For napus varieties, the correlations were very low (R^2 < 0.1) although some decreasing trends of emergence were noted in 1990 and 1992 (Figure 20). The napus varieties bore a flat trend in yield-seeding depth comparisons. This can be attributed to the fact the napus varieties were sown over a shallower depth range than the rapa varieties.

Seedbed Depth

Emergence and yield were affected by the depth of seedbed. Over all, seedbeds were tilled deeper for rapa than for napus varieties. For rapa varieties, emergence counts in 1990 and 1991 had decreasing trends with correlation coefficients of R^2 = 0.11 and R^2 = 0.31 (Figure 21). Similar to the analysis of emergence on seeding depth, as the tillage depth increased, emergence increased in 1992 with the highest correlation coefficient (R^2 = 0.32). The relationship between yield and seedbed depth showed a decreasing line with the highest correlation in 1990 (R^2 = 0.37). But 1991 and 1992 data had very low linear relation (R^2 < 0.1). However, the higher yield occurred in the range of seedbed depth from 4 to 6.5 cm. For napus varieties, seedbeds were not tilled as deep as rapa (Figure 22). Only in 1991 did napus show a tendency for yield to decrease with an increase in seedbed depth but all correlations were very low (R^2 < 0.1). Emergence counts were flat lines corresponding to seedbed depth with low correlation. The reason for low emergence with increased tillage depth may be due to the fact that shallow seeded canola was not close enough to the bottom of the seedbed to utilize the available moisture.

Surface Roughness

Canola responded to soil surface roughness differently for rapa and napus varieties as illustrated in Figure 23 and Figure 24. For rapa varieties, as surface roughness increased, emergence decreased. Higher correlations were in 1990 and 1992 (R^2 = 0.21 and R^2 = 0.36). Yield in 1990 had a decreasing trend when surface heights varied from 1.5 to 6 cm (R^2 = 0.37) but yield in 1992 increased with an increase in surface roughness in the range from 2.3 to 3.7 cm (R^2 = 0.27). For napus varieties, emergence in each year increased with increased surface roughness but yield decreased. Only yield in 1990 had an increasing trend along with the emergence line when surface roughness was in a range lower than 4 cm (R^2 = 0.7 for yield, R^2 = 0.66 for emergence). The factor causing decreasing yield with an increase in surface roughness was probably due to the fact that larger aggregates (>9.5 mm) in the soil surface increased the surface roughness.

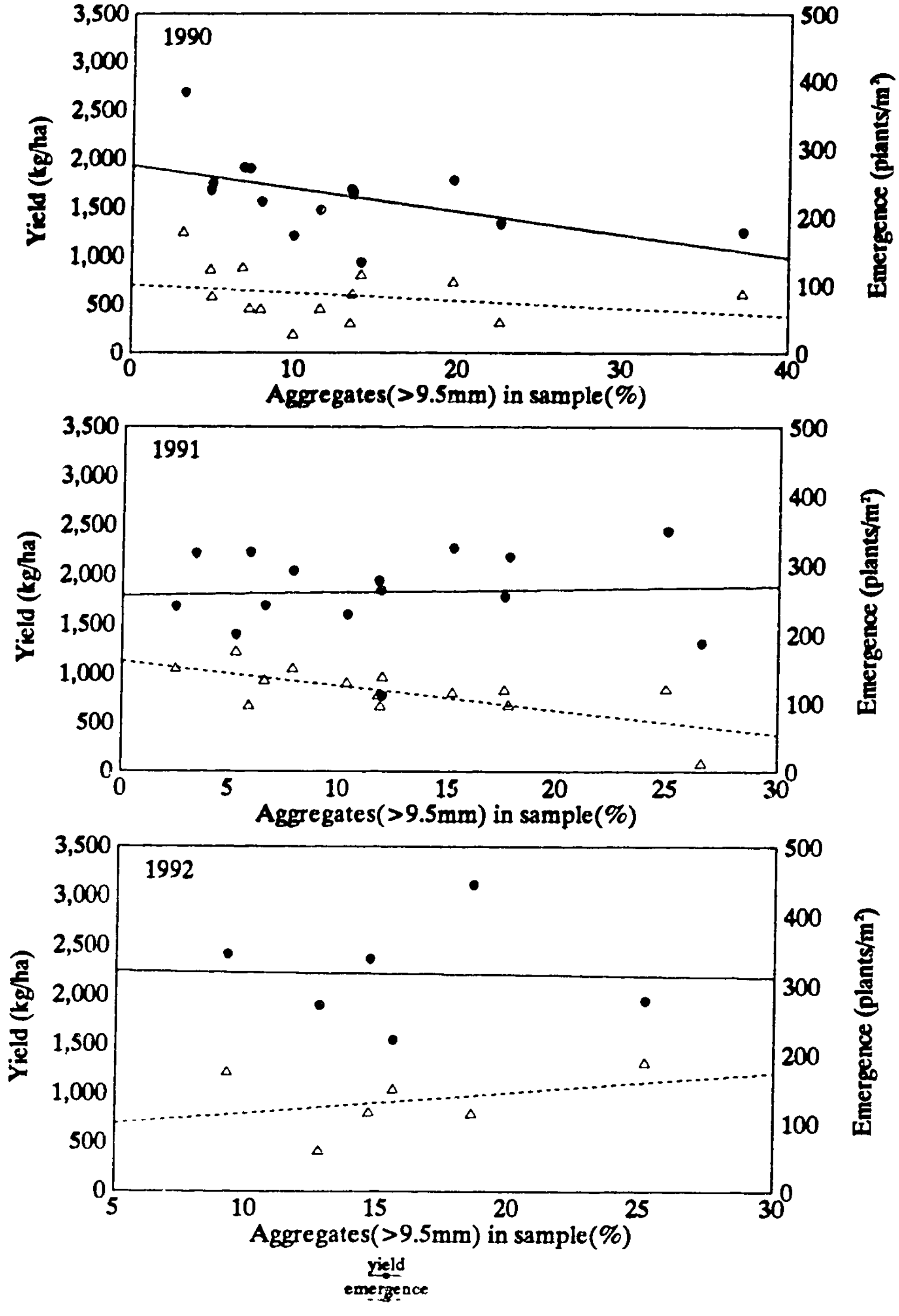


Figure 13. Emergence and yield vs aggregates (>9.5 mm) for rapa variety

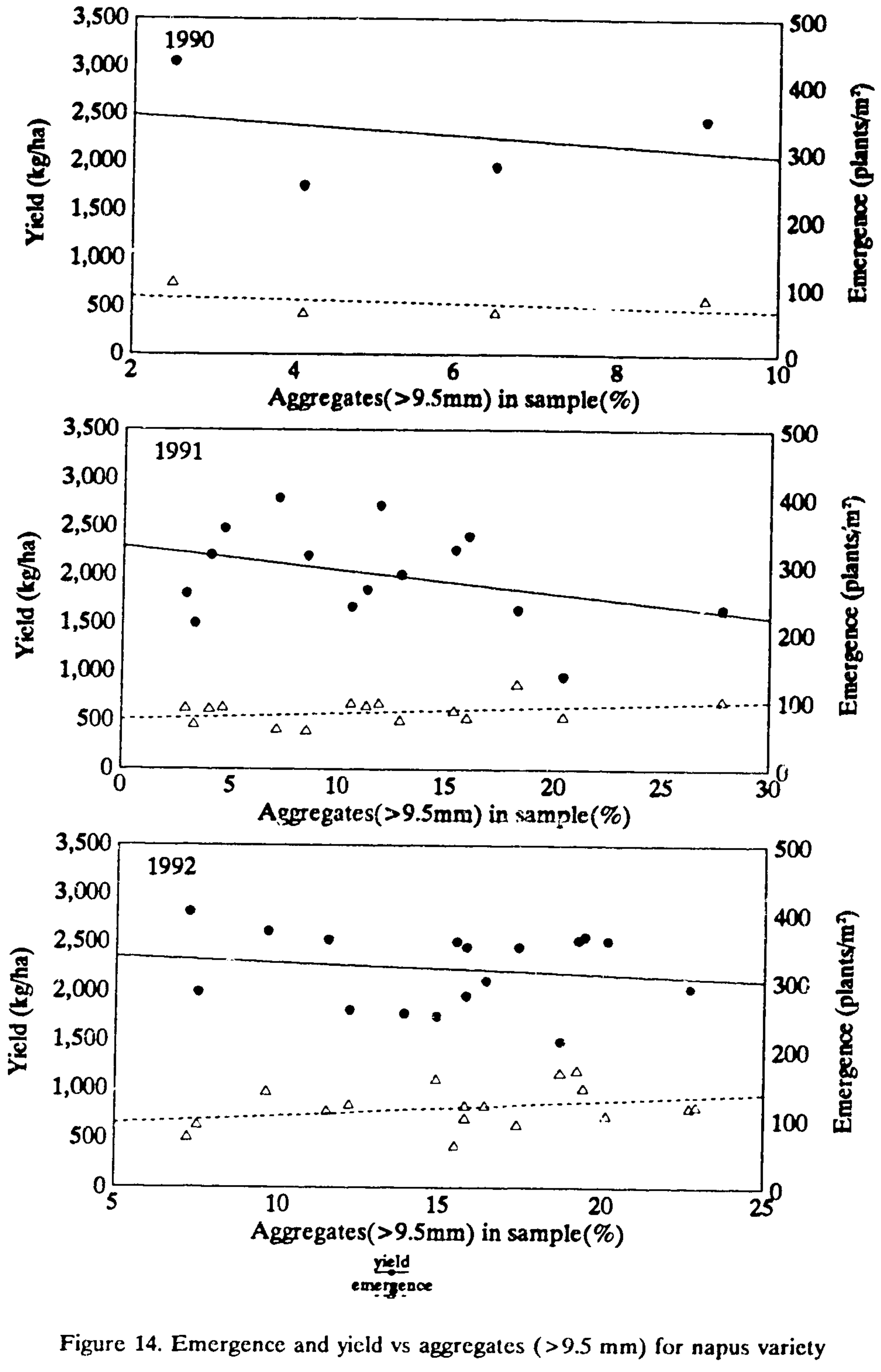


Figure 14. Emergence and yield vs aggregates (>9.5 mm) for napus variety

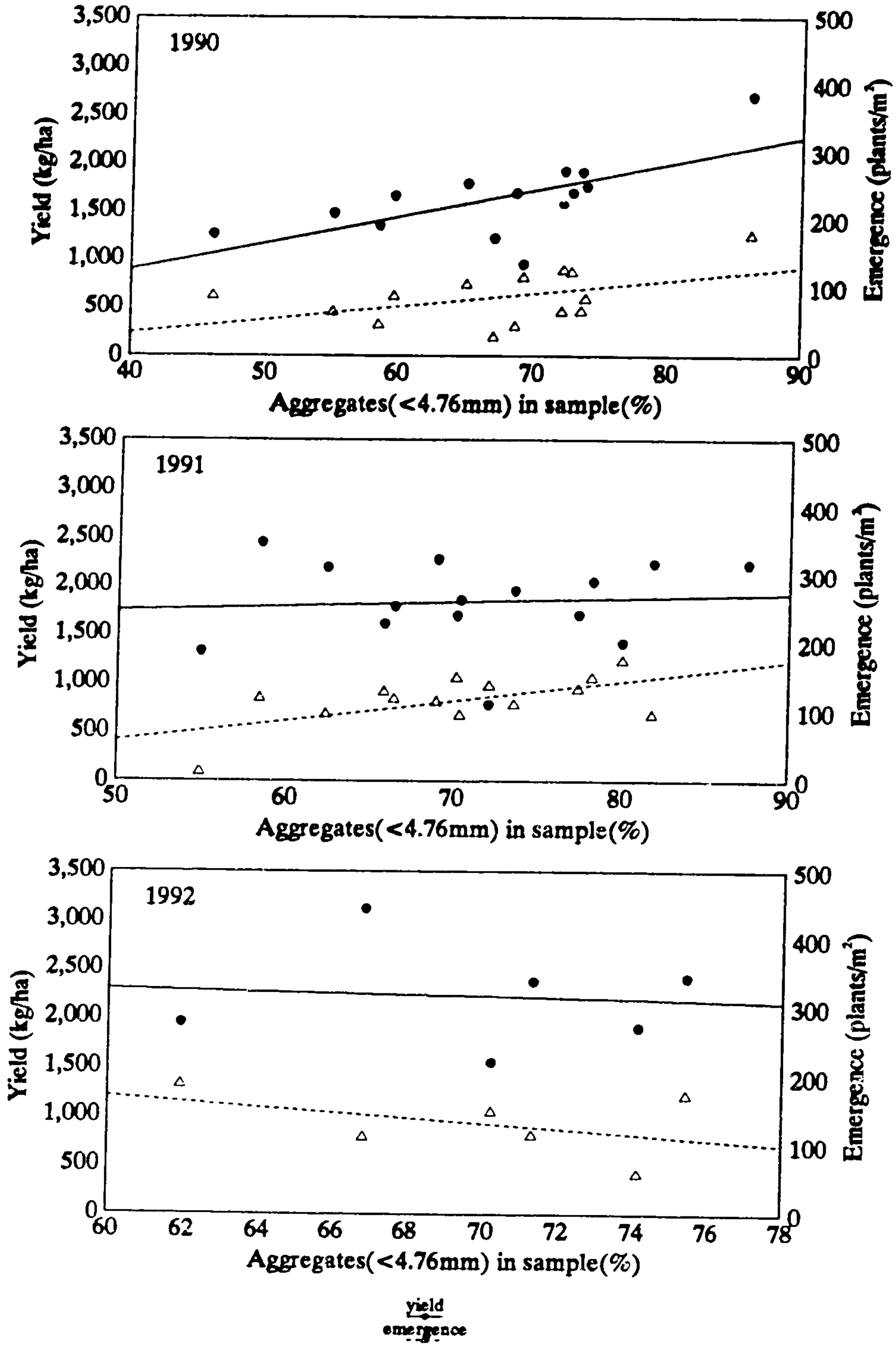


Figure 15. Emergence and yield vs aggregates (< 4.76 mm) for rapa variety

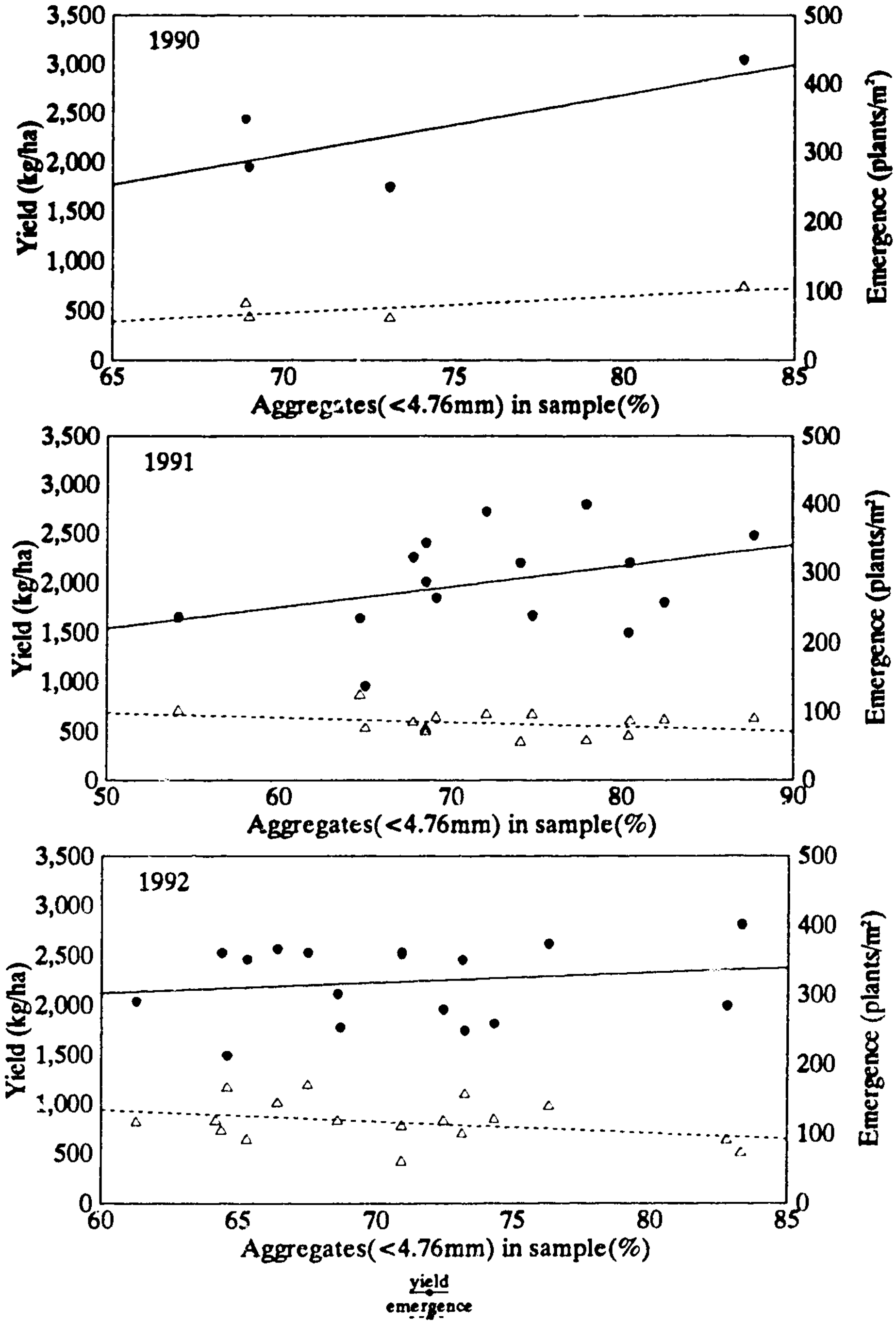


Figure 16. Emergence and yield vs aggregates (< 4.76 mm) for napus variety

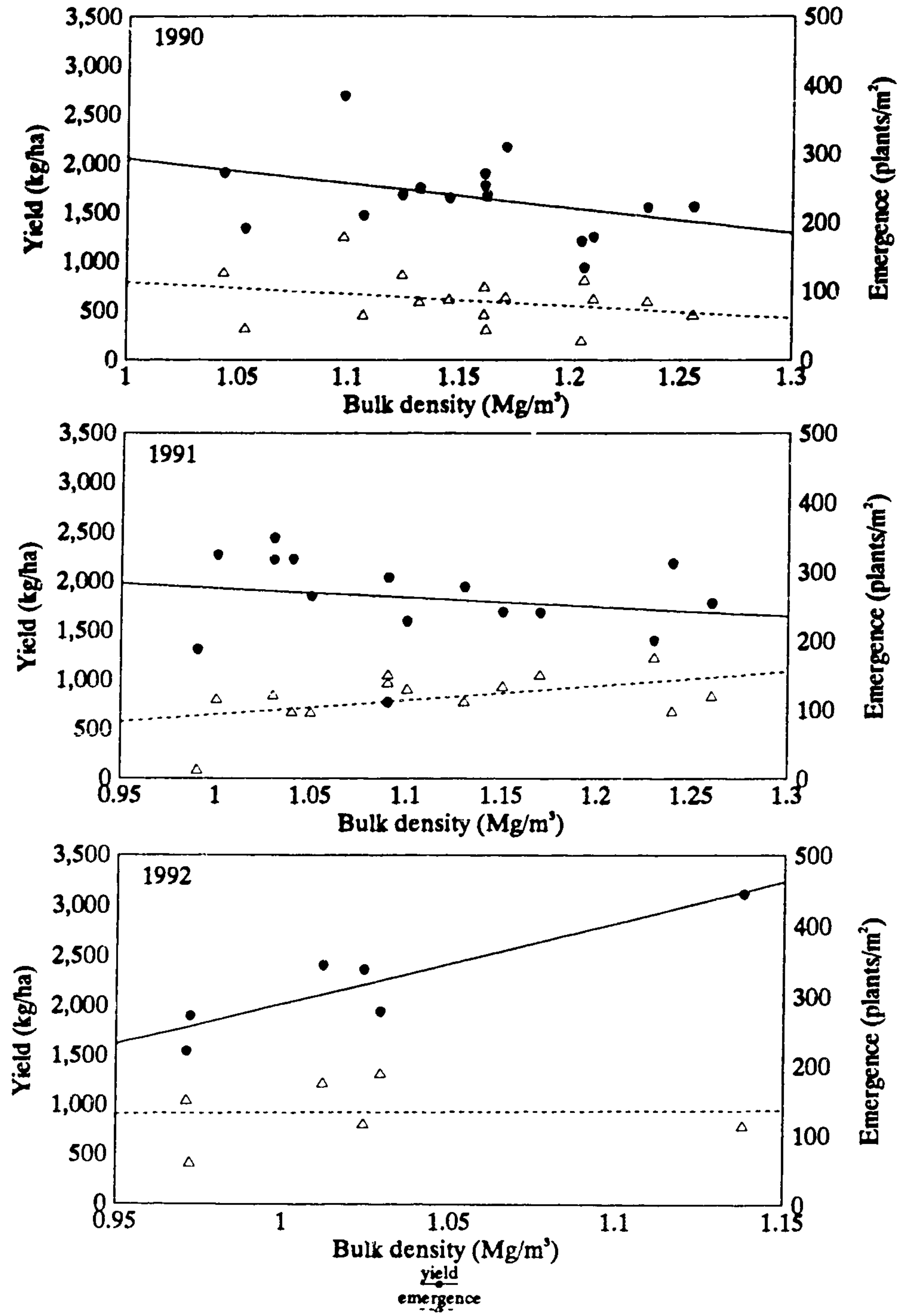


Figure 17. Emergence and yield vs bulk density for rapa variety

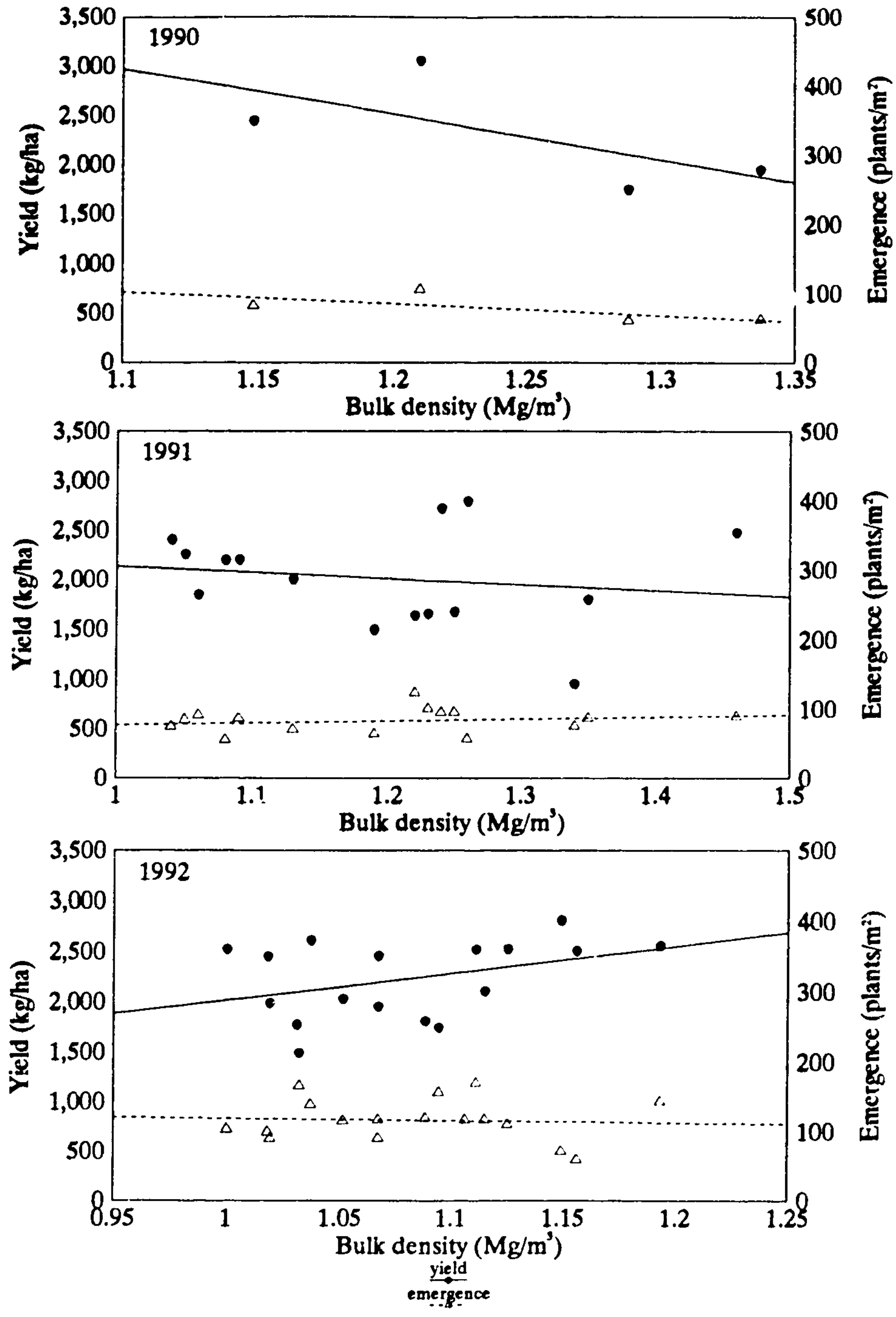


Figure 18. Emergence and yield vs bulk density for napus variety

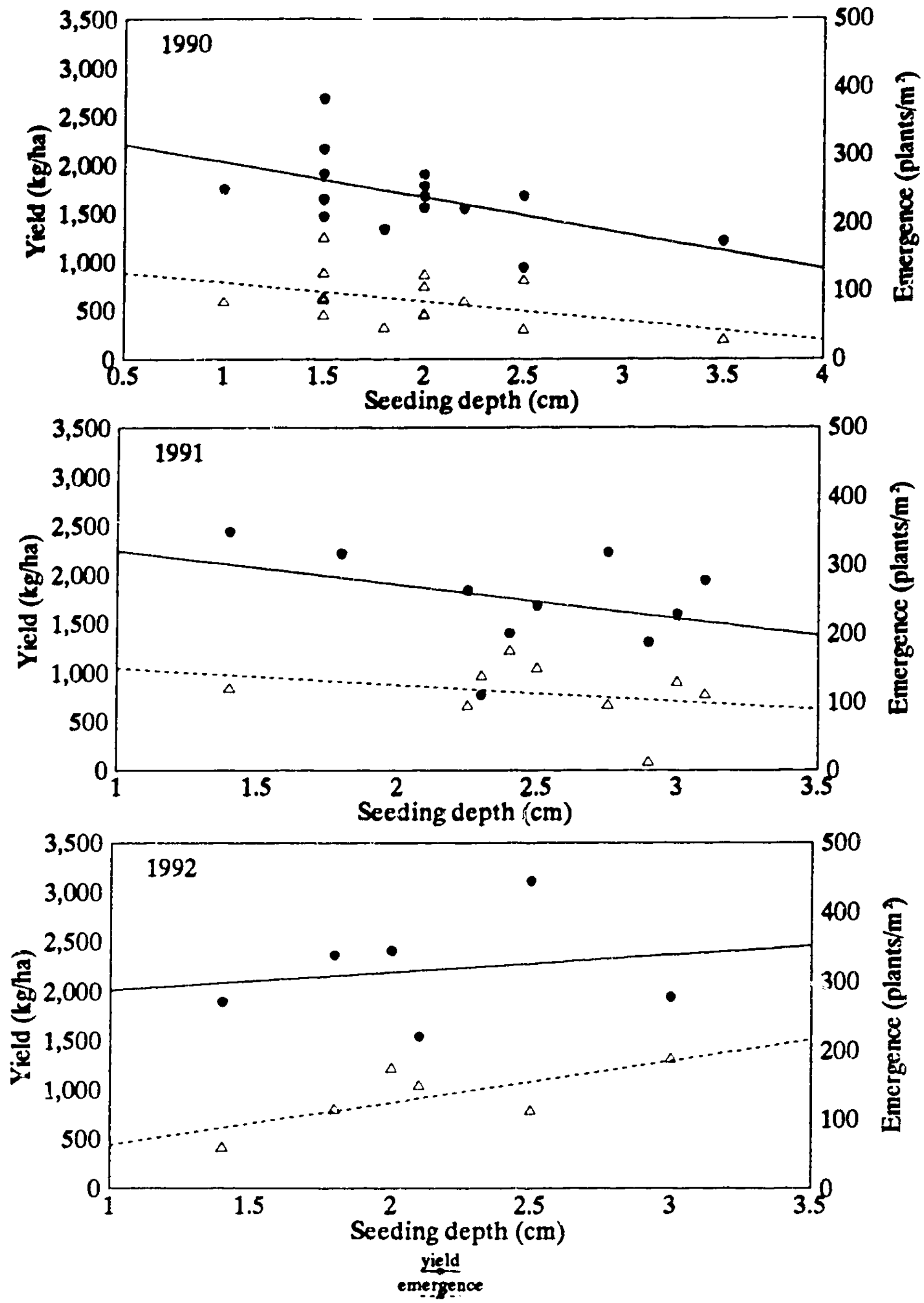


Figure 19. Emergence and yield vs seeding depth for rapa variety

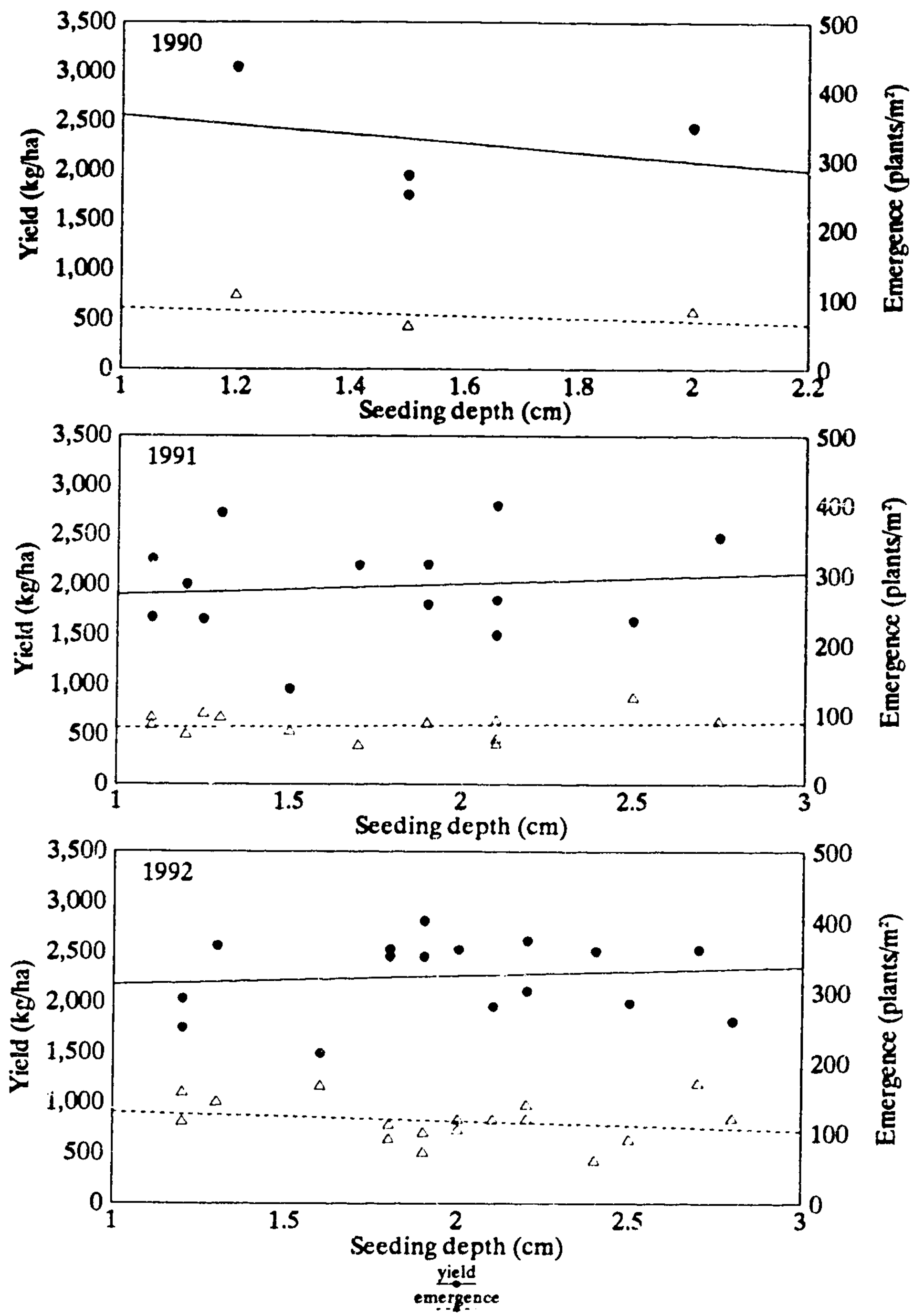


Figure 20. Emergence and yield vs seeding depth for napus variety

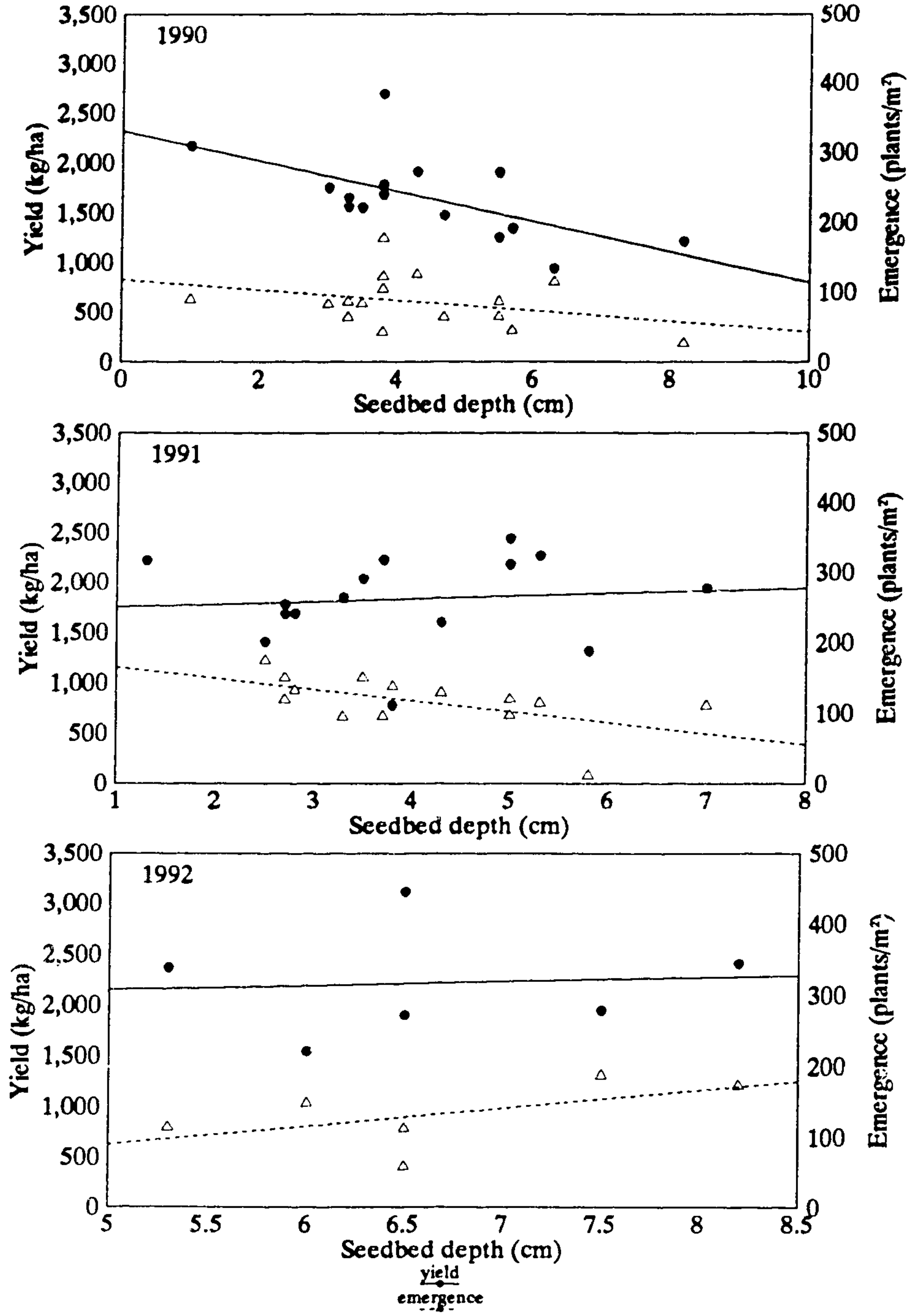


Figure 21. Emergence and yield vs seedbed depth for rapa variety

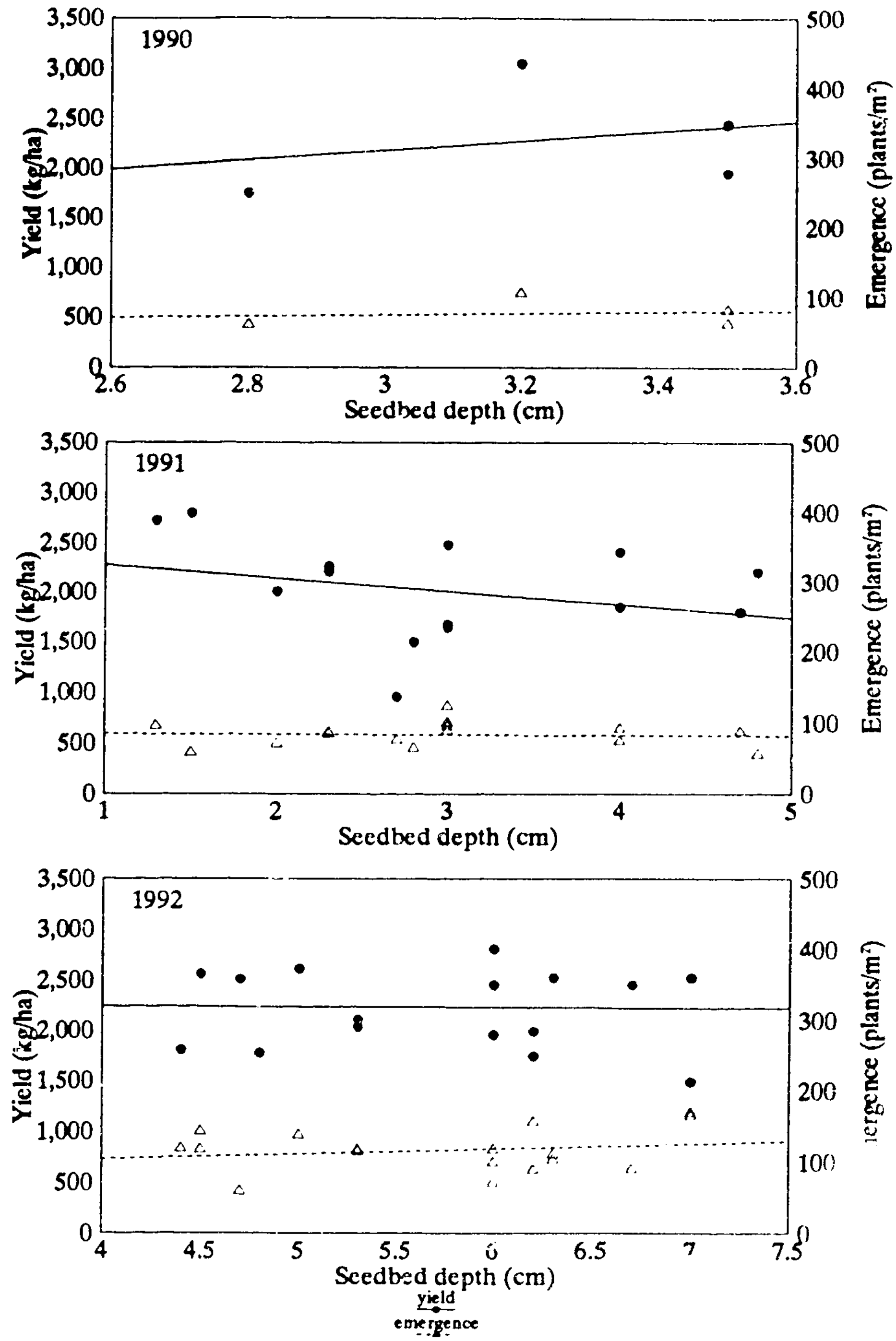


Figure 22. Emergence and yield vs seedbed depth for napus variety

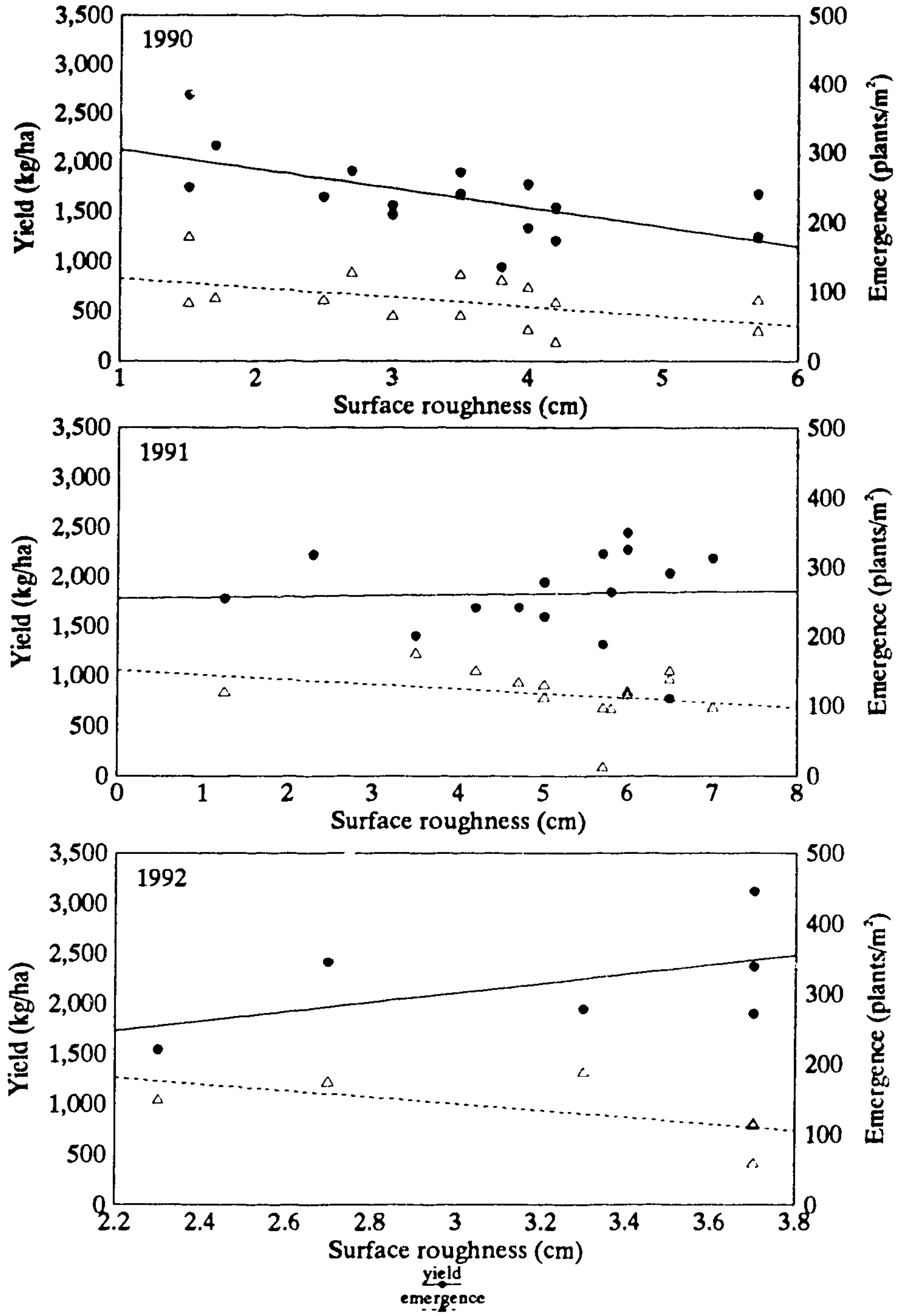


Figure 23. Emergence and yield vs surface roughness for rapa variety

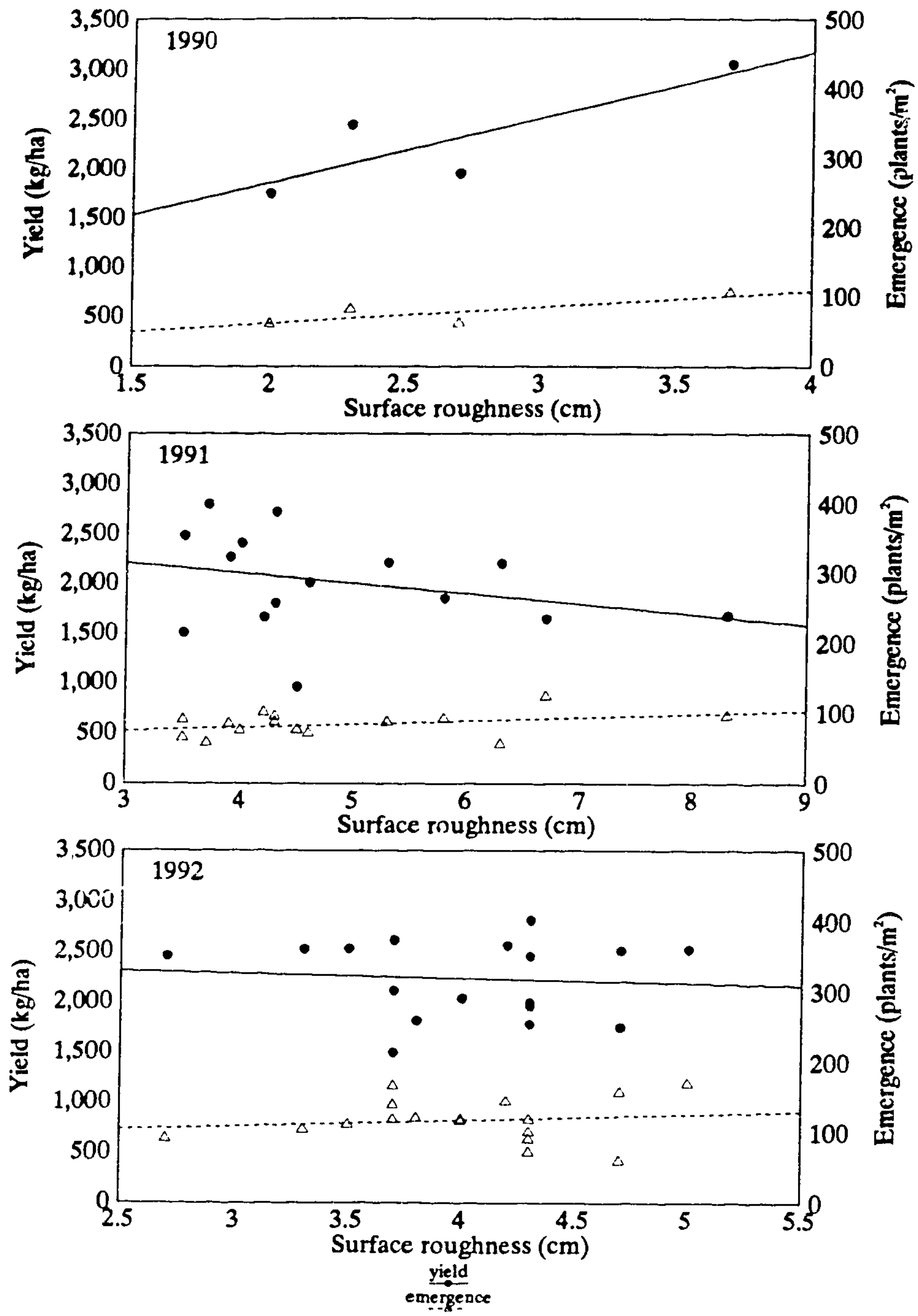


Figure 24. Emergence and yield vs surface roughness for napus variety

3.2.7 Summary

Survey results gathered over three growing seasons suggests seedbed preparation plays an important role in maintaining a good canola stand. Adoption of proper management techniques which pay attention to factors such as: aggregate size distribution, soil packing, tillage and seeding depth can lead to better canola yields. Because of the large amount of variation in factors such as differences between soil types, local weather conditions, tillage and seeding management and fertilizer applications in seedbeds surveyed, only general conclusions are drawn as follows:

Aggregate size distribution in the seedbed has a noted trend on canola growth. Soils should be tilled shallow with the proper implement to obtain smaller aggregates at seeding depth. The proper bulk density produced by packing is essential to canola growth. Generally, the seedbed should be packed before or after seeding when low soil moisture is expected. If the soil is high in clay content, packing may cause a problem by reducing pore space under high moisture conditions. Because canola is a small seed crop, seeding depth and tillage depth should be as shallow as moisture conditions will allow. Quick emergence of canola will result in better competition against weeds and better growth under early season moisture stress. A firm and level soil surface is necessary to allow for quick and uniform emergence, better weed competition, and will lead to higher yields.

3.3 Experiment III: Soil Compaction Experiment for Canola

3.3.1 Seedbed Depth

The effects of soil compaction on seedbed depth were indicated in Figure 25 and Table 41. Seedbed depth decreased as the soil was more compacted. Unlike the seedbed preparation at Stettler and Rycroft where the canola was directly seeded after the compaction treatment, the seedbed at Ellerslie was cultivated after compaction. Significant differences in seedbed depth were observed in ST compared to other treatments (Figure 25a). The reason for the decrease in seedbed depth with an increase in compaction was probably that the higher resistance in the compacted soil led to a shallow tillage depth of the cultivation. There were no significant differences in the seedbed depth between DO, SO and CO treatments. The results from the sandy loam showed that significant differences existed between CO and OP, TP and FP. The reduction in seedbed depths was very evident when the plots were compacted. There were no significant differences between OP, TP and FP treatments but a decreasing trend was found as the compaction increased (Figure 25c). The experiment on the clay soil produced similar results to the experiment on the sandy loam except that there was an insignificant difference between NP and OP. OPP yielded the shallowest seedbed depth among treatments (Figure 25b). The similarity above was due to the fact that both of experiments produced seedbeds which did not need cultivation after the soil compaction was conducted.

3.3.2 Bulk Density

Soil dry bulk density was closely related to soil compaction treatment. As the compaction increased, soil pore size reduced resulting in denser soil in the seedbed and the soil under the seedbed as well. The dry bulk density varied differently for different type of soils with the following average breakdown: for seedbed soil, 0.72-0.77 Mg/m^3 in the clay soil (Rycroft), 0.79-0.85 Mg/m^3 in the silt loam (Ellerslie) and 0.80-0.89 Mg/m^3 in the sandy loam (Stettler); for the soil under the seedbed, 1.55-1.68 Mg/m^3 in the clay soil, 1.09-1.14 Mg/m^3 in the silt loam and 1.37-1.44 Mg/m^3 in the sandy loam. The statistical results are listed in Table 42.

The effects of different compaction treatments are given in Figure 26. On the silt loam, DO had a greater influence on bulk density in the seedbed and the lower layer of the soil under the seedbed. SO and ST produced more compaction in the upper layer of the soil under the seedbed (Figure 26a). For the clay soil, OPP yielded lower dry bulk density than TP and FP treatments because of the fact that post packing had less passes over the plots (Figure 26b). The compaction experiment on the sandy loam did not show the trend that an increase in compaction would lead to an increase in dry bulk density (Figure 26c). However, TP induced the highest dry bulk density in the seedbed soil. The reason for lower bulk density in the compacted plots than in the control plot was probably attributed to large variations in the soil, which could mean that higher density existed in the soil of the control plot and less compacted plots and the compaction was not high enough to produce higher bulk density. Because the soil with lower clay content was less sensitive to compaction than the soil with higher clay content, the control plot had a higher density than the compacted plots.

Table 41. Seedbed depth for compaction experiments on silt loam, clay and sandy loam

soil type	compaction treatment	seedbed depth (cm)* (means)
	CO	4.3a
silt loam	DO	4.1a
	SO	4.0a
	ST	3.6b
	NP	5.2a
clay	OP	4.7ab
	TP	4.4b
	FP	4.3b
	OPP	4.3b
	CO	5.6a
sandy loam	OP	3.4b
	TP	2.9b
	FP	3.0b

Table 42. Dry bulk density in the seedbed and the layer under the seedbed for silt loam, clay and sandy loam

soil type	compaction treatment	dry bulk density* (Mg/m^3) (means) in seedbed	in sublayer
	CO	0.79b	1.09a
silt loam	DO	0.85a	1.12a
	SO	0.82ab	1.10a
	ST	0.82ab	1.14a
	NP	0.73a	1.55b
clay	OP	0.72a	1.58b
	TP	0.74a	1.62ab
	FP	0.77a	1.68a
	OPP	0.75a	1.55b
	CO	0.81ab	1.44a
sandy loam	OP	0.79b	1.37a
	TP	0.88a	1.40a
	FP	0.80ab	1.38a

* for each type of soil, values followed by same letter are not significantly different at the α = 0.05 level.

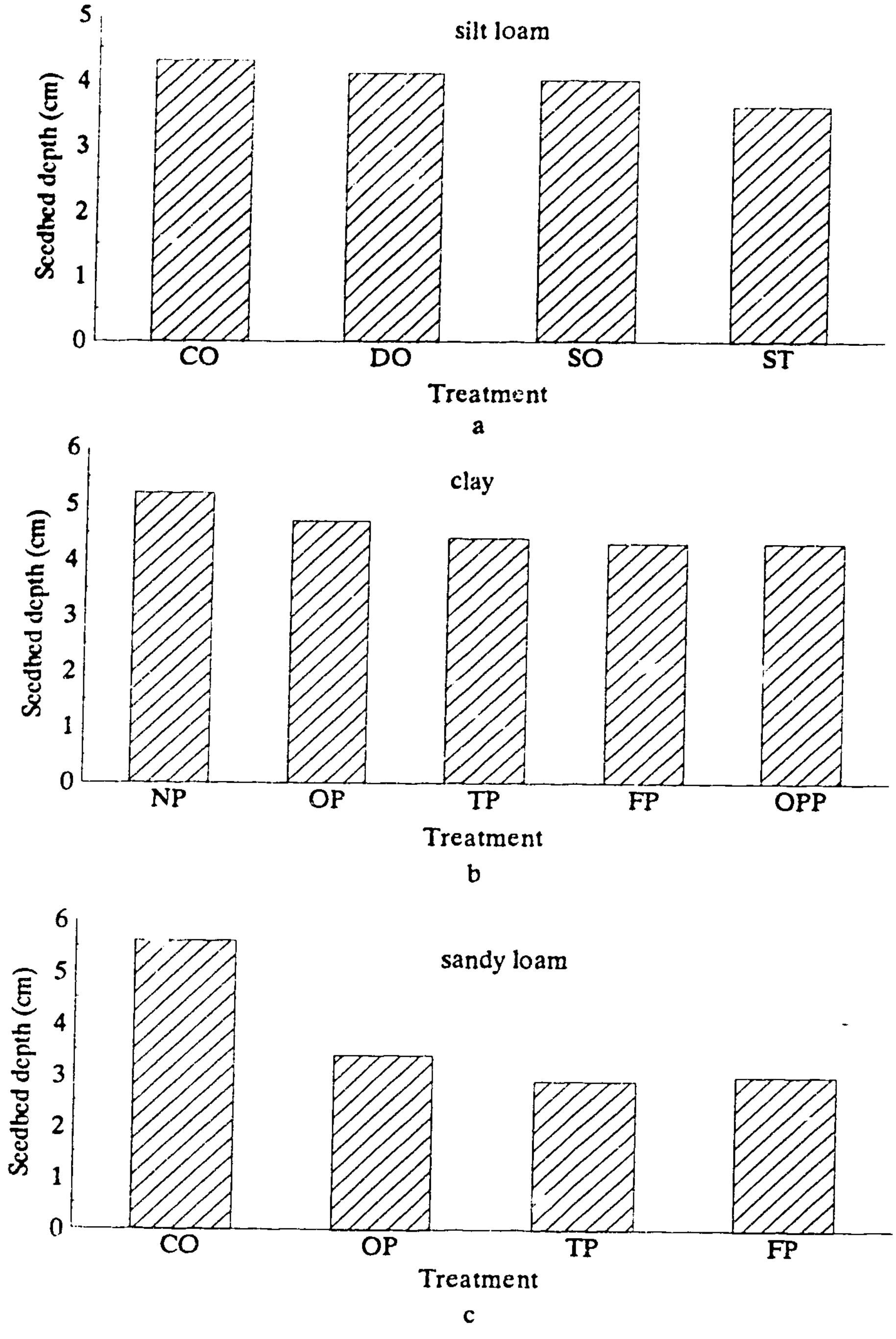


Figure 25. Seedbed depth vs compaction treatment

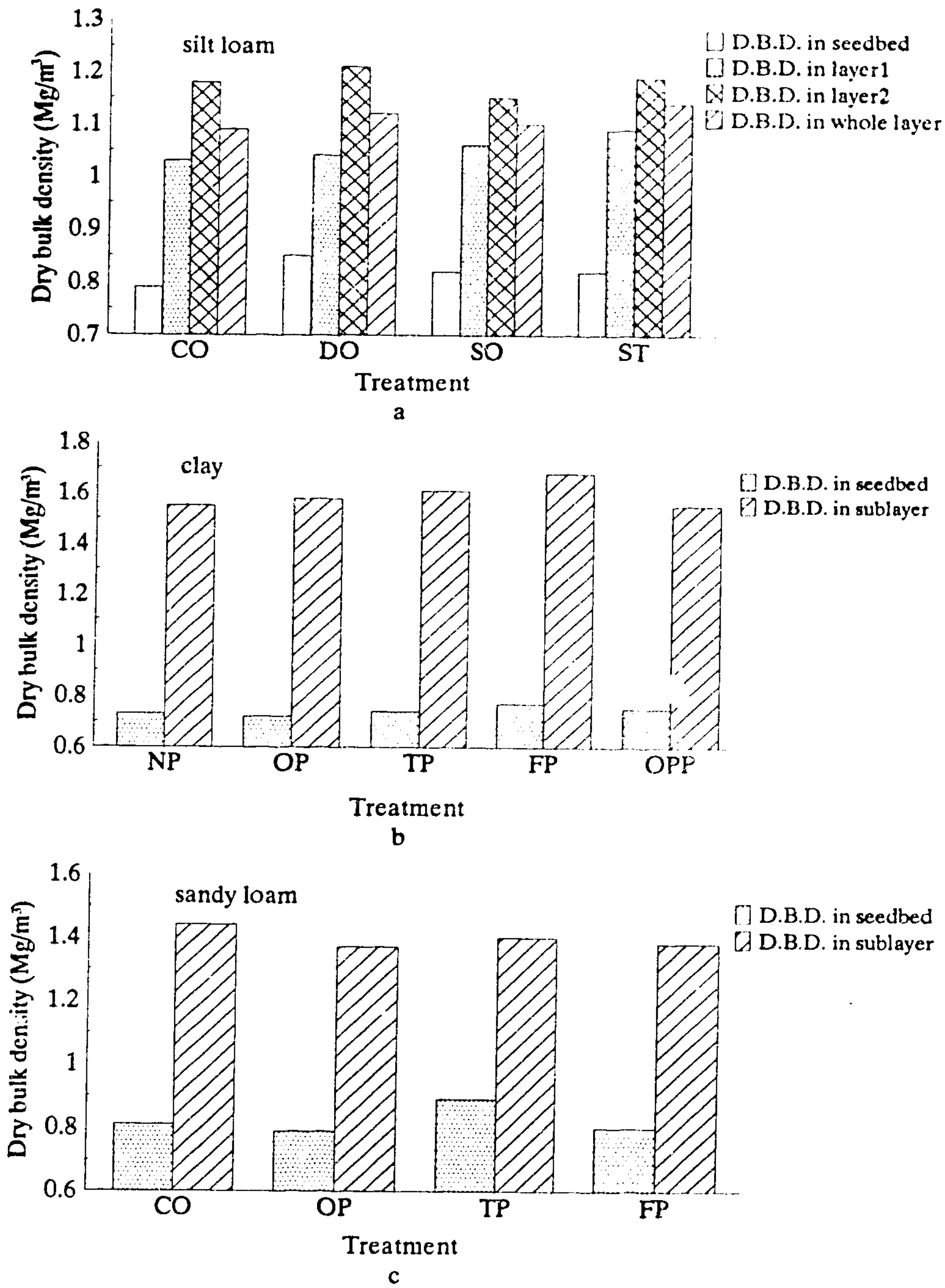


Figure 26. Dry bulk density vs compaction treatment

3.3.3 Soil Moisture Content

Soil moisture states in the seedbed and the sublayers are given in Figure 27 and Table 43. With tillage after compaction (Ellerslie), the control plot had higher moisture content in the seedbed and the soil under the seedbed as well (Figure 27a). The differences in moisture content between control and compacted plots were due to the fact that shallow seedbeds with compaction enhanced evaporation in the seedbed and at the time of soil sampling, high rainfall occurred, water infiltrated into the loose soil in control plots more than that in the dense soil in compacted plots. With no tillage after compaction (Rycroft and Stettler), moisture content in both of the seedbed and the soil under the seedbed increased when the soil was compacted. Because dry weather occurred at the time of soil sampling, plots with compaction reduced moisture evaporation more effectively than control plots (Figure 27b and 27c).

3.3.4 Penetration Resistance

Penetration resistance as a function of depth in the soils is illustrated in Figure 28. The mechanical resistance in the soil was affected by both bulk density and moisture content. Data from the silt loam showed that ST produced highest soil strength through the soil profile (Figure 28a). The penetration resistance from SO was slightly higher than that of DO in the depth from 100 to 200 mm. Although the DO treatment had a small decrease in soil moisture content, it still had lower penetration resistance because of its lower bulk density in the upper soil layer as compare to the SO treatment. Under the conditions of the soil and the tractor used at Ellerslie, the highest compaction as sensed by the penetrometer occurred at the depth around 90 mm. For the clay soil, penetration resistance produced by packing treatments was higher than that by no packing in the depth from 50 mm to 150 mm (Figure 28b). In the upper layer (0-50 mm) OPP yielded the highest penetration resistance. When the penetrometer penetrated deeper into the soil, irregular data was obtained. This might be explained by the fact that the interaction of moisture content and bulk density varied at each depth where the penetrometer reading was taken. The sandy loam (Stettler) reacted differently to different compaction treatments (Figure 28c). In the layer of 0-150 mm, TP and FP produced higher soil strength than OP and CO. However, as the penetrometer went down deeper, FP treatment had lower penetration resistance than the others. This was probably caused by the combinations of lower bulk density and higher moisture content which were mentioned in the discussion of bulk density and moisture content.

Table 43. Soil moisture content in the seedbed and the layer under the seedbed for silt loam, clay and sandy loam

soil type	compaction treatment	moisture content* (w/w,%) (means) in seedbed	in sublayer
	CO	19.4a	32.5a
silt loam	DO	18.1a	30.9ab
	SO	18.2a	32.0ab
	ST	19.4a	30.0b
	NP	10.1a	24.7a
clay	OP	10.8a	25.8a
	TP	10.7a	25.2a
	FP	10.5a	24.1a
	OPP	11.2a	25.7a
	CO	14.2a	18.1a
sandy loam	OP	17.0a	21.3a
	TP	15.2a	19.7a
	FP	15.5a	19.7a

* for each type of soil, values followed by same letter are not significantly different at the $\alpha = 0.05$ level.

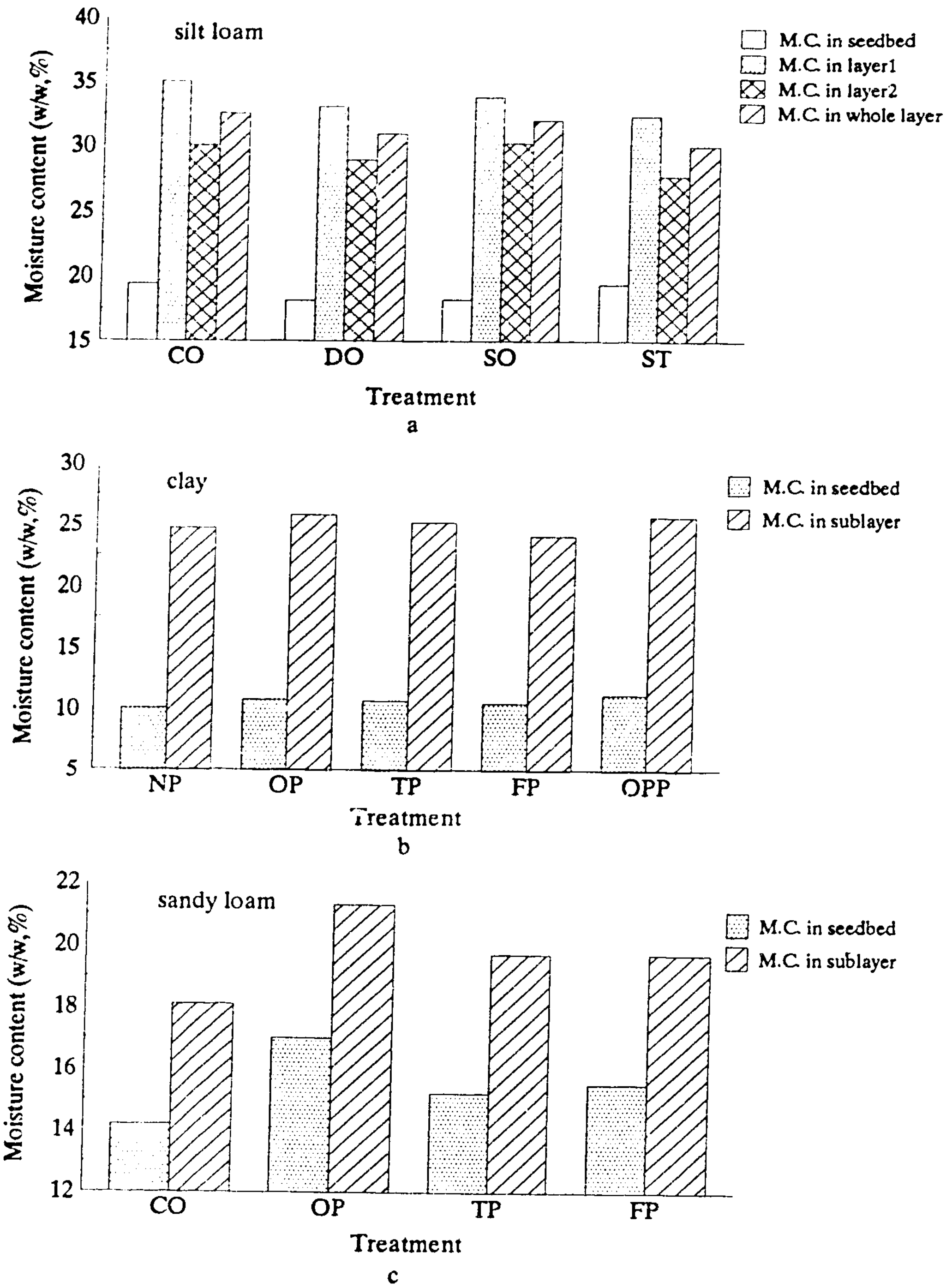


Figure 27. Moisture content vs compaction treatment

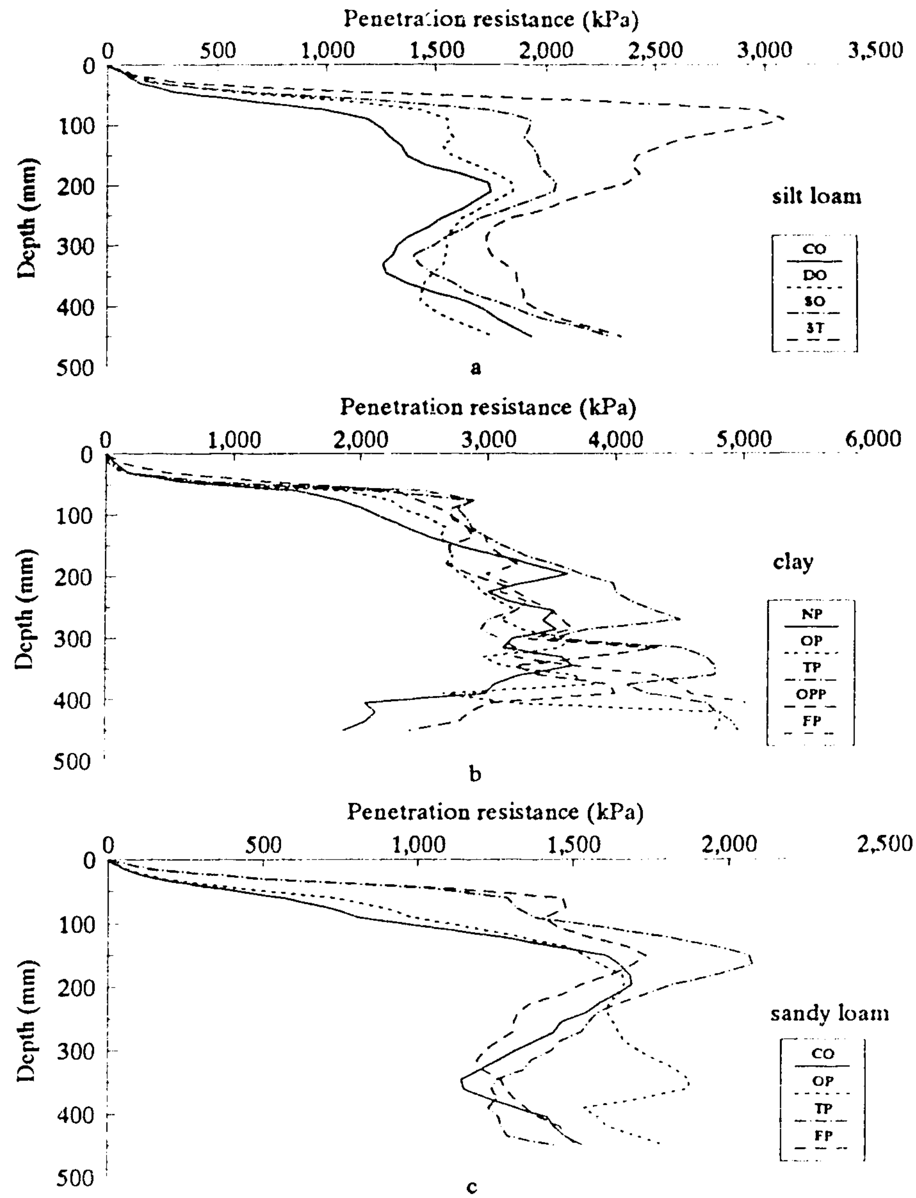


Figure 28. Penetration resistance vs soil depth

3.3.5 Crop Response

Crop response to compaction treatments are given in Figure 29 and Table 44.

Emergence counts increased with increases in soil compaction for the silt loam (Figure 29a). ST had a significantly higher emergence than the other treatments. There were no significant differences between DO and SO treatments which had better emergence than CO. The factors promoting higher emergence for the highly compacted soil were mainly the shallow seedbed depth and the higher bulk density in the seedbed which provided a good environment for seed germination by increasing water utilization and seed-soil contact. Similar to the results for the silt loam, highly packed plots on the clay soil had higher emergence (Figure 29b). The post packing treatment did not show any benefit on emergence. The experiment on the sandy loam did not indicate any significant differences in emergence between compaction treatments and the control. However, OP produced the highest emergence which was probably due to a higher moisture content at the time of germination though the soil had a slightly lower bulk density than the other treatments (Figure 29c).

Yield varied with the changes in properties of the soil below the seedbed. As the soil compaction on the silt loam reached the highest level (ST), yield significantly decreased compared to the other treatments (SO, DO and CO). The factors causing the yield decrease were high bulk density and high penetration resistance in the soil compacted by ST. Under this condition, the roots of the plant probably could not penetrate deeper in the soil. Generally, most of the water and nutrients used by the plant come from that portion of the soil that the plant roots are in direct contact with. The plant with a shallow or weakly developed root system would have had less supply of water and nutrients to draw from than the plant with a well developed root system (Hassett, 1978). The highest yield was achieved from SO treatment but this was not significantly different from DO or CO treatments. An explanation for this could be drawn by considering the difference in the bulk density between the treatments. The bulk density in the deeper layer (layer 2) under DO compaction was higher than that under SO compaction, therefore, the further development of roots could have been reduced in the soil compacted by DO. Another reason that may have caused the yield for DO to be lower than for SO was the lower emergence for DO even though the soil mechanical resistance was quite similar in the root zone for DO and SO. For the clay soil, yield results were similar to those for the silt loam except for the post packing treatment in which lower emergence led to lower yield compared to NP and OP. The experiment on the sandy loam also showed a negative relationship between yield and bulk density despite the fact that the bulk density did not increase when the compaction increased. There were no significant differences between treatments.

Seed germination and emergence were dependent on seedbed conditions. A better yield will be gained as results of better germination and emergence if the root zone was in a well developed environment. However, yield can be depressed when high soil density and mechanical impedance are formed in the root zone although a better emergence was obtained in the early growing season.

Table 44. Canola emergence and yield data for silt loam, clay and sandy loam

soil type	compaction treatment	crop response* (means) emergence (plants/m^2)	yield (kg/ha)
	CO	73c	1888a
silt loam	DO	105b	1912a
	SO	119b	1925a
	ST	161a	1802b
	NP	70**	1302a
clay	OP	85**	1394a
	TP	112**	1381a
	FP	122**	1285a
	OPP	50**	1207a
	CO	116a	1735a
sandy loam	OP	130a	1937a
	TP	114a	1979a
	FP	117a	2108a

* for each type of soil, values followed by same letter are not significantly different at the α = 0.05 level.

** values are averaged for each treatment with no statistical analysis.

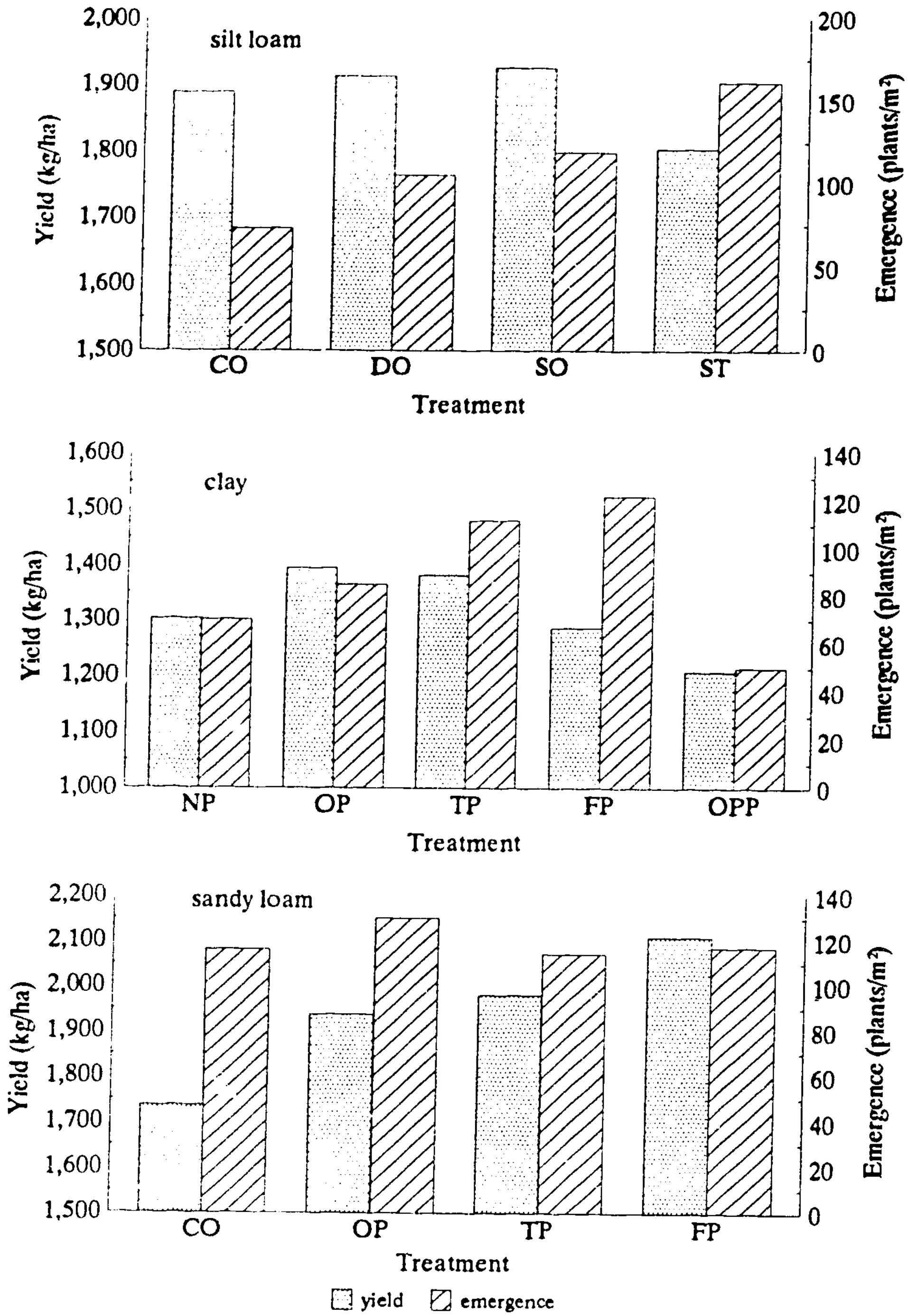


Figure 29. Canola emergence and yield vs compaction treatment

3.3.6 Summary

The soil compaction induced by tractor tires and seeding implements had an effect on the emergence and yield of canola. Soil physical properties in both the seedbed soil and the soil under the seedbed changed with the changes in compaction.

Increasing compaction will decrease the seedbed depth which promotes better germination and emergence. For silt loam and clay soil, yields decreased when the soils were highly compacted. The post-seeding packing on the clay soil resulted in low canola emergence and yield. Maximum yields were obtained as the soil compaction reached an intermediate state of compaction. Bulk density and penetration resistance in sandy loam negatively affected canola yield regardless of effects of compaction on these two properties of the soil. A better yield did not always result from better emergence unless a proper environment of the root zone was well developed.

4 SUMMARY AND CONCLUSIONS

The management of tillage, packing and seeding operations on the seedbed, the properties of the seedbed, and the soil compaction caused by tractor tires are highly related to the production of small seed crops. With the completed experiments and the culmination of survey results under the weather conditions in central Alberta, the following conclusions can be made:

A. The emergence of canola and flax responded favourably to pre-seeding packing. The combination of pre-seeding and post-seeding packing improved canola and flax emergence and yield.

B. A large proportion of aggregates < 4 mm in the seedbed resulted in better emergence and yield of canola and flax.

C. Emergence and yield for both canola and flax were depressed with seeding depths greater than 30 mm. A shallow seedbed depth resulted in better emergence.

D. Increased soil compaction reduced the seedbed depth and increased the bulk density in the seedbed.

E. Canola yield decreased as the soils below the seedbed were compacted with bulk density in the range of 1.10-1.14 Mg/m^3 for silt loam and 1.58-1.68 Mg/m^3 for clay soil. When the soils were compacted to bulk density of 1.10 Mg/m^3 for silt loam and 1.58 Mg/m^3 for clay soil, the yield was maximized.

F. Even though poor emergence occurred in the early growing season higher yields were achieved. The suitable environment of the root zone allowed canola to compensate itself to develop well through the whole growing season.

G. In order to confirm the effect of soil compaction below the seedbed, long term experiments are necessary.

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APPENDIX

A. Soil Particle Size Analysis

Type of soil	# of sample	Particles in sample (%) Clay	Silt	Sand
Silt loam	1	21.2	52.2	26.5
	2	23.6	50.7	25.7
	3	20.9	51.5	27.5
	4	26.6	47.1	26.3
	5	19.1	48.1	32.8
	6	19.8	49.1	31.1
	Average	21.9	49.8	28.3
Clay	1	51.6	32.4	16.0
	2	57.7	28.5	13.8
	3	47.7	39.2	13.4
	4	58.9	32.2	8.9
	5	47.6	38.1	14.3
	6	56.3	33.2	10.5
	Average	53.3	33.9	12.8
Sandy loam	1	14.2	25.5	60.3
	2	13.1	24.2	62.8
	3	14.4	27.5	58.1
	4	13.9	30.6	55.5
	5	15.0	24.7	60.3
	6	14.0	29.2	56.9
	7	12.6	22.3	65.1
	8	12.7	20.3	67.0
	Average	13.7	25.5	60.8

B. Soil Organic Matter Content

Type of soil	Soil layer*	# of sample	Organic matter (%)	Average
Silt loam	Top	1	10.88	
		2	10.84	
		3	11.07	10.93
	Bottom	1	8.83	
		2	8.62	
		3	8.98	8.81
	Average			9.87
Clay	Top	1	8.96	
		2	9.67	
		3	10.09	9.57
	Bottom	1	6.48	
		2	6.76	
		3	7.78	7.01
	Avergae			8.29
Sandy loam	Top	1	7.31	
		2	7.02	
		3	6.36	
		4	5.83	6.63
	Bottom	1	4.40	
		2	6.24	
		3	6.62	
		4	4.24	5.38
	Average			6.01

* Top layer: 0 - 5 cm.
Bottom layer: 5 - 30 cm.

C. List of Equipment

40 x 40 x 10 cm high square frame
40 x 25 x 10 cm high wing
25 x 28 x 10 cm high flat scoop for scooping out layers
50 x 50 x 30 cm square frame
30 litre graduated pail for measuring volumes
1 litre graduated cylinder
plastic funnel
plastic scoop for scooping out seedbed
sieve sizes: 9.5 mm, 4.76 mm, 2 mm, 1 mm, pan
sieve sizes: 19 mm, 12.5 mm, 8 mm, 4 mm, 2 mm, 1 mm, 0.5 mm, 0.25 mm, pan
50 cm straight edge
45 cm ruler
freezer bags for soil samples
drying oven
Troxler Electronics Labs Ltd Nuclear Gauge Model 3401
soil cone penetrometer with paper trace (ASAE Standard S313.2 Specifications)
CP10 cone penetrometer, Rimik PTY Ltd
electronic scale
thermometer
pen, paper
50 foot tape
1 m^2 frame
pen, paper
1 m^2 frame (one side open)
1 m rod
hand sickle
cloth bags
tags, string, pens, paper
threshing apparatus