DIFFERENETAL RESPONSE OF COLORED AND NON-COLORED BEANS (PHASEOLUS VULGARIS L.) TO A COMPACTED CHARITY CLAY

By

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A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Crop and Soil Sciences

1981

ABSTRACT

DIFFERENTAL RESPONSES OF COLORED AND NON-COLORED DRY BEANS (PHASEOLUS VULGARIS L.) TO A COMPACTED CHARITY CLAY SOIL

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Differences in plant response due to soil compaction were studied using two black and two white-seeded cultivars. Compaction resulted in increased bulk density, soil moisture levels and decreased air porosity. Compaction decreased the accumulation of roots at 14.0 cm and 21.6 cm depths and increased accumulation of roots in the surface 6.4 cm .

Adverse effects of soil compaction included decreased shoot dry matter accumulation, plant height, and increased starch retention in roots and stems. Pod abscission was higher for plants grown on compacted plots. In contrast to other studies seed yield of black-seeded cultivars were reduced more than white-seeded cultivars.

Yield comparisons of seven pairs of near-isolines, white and black-seeded showed a 28 percent reduction in seed yield due to compaction. Sixty-five cultivars grown at two levels of soil compaction for two years revealed a 13.1 percent reduction in seed yield due to compaction.

To

Kim and Jeff

ACKNOWLEDGEMENTS

I wish to express my sincere gratitude and appreciation to Dr. M. W. Adams, my major professor, for his moral support, kindness and valuable guidance throughout this study and during thesis preparation.

A special thanks to T. Falk, A. Guri, S. McBurney and others on the 1979 root soil sampling crew, for their assistance in taking soil core samples and washing roots. Also thanks to J. Pipoly for his assistance in collection of data on plant growth parameters.

My special thanks extended to Dr. C. Cress for his patience and suggestions for statistical analysis. I am also very grateful to Dr. A. W. Saettler, Dr. A. Ghaderi, Dr. G.L. Hosfield, Dr. D. Christenson, and Dr. L. S. Robertson for their suggestions.

I am very grateful to those who are very special to me, my wife Sandy, daughter Kim, and son Jeff, for their understanding and sacrifices made during the course of this study.

I wish to thank the members on my committee, Dr. M. W. Adams, Dr. G. L. Hosfield, Dr. L. S. Robertson, Dr. A. W. Saettler, and Dr. A. J. M. Smucker for their review of this study.

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INTRODUCTION

An erratic decline over several years in average yield of navy bean (Phaseolus vulgaris L.) in Michigan accented the need for increased research. Variety selection, soil fertility, disease, seed quality, soil management, nematodes, and weed control are production aspects now being studied. While meteorological changes in temperature and moisture can cause fluctuating yields in beans, such effects generally average out over several years. While we cannot control the weather, it is possible to modify both the physical and chemical properties of soils used for bean production through the process of soil management.

Most of Michigan's beans are grown on the fine textured soils of the Saginaw Valley and the thumb area of the state. Such soils require a high degree of skillful management. With the decrease in livestock numbers and the associated forage crops, and an increase in cash crop operations, soil physical problems have become more prevalent.

The use of larger and heavier farm tractors and implements seemingly has increased the soil compaction problems. The use of large flotation tires on tractors and machinery to reduce the pressure per unit area, is partly nullfied when treading wet soils. Compacted soil cause low crop yields because of oxygen deficiencies mechanical impedance to root penetration and soil crusting. In addition, stress caused by drought or excessive precipitation are accentuated in compacted soils.

This research was undertaken to study the determine the effects of soil compactions by impliments on growth characteristics of different strains of dry beans. The objective was to determine the extent soil compaction affected plant growth and yield of dry beans.

LITERATURE REVIEW

Economic yield reduction and slower vegetative growth rates of agronomic crops when grown under conditions of soil compaction have led to the study of soil compaction by wheeled traffic as a contributing cause of the declining yields of beans (_Phaseolus vulgaris L._) grown on these soils. Data on other agronomic crops grown at various levels of soil compaction strongly implicate compaction as a causative factor of low yields.

The degree of compaction of soil is directly related to moisture content of the soil when compactive forces are applied (Nelson _et al._, 1967; Blake _et al._, 1976; Strandberg and White, 1979). As depth from the soil surface increased, soil moisture content increased (Nelson _et al._, 1967).

Any increase in soil bulk density reduces macroporosity, resulting in a decreased water intake, and restricted gas movement, as reported by Nelson _et al._, 1967. Blake _et al._, 1976 showed that soil compaction impeded internal drainage, decreased volume of macropore space, and increased root impedance. Any decrease in macropore space, the easily dried pore space, would effect soil water properties. Micropore spaces hold soil water with increased force thus restrict soil water movement. (Blake _et al._, 1976), also stated that soil permeablility, either in saturated or unsaturated condition of moisture, was reduced by packing or by an increase in bulk density.

When moisture potential was greater than or less than that giving optimun yield, there was a reduction in yield, according to Forsythe and Legorda (1978). Seed production loss per unit bar of moisture potential suction change was 15 times greater where the matric suction was less than the optimun value, than when greater than the optimun value. With increasing moisture potential suction evaportranspiration decreased.

Morris and Daynard (1978) stated that soil compaction can accentuate excess water stress. Excess water stress may be responsible for growth and yield restrictions that are frequently associated with compaction. Under field conditions soil compaction can seriously restrict water uptake and root elongation and hence the volume of soil in close contact with plant roots.

Blake _et al_., (1976), stated that an air-filled volume fraction of 0.1 comprised a critical threshold level for O_2 diffusion in the soil. Gill, Phillips, and Kirkham (1972) reported that a concentration of O_2 in the soil air greater than 10% was adequate for plant growth. Thus, the concentration of O_2 in the soil air would be just as important as the total air-filled volume of the soil. Plants get O_2 from soil water, and O_2 in soil water must be maintained by diffusion from the soil air.

Hopkins and Patrick (1969) reported that soil compaction and O_2 content interacted in their effect on root penetration. At highest soil compaction and lowest O_2

levels, little or no root penetration occurred. At intermediate levels, both factors were operative in root penetration, but at optimun levels of either factor root penetration was governed by the other factor. Root penetration and soil compaction were highly related when oxygen concentration was high enough for adequate O_2 diffusion. Hopkins and Patrick (1969) stated in finer textured soil that O_2 content may be a more limiting factor than mechanical impedance.

In a greenhouse experiment which measured vegetative growth of green beans, and cotton, a reduction in dry shoot weights due to periods of low soil O_2 was reported by Letey *et al.*, (1962). Little or no root growth occurred during periods of low O_2, and plants used less water. There was a definite time lag for recovery in root penetration at a normal O_2 level after a period of low O_2 levels. Low soil O_2 is most detrimental during the early stages of growth, following germination. Green bean plants were not able to survive seven days of low O_2 levels during the early stage of growth.

Lemon and Wiegand (1962) reported that the rate of metabolic O_2 uptake by root tissue varied with variety and physiological age of the tissue. When O_2 was plentiful the "substrate supply" at the reaction locus determined the reaction rate, a chemical process sensitive to temperature. When O_2 at the root surface was below the critical level, diffusion controlled the rate of O_2 uptake, a physical process insensitive to temperature. The critical O_2 level concentration at the root surface is strongly dependent upon the radius of the root, and the diffusion coefficient of O_2 within the root.

Nelson et al., (1975) reported that roots cannot grow into openings smaller than a root diameter. Thus, roots in a compacted soil must follow voids or avenues of weakness. Voorhees et al., (1971) in a study of root penetration of non-compacted and compacted soil aggregates as compared with porous aggregates, which allowed roots to grow into and through. As density of soil aggregates increased so did aggregate strength and impedance to root penetration. Barley et al., (1965) indicated that soil strength has an important influence on the penetration of clods (aggregates) or finely structured layers by plant roots of peas and wheat. Roots on non-compacted plots had more extensive distribution of finer roots (Blake et al., 1976). Taylor et al., (1963) concluded that root penetration is a function not only of soil strength but also of soil porosity-size continuity and tortuosity of voids within the soil.

Thruman and Pokorny (1969) reported in studies with Bermuda grass that root length and dry weight of roots and tops decreased as compaction pressure increased. Fisher et al., (1975) investigated barley and kale grain on sandy clay loam, with wet and dry plowing and cultivating, ploughing when wet increased mean bulk density from 1.35 to 1.4 grams per cm^3 . Wet cultivation reduced air porosity from 17.3

to 14.1 cm^3 per 100 cm^3 . Dry matter accumulation of kale and vegetative growth of young barley were reduced by wet plowing and wet cultivation.

Investigations by Smittle and Williamson (1977) indicated an 80% reduction in root growth due to tractor wheel compaction. Soil strength increased, soil porosity decreased and dry root weight decreased with depth; as soil bulk density increased, soil strength increased, except for the 0 to 8 cm level of soil. Compacted plots yielded 25 to 35 percent less with a 50 percent reduction of tissue NO_3 and a decrease in fruit length/diameter ratio. Smitlle et al., (1978) indicated that yield responses to nitrogen were different when cucumbers were grown on non-compacted and compacted sites.

Smittle et al., (1977) reported studies on squash grown on a Tifton loamy sand; fruit yield was reduced by 46 to 58 percent by increased soil strength produced by tractor wheel traffic. Root dry weights were higher for 7.6 to 15.2, 15.2 to 22.9, and 22.9 to 30.5 cm levels, on the non-compacted plots; but the surface to 7.6 cm levels had higher root weights on the compacted plots. Soil compaction reduced nitrogen use efficency, as indicated by both petiole NO_3 analysis and economic yield.

Investigations with carrots on an organic soil by Strandberg and White (1979) revealed tap roots were significantly shorter as soil strength increased. Impeded roots were thicker, convoluted and had increased branching. Olymbias and Schuabe (1978) in a greenhouse experiment with carrots, stated as mechanical resistance to root elongation increased in soil, that air capacity decreased affecting patterns of dry matter distribution between roots and tops. Reduction in root weight was 32 percent compared to a 19% reduction for tops. This was caused by the combined effects of lowered aeration and increased mechanical pressure.

Economic yield of soybeans decreased with increased traffic from 0 to 8 passes of a tractor wheel on a 1.1 m row width. First pass caused a greater increase in soil strength than subsequent passes (Nelson et al., 1975). Compaction of the whole profile of a La Morgot soil by 21 bars of pressure produced low yields and short plants of red kidney beans (Huertas, 1975). A high positive relation was found between penetration resistance and bulk density, and high negative relation between penetration resistance and the percent of soil porosity.

Soil compaction reduced phosphate availability and increased mositure stress by impeding root growth (Janssen et al., 1977). An increase in soil strength gave rise to an increase in the cation exchange capacity of roots and carboxyl groups on the roots (Kulkarni and Sarant, 1977).

Persistence of sub-soil compaction in a Mollisol was easily identified by penetrometer measurements nine years after a 7.5 bar pressure was applied to the bottom of the plow furrow. Bulk density did not change, and corn and alfalfa mean root weights were reduced 36 percent in the 40 to 90 cm soil layer. Packing affected the distribution of tap roots and fibrous roots in the profile (Blake 1976). Zone of compaction lasted two years in a sandy loam, even when wheel traffic was absent. Working soil early produced a good surface tilth, but left a compaction zone beneath (Pollard and Elliott, 1975). Growth and grain of spring barley were adversely affected by soil compaction which was related to wet soil conditions.

Surface compaction had more influence on the date of heading of sorghum and sudangrass because of the importance of the physical condition of the sub-plow layer on the mature plant (Wittsell and Hobb, 1965). Weathering and the action of plant growth over three cropping seasons were not effective in improving water permeability of the compacted surface.

Snap bean root and shoot weights were higher at lower moisture stress and increased with an increase in soil aeration (Schulteios and Kattan, 1971). Miller and Burke (1977) concluded that aggravation of root rot by low O_2 diffusion rates is the principal cause of plant stunting and yield reduction that result from temporary excessive wetting of the soil in _Fusarium_ infested soil. Near zero O_2 levels in the soil air increased bean root injury by the fungus. Bean roots are restricted by relatively more compacted soil, such as that below the bottom of disked and plowed layers, (Burke _et_ _al_., 1972). Bean roots are geotropic, but tend to grow laterally on compacted horizontal soil layers such as disk and plow soles.

Phillips and Kirkham (1972) identified the problem in determining the exact mechanism by which soil compaction reduces plant growth, a difficulty in seperating out effects of root impedance, soil density, poor aeration, and excess moisture stress. From the stand-point of water and nutrient uptake, a considerable volume of soil must be explored under most field conditions to satisfy plant requirements (Voorhees et al., 1975). Thus, the most efficient root configuration for total water and nutrient uptake should allow near-maximun rates of both root branching and root elongation.

MATERIALS AND METHODS

Field research was conducted at the Saginaw Valley Bean and Beet Research Farm near Saginaw, Michigan in 1979. The soil is a Charity clay (containing 53% clay and in soil management group 1 c-c). It was used for this study because it has an unstable structure. Soil test results showed a pH of 7.6 with 38, 507, 11277, and 1854 kg/hectare of "available" P, K, Ca, and Mg, respectively. This soil contains 4.7% organic matter. The previous crop was corn. The soil was moldboard plowed in October of 1978 to a depth of 23 cm .

The plot area was marked on two opposite sides by flags, spaced 6.4 m apart. By centering on these flags a traffic control pattern was established, where no wheel tracks were on the individual plots. (Fig. 1) Spraying and all secondary tillage was performed following the same tractor wheel marks. This traffic control pattern provided an alley 1.5 m wide between ranges of plots and 4.9 m for length of individual plots.

Soil compaction was accomplished by use of a sheep's-foot traffic packer on May 18, 1979. It penetrated the soil surface approxiamtely 10 cm , with a pressure of 4.22 kg/cm^2 . The intent was to leave the top (0-7) cm of soil relatively non-compacted for better seed germination and plant emergence. An International 656 tractor, weight approximately 3000 kg was used to pull the sheep's-foot packer; which

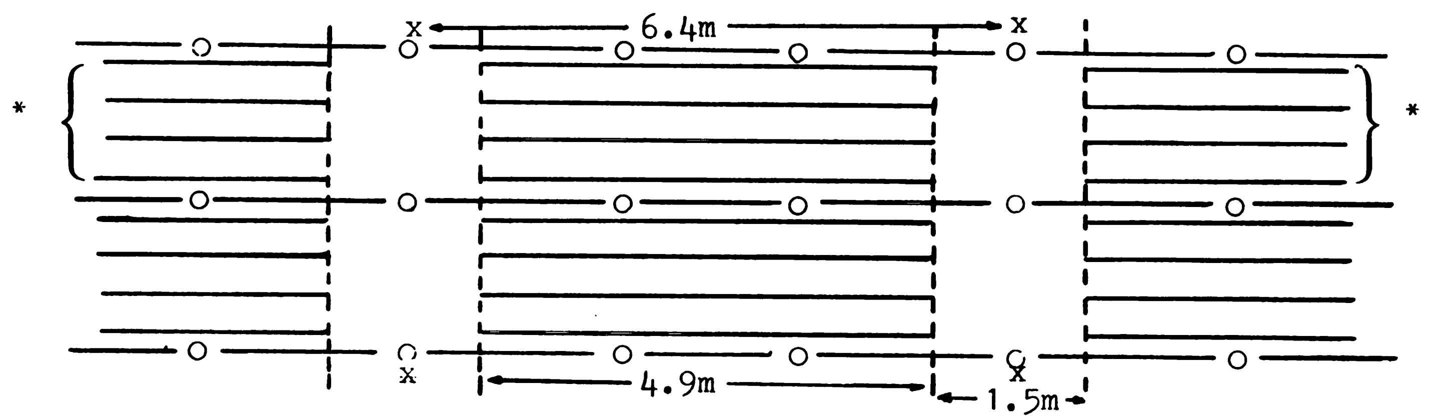


Figure 1. Field Layout Used on the Bean and Beet Research Farm, 1979.

x Flags 6.4m apart
---- Tractor Wheel Tracks (tillage)
Tractor Wheel Tracks (planting)
Bean Row
* Each plot consists of four rows

meant that some surface compaction (0.85 kg/cm^2) would be present. Two passes of the sheep's-foot traffic packer were used on the compacted treatment. Some variation in surface compaction could be expected since approximately 60 percent of the soil surface was treated by tractor wheels.

All secondary tillage was done using a spring tooth harrow 6.6 m wide with two passes over both non-compacted and compacted plots to smooth and level the soil surface. A preplant tank mix of Eptam (2.5 kg.ha) and Treflan (0.6 kg/ha) was used for weed control, which was incorporated once by the spring tooth drag.

Planting was done with a Ford 3000 tractor, pulling a mounted three-point hitch modified "Plantair" precision planter (Taylor, 1975). The tractor wheels were centered 2.03 m apart which straddled four rows spaced 50.8 cm apart. Out side rows were used as guard rows with all data collected from the center two rows. May 25 through 27 were planting dates with soil and soil moisture in good to excellent condition.

An 18-46-0 fertilizer with 5% Mn and 2% Zn was banded to one side and below the seed at a rate of 314 kg/ha planting. Disyston for root worm control was applied in the fertilizer band at 9 kg/ha.

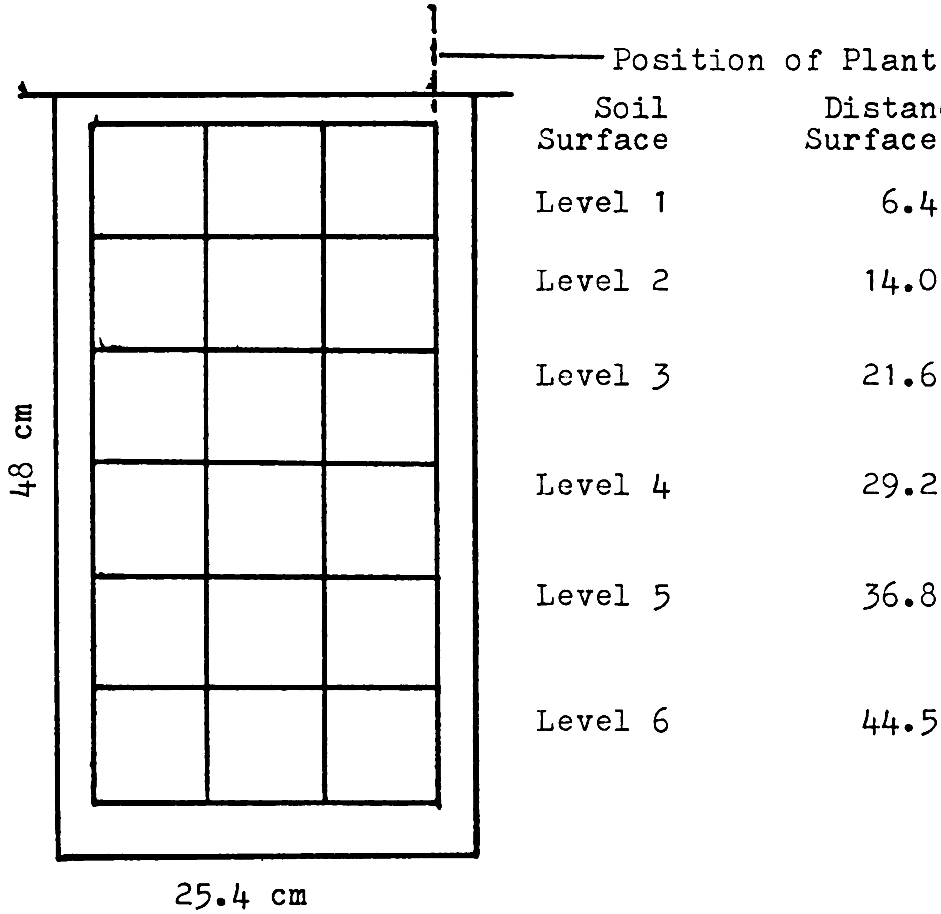
Data was collected on four dry bean varieties, (*Phaseolus vulgaris* L.), namely, Seafarer, a commerical bush navy; Black Turtle Soup, a semi-vine type grown commericially; San-Fernando, a black colored semi-vine upright type, and

NEP-2, a white mutant of San-Fernando, also an upright semi-vine type. Also included was a set of seven pairs of near-isolines, of black and white seed color grown on similar compacted and non-compacted plots.

A tractor mounted soil core sampler was used to collect all soil samples (Srivastava, et al., 1980). Each soil core was divided by a fractionator (Srivastava et al., 1980) into six sets of three, 7.5 cm cubes. The mid-point depths were 6.4, 14.0, 21.6, 29.2, 36.8, and 44.5 cm below soil surface (Fig.2). One dry bean plant was centered approximately 2 cm from the side of the soil core samples. When fractionated the tap root would be at the outside edge at level one. (Fig.2)

Soil core samples were taken on June 27, July7, August 28, and September 9. Samples for soil bulk density and soil moisture were collected on June 27, August 28, and September 9. Core samples taken on June 27 and July 7 included only the 6.4, 14.0, and 21.6 cm depths, whereas core samples taken on August 28 and September 9 contained all six depths. Each core sample contained 430 cc. Three soil cores at each level, e.g. 6.4 cm, were averaged for data point.

Soil moisture was calculated on a dry weight basis. Bulk density was measured in grams per cubic centenmeters weight/volume. Percent moisture on a volumetric basis was calculated by multipling percent moisture (gravitational) by bulk density. Percent total pore space equals one minus



Soil Surface	Distance from Surface to Mid-cube
Level 1	6.4 cm
Level 2	14.0 cm
Level 3	21.6 cm
Level 4	29.2 cm
Level 5	36.8 cm
Level 6	44.5 cm

Figure 2. Soil core sample. Soil sample divided into 18 cubes with a volume of 430 cc each. Soil core is 7.62 cm thick.

bulk density divided by particle density times one hundred. Percent saturation is equal to percent moisture (valumetric) divided by percent total pore space (Baver, et al., 1972).

To use the preceding equations, it must be assumed that particle density of a soil is a constant. An average value of 2.65 g/cm^3 was used without appreciable error, (Baver et al., 1972). Another assumption is that bulk density is constant at changing moisture contents. The Charity clay soil, containing 53% clay, swells with an increase moisture. Thus bulk density increases as this clay lost moisture (Baver et al., 1972). This is a volumetric decrease per given volume of soil with amount of particles remainig the same. No account for soil with swelling and shrinking, by an increase or decrease in moisture was used in this study.

Samples taken on July 7, August 28, and September 9 for root data were soaked in sodium sesquicarbonate and sodium tripolyphosphate solution for 24 hours to disperse soil aggregates. They were washed in an air bubbled water stream (Fig. 3), McBurney et al., (1981). Roots were collected on a fiberglass screen with a rectangular opening of 0.15 cm by 0.18 cm. Roots were washed again with water and lose organic was removed by hand, with forceps. Water was removed by filtering with #4 filter paper, the residual material was allowed to air dry and was weighted. Several root samples were entangled with organic matter to such

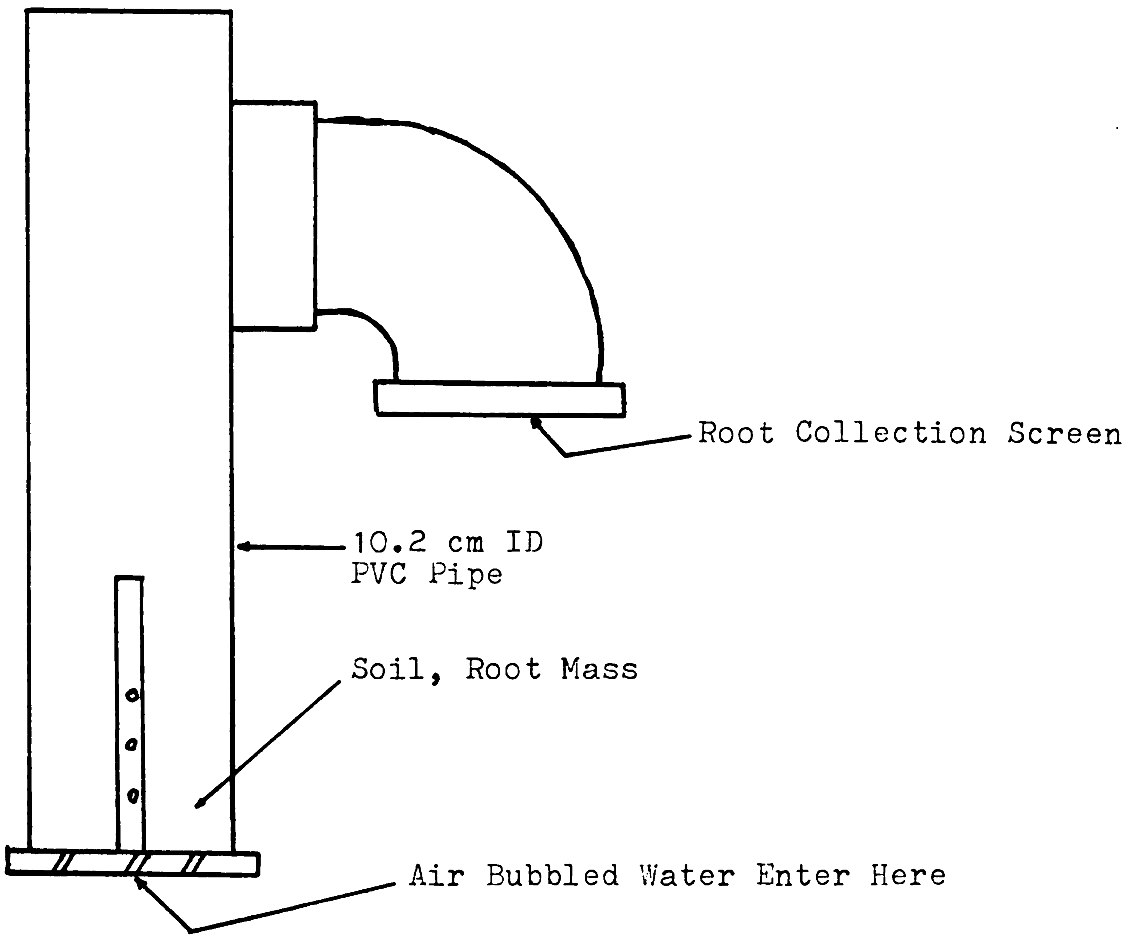


Figure 3. Phase two of root washer used to separate soil from roots in November 1979.

an extent that they were discarded.

Stand counts were taken 15 days after emergence. Two 3 m row samples were counted per plot. Also, flowering dates were recorded and measured from day of emergence, (when 50 percent of the plants in a plot were flowering).

At this time a solution containing 1 gram each of I_2 and 1 gram of KI per 100 ml distilled H_2O (Sass, 1958) was used to measure starch at the mid cross-section of the second internode of the stem and cross-section of the tap root 3 to 5 cm below the soil surface. Starch readings were subjective and ranged from 1 (no stain) to 5 (near complete staining of the cross section). Four plants per replication per treatment per strain were taken for these data. Starch readings were repeated at mid-pod and at physiological maturity.

Canopy heights were measured on July 18. Three measurements were taken per plot and averaged for each data point. No extension of the plant stems or branches were done during measuring.

Pod growth rate was measured every other day for a period of 8 days. Twenty pods per replication, per treatment, per strain, were selected and tagged when initial measurement was made between 1 to 1.5 cm in length. Due to time difference strains in flowering, these measurements were taken at different times for strains, but not treatments. Also, data was taken on percent of pods lost between first and last measurements.

Maturity was based on PM and measured from day of emergence. Four meters of row were hand pulled, field dried, and threshed with a hand-fed plot thresher. Beans were cleaned using hand screens and weighed. No adjustment for moisture was made. Weight per 100 seeds and harvest index are shown.

Due to grouping of replications for compacted and non-compacted treatments, a semi-split plot design was incorporated into the analysis of variance. Sums of squares for replications and the interaction of treatment sums of square x replications sums of squares were added together for error A. Sub-plots were treated as usual in split plot design. An analysis of variance (Table 1) was performed;

Table 1. Analysis of Variance Format

Source	Degree of Freedom	
Treatment	(t-1)	1
Error A	(r-1)+(r-1)(t-1)	4
Strain	(s-1)	3
Strain x Treatment	(s-1)(t-1)	3
Error B	(r-1)(s-1)+(t-1)(r-1)(s-1)	12

Yield data on seven pairs of isolines (black and white colored seed coats) are included. No root or soil data were taken on this test, but the non-compacted, compacted, and tillage treatments were the same as used on the four strains.

These tests were included to see if other strains of beans have the same effects as the four cultivars used in this study. The seven isoline pairs were added to study possible differential response of black and white colored strains. These seven pairs of near-isolines included white and black lines from NEP-2 and Black Turtle Soup crosses, also white mutant lines from Black Turtle Soup, N 203, and San-Fernando black seeded lines.

In 1979 and 1980, advanced breeding lines were tested for yield at a non-compacted and compacted level. Yield testing at two levels of compaction increases cost, since more land and labor is needed per breeding line than with one level of soil compaction. To determine if we could eliminate the compacted treatment without losing our selection efficiencey, the following study was conducted.

Sixty-five entries, both black and white, including seven commerical varieties used as checks, were selected for this study. Entry selection was based on each breeding line grown and harvested in both 1979 and 1980 on the Saginaw Bean and Beet Research Farm on non-compacted and compacted sites. These entries had not been previously selected for yield performance at different levels of soil compaction.

Entries were ranked, on yield data, from 1 to 65 for each level of treatment for 1979 and 1980 and on the average over both years. The average and the standard deviation for each level of treatment for each and two year average, were calculated. Each ranking (1 through 65) was divided into three groups:

Group one; those entries yielding higher than one half the standard deviation above the average.

Group two; those entries yielding no more nor less than one half the standard deviation above or below the average, respectively.

Group three; those entries yielding lower than one half the standard deviation below the average.

Each level of treatment for each year and average over two years had its own particular average and standard deviation. The entries (advance breeding lines) in group one of non-compacted treatment were compared to the entries in group one of the compacted treatment for each year. The number of entries that were common to both groups were divided by the total number in that particular group for a percentage rating. Similarly low yielding entries in group three of both treatments were compared. The higher this percentage figure, the more similar these entries yielded across treatments.

For yield data averaged over two years, entries were given either a plus if above the average or minus if below the average for each level of treatment. If yield for both levels of treatment, for each entry, were above the average (+,+) or below the average (-,-) it was considered a match; if one treatment was above the average (+) and the other one below (-) the average it was not a match. The more matches there were, the more entries that yielded above the average for both treatments or below the average for both treatments.

An anlysis of variance was calculted on yield for the two years at both treatment levels. The sources of variation that should be tested would be compaction (two levels), years, the interaction of compaction times year, entry, entry times compaction interaction, and entry times year interaction. The entry times year times compaction three way interaction was used for testing the above source of variation.

We would be most interested in the "entry times compaction" interaction. If it should prove significant, there would be a real difference in yield across the compacted and non-compacted treatments for entries. We could not drop (without loss of sufficient information) the compacted treatment since low yielding lines on non-compacted might be high yielding on non-compacted treatment and vice versa. None-the-less if " entry times compaction" interaction proved not significant, then there would be reason to eliminate the compacted treatment since low yielding lines would tend to yield low for both treatments and high yielding lines would tend to yield high for both treatments.

A correlation analysis was calculated between yield on non-compacted and compacted plots averaged over two years. A high correlation coefficient near untiy would indicate that low yielding lines would yield low and high yielding lines would yield high at both treatments. A correlation coefficient near zero would indicate no or little predictability on what a line would yield on the compacted treatment from known performance on the non-compacted treatment.

The 65 cultivars were rated by regression on their performance over different environments (Eberhart and Russel, 1966). There are four environments in this study, two years of testing at two levels of soil compaction. Each environment has an environmental index which is equal to the average yield for all lines for that particular environment. Yield values for each cultivar are regressed against the environmental indexes. From this regression a response line of slope, b, and the sums of deviation from regression, d^2, are calculated.

A desired cultivar would have a high average yield, a slope, b near 1, indicating a cultivar stable over environments, and the deviations from regression, d^2, was small as possible.

RESULTS AND DISCUSSION

1.0 Soil and Root Data

1.1.1 Soil Sampling on June 27.

Highly significant differences were found between bulk densities of compacted and non-compacted treatments at soil profile level one (6.4cm) and level two (14.0cm), but not at level three (21.6cm) on June 27 (Table 2 and 3). The low values for replication and treatment times replication sums of squares compared to treatment sum of squares indicate little interaction for replication and treatment times replication sources of variation. This indicates a true difference between compacted and non-compacted treatments.

Table 2. Effect of compaction on bulk density in soil profile level one of a Charity clay soil at the Bean and Beet Research Farm on June 27, 1979.

Analysis of Variance				
Source	df	Sum of Squares	Mean Square	F
Treatment	1	.0968	.0968	47.5**
Replication	2	.0011	.0006	.27
Treatment x Replication	2	.0161	.0081	3.95
Error	12	.0245	.0020	
Total	17	.1386	-----	

Table 3. Effect of compaction on bulk density in soil profile level two of Charity clay soil at the Bean and Beet Research Farm on June 27, 1979.

Analysis of Variance				
Source	df	Sum of Squares	Mean Squares	F
Treatment	1	.0365	.0365	29.69**
Replication	2	.0020	.0010	.82
Treatment x Replication	2	.0021	.0011	.86
Error	12	.0147	.0012	
Total	17	.0553	-----	

Table 4 indicates that differences between soil bulk densities between treatments were greater near the soil surface and decreased as depth below soil surface increased. Averaged differences were 0.15, 0.09, and 0.00 for levels 1,2, and 3 respectively. Due to the soil core sampling procedure, no difference in soil bulk densities between different strains of dry beans were taken.

Table 4. Averaged soil bulk densities at three soil profile levels averaged over strains of a Charity clay soil at the Bean and Beet Research Farm on June 27, 1979.

	Soil Profile Level 1 (6.4 cm)	Soil Profile Level 2 (14 cm)	Soil Profile Level 3 (21.6 cm)
Non-compacted	1.16	1.30	1.37
Compacted	1.31	1.39	1.37
LSD (.05)	.046	.03	

Note: Values are in grams/cc of oven dry soil

Percent moisture on a volumetric basis showed a highly significant difference for soil profile levels one and two (Table 5). These average percent volumetric moisture figures were highly correlated, r= 0.98, with the average bulk density figures in Table 4.

Table 5. Percent volumetric moisture in a Charity clay soil at three soil profile levels at the Bean and Beet Reserach Farm on June 27, 1979.

	Profile Level 1	Profile Level 2	Profile Level 3
Non-compacted	32.0	38.5	40.3
Compacted	37.3	41.0	39.4
LSD (.05)	2.25	1.86	NS

Simple correlations were calculated between bulk density (BD) and percent volumetric moisture (PVM) at each soil profile level (Table 6). Highest correlations are shown between level one and two for BD 1 versus Bd 2, BD 1 versus PVM 1, and PVM 1 versus PVM 2. All three correlations between level one and level three are negative, but near zero. Apparently, bulk density and soil moisture in level three had little relationship with levels one and two.

Table 6. Simple correlations on a sample basis between bulk density and percent volumetric moisture at three soil profile levels of a Charity clay soil at the Bean and Beet Research Farm on June 27, 1979.

	BD 1	BD 2	PVM 1	PVM 2	PVM 3
BD 1	1.00	---	.72	---	---
BD 2	.79	1.00	.57	.52	---
BD 3	-.07	.27	-.04	.16	.36
PVM 2	---	---	.74	1.00	---
PVM 3	---	---	.18	.01	1.00

BD = Bulk density
PVM = Percent volumetric moisture
1,2,3, = Soil profile levels 1,2,or 3

By using bulk density means, percent volumetric moisture means and the average particle density, percent of volume occupied by soil particles, the percent saturation and percent pore space occupied by air are shown in Table 7. As soil is compressed individual soil particles and water are not compressable thus, air-filled porosity is reduced. Table 7 indicates little changes with depth in pore space occupied by air in the compacted treatment compared to levels one verses level two and three on the non-compacted treatment. The percent pore space occupied by air is apparently, high enough (greater than 10 percent) for root development.

Table 7. Percent soil solids, soil moisture, and soil air at three soil profile levels of a Charity clay soil at the Bean and Beet Research Farm on June 27, 1979.

Soil Profile Level	Percent Soil Solid	Percent Saturation	Percent Air
1	43.8(49.4)	56.9(75.5)	43.1(24.5)
2	49.1(52.5)	75.5(78.2)	24.4(21.8)
3	51.7(51.7)	77.9(76.2)	22.0(23.8)

Note: ( ) denotes values are for the compaction treatment
unbracketed values are for the non-compaction treatment

Brake (1976) has given an air-filled porosity value of 0.1 as the critical value. The data in table 7 indicates that percent soil particle increased and percent saturation increased as depth from soil surface increased. Percent air-filled porosity of the non-compacted treatments decreased with depth. The non-compacted treatment at level one which had lowest bulk density also had lowest percent saturation and highest percent air-filled porosity.

Rainfall for each of the first three weeks after June 27 was 4.78, 1.96, and 9.17 cm , respectively. Pan evaporation for the same weeks were 1.11, 3.18, and 3.25 cm (Table A 1). The relationship between pan evaporation and evapotranspiration of dry beans near full canopy is 0.8. Rainfall for the next three weeks, June 27 through July 17 was 15.9 cm . Pan evaporation was 7.5 cm for the same period giving an apparent increase of 15.9 cm rainfall minus the quanity (7.5 cm x 0.8), 9.9 cm of moisture. Tiles did drain, but the amount of water removed by tile drainage is unknown, but evidence points to an increase in soil moisture with a decrease in air-fiil porosity during this period.

1.1.2 Root data on July 6.

No significant differences were found in root weights at any soil profile level, between strains or treatments in samples taken on July 6. Root weights from sample cores were averaged at each level (Table 8). The greatest difference between treatments is the 14.1 percent difference in level two. In level one root weights on compacted plots were larger than in non-compacted plots. Figure 4, 5, 6, and 7 show the horizontal secondary roots of plants in compacted plots that gave larger root weights in level one. The weight of the tap root in level one is not included in either treatment (Table 8).

Table 8. Average root weights over four varieties at each of three soil profile levels as determined on July 6, 1979 on the Bean and Beet Research Farm

Soil Profile	Weight of Roots (air dry in grs)	Percent of Total Root Weight
1	.0816(.0931)*	47.4(58.3)
2	.0645(.0373)	37.5(23.4)
3	.0260(.0292)	15.1(18.3)
Total	1.721(1.596)	

Treatment differences are significant
* ( ) denotes compacted treatment
Unbracketed denotes non-compacted treatment

Simple correlations were calculated between average root weights as related to soil air, bulk density, and soil water, from samples taken on June 27 on both compacted and non-compacted treatments (Table 9). Root weights were positively correlated with soil air, but negatively correlated with bulk density and soil water. Since there were no significant differences between root weights, one shoul be careful not to emphasize the correlations in Table 9, only look at the trends they suggest. As soil bulk density increased weights of collected roots decreased.

Table 9. Correlations between root weights and soil parameters. Root weights averaged over 4 varieties, sampled on July 6, 1979 at the Bean and Beet Research Farm.

	N	Root Weights Non-compacted	Root Weights Compacted
Soil Air	6	.64	.61
Bulk Density	6	-.92*	-.98*
Soil Water	6	-.60	-.68

* significant at P = .05

1.2 Soil Sampling at Physiological Maturity

1.2.1 Soil Bulk Density on August 28.

Highly significant differences at soil profile levels one and two and significant differences at levels three and four, with no significant differences in levels five and six were found in soil bulk density at physiological maturity (Table 10). Level one showed the greatest differences of

0.22 grams/cc between treatments. Soil bulk density differences decreased with depth with no differences in levels five and six between treatments. Level five and six showed evidence of a hard pan or clay accumulation layer, with an increase in bulk density. The use of secondary tillage (3 times with harrow) did not loosen level one of the compacted treatment. No change was noted between levels 2, 3, and 4 in bulk density on compacted plots. The soil bulk density of the A horizons were 1.23 grams/cc and 1.40 grams/cc on non-compacted and compacted treatments, respectively.

Table 10. Averaged soil bulk densities on six soil profile levels of a Charity clay soil taken at the Bean and Beet Research Farm on August 28, 1979.

Soil Profile Level	Non-compacted	Compacted	Difference
1(6.4)[1]	1.15[2]	1.37	0.22**
2(14.0)	1.23	1.42	0.19**
3(21.6)	1.30	1.42	0.12*
4(29.2)	1.35	1.42	0.07*
5(36.8)	1.50	1.52	0.02
6(44.5)	1.48	1.48	0.00

1 cm from mid-point of soil cube to soil surface
2 Grams/cc

Table 11. Percent volumetric moisture of soil samples taken at six profile levels of a Charity clay soil on August 28, 1979 at the Bean and Beet Research Farm.

Soil Profile Level	N-C	C	Difference (c-nc)
1(6.4)	22.1	28.8	6.7**
2(14.0)	24.0	31.4	7.4**
3(21.6)	26.6	29.4	2.8*
4(29.2)	27.1	30.6	3.5*
5(36.8)	30.5	30.6	0.1
6(44.5)	28.7	31.4	2.7*

* Significant at .05
** Significant at .01

1.2.2 Soil Moisture on August 28.

Comparison of soil moisture means is presented in Table 11. All levels, except level five, showed either highly significant or significant differences between non-compacted and compacted treatments. Moisture percent was always higher on compacted plots. Percent moisture increased with depth, except at level five, which had the highest bulk density, 1.5 gr/cc, in both treatments. The 31.4 percent moisture in level two of the compacted treatment may be attributed to sampling varietion.

Table 12. Percent soil solids, saturation and sir of soil samples taken at six profile levels, at two rates of soil compaction on August 28, 1979 at the Bean and Beet Research Farm.

Soil Profile	Soil Particles		Water		Air	
Level	NC	C	NC	C	NC	C
1	43.4	51.7**	39.0	59.6**	61.0	40.4
2	46.4	53.6**	44.8	61.1**	55.2	32.3
3	49.1	53.6*	52.3	63.4*	47.7	36.6
4	50.9	53.6*	55.2	65.9*	44.8	34.1
5	56.6	57.4	70.3	71.8	29.7	28.2
6	55.8	55.8*	64.9	71.0	35.1	29.0

All means in percent
** Treatment differences were highly significant
* Treatment differences were significant

1.2.3 Soil Structure on August 28.

Percent soil solids along with percent saturation and percent air saturation are shown in table 12. The compacted soils have higher moisture saturating percentages, especially soil profile levels one, two, three, and four with 20.6, 23.1, 10.1, and 10.7 percent differences, respectively. Percent of soil pore space which is air decreased with depth below soil surface and decreased as soil bulk density increased. None of the percent air saturation values (Table 12) are below or close to the 0.1 critical air-filled volume fraction given by Blake *et al*., (1976). These data indicated by the values for percent air-filled pore space, that lack of oxygen was not detrimental to plant growth at this period.

Rainfall for the previous three weeks was 0.79 cm and pan evaporation was 7.97 cm thus suggesting a loss of soil moisture and an increase in the air-filled volume fraction for this period (Table A 1). The heavy rain on July 11 of 9.17 cm may have caused a temporary period in which soil moisture saturation was high enough to lower the air-filled volume fraction of the soil below the critical 0.1 volume (Blake _et al_., 1976). Water remained standing on the compacted soils, but not on the non-compacted soils as long as 24 hours after this rain.

1.3 Plant Roots at Physiological Maturity.

Comparison of mean air-dried root weight showed significant differences at levels two and three with an LSD of .021 and .013 grams, respectively, between non-compacted and compacted treatments (Table 13a and 13b). In level two Seafarer had the largest difference, .064 grams, with San-Fernando showing difference of .028 grams, and NEP-2 with a difference of .052 grams. In level three Seafarer showed a difference of .017 grams and San-Fernando .014 grams.

With one exception, (Seafarer at level two) root weights for both treatments decreased as depth below soil surface increased. Colored strains had a higher percent of their roots in level one than non-colored strains at both soil compaction levels. Plants in the compacted treatment had a higher percent of their roots in level one than plants in the non-compacted treatment. In level two, differences in percent root weights between treatments were greater for non-colored strains than colored strains.

Significant differences between strains occurred only in soil profile level one with an LSD (.05) of .027 grams. Roots of Seafarer, Black Turtle Soup, and San-Fernando at level one in compacted plots out weighed the corresponding roots produced in the non-compacted plots. NEP-2 was an exception. San-Fernando was the only strain with significant differences in root weights. The short tap root on plants from compacted plots, (Fig. 4,5,6, and 7) illustrates the higher root weights in level one. In the non-compacted plots the tap roots were not obstructed, they elongated deeper into the soil, and thus, less secondary and lateral roots developed in level one.

High coefficients of variation, especially in levels four, five and six, among root weights indicate that air-dried weights of roots may not be the best indicator. A system estimating root length, diameter, and number of roots may better indicate relationships with above ground plant parameters.

Table 13a. Average root weights (air-dried, in grams) of non-colored Seafarer and NEP-2 varieties at six soil profile levels of soil compaction on September 9, 1979 at the Bean and Beet Research Farm.

Soil Profile Level	Seafarer	NEP-2	Average	Percent
1	.1328(.1414)	.1337(.1116)	.1333(.1266)	31.9(39.2)
2	.1138(.0496)	.1289(.0772)*	.1214(.0634)	29.0(19.6)
3	.0852(.0678)*	.0703(.0595)	.0778(.0637)	18.6(19.7)
4	.0395(.0285)	.0331(.0294)	.0363(.0290)	8.7(9.0)
5	.0291(.0148)	.0317(.308)	.0302(.0228)	7.2(7.1)
6	.0183(.0148)	.0203(.0214)	.0193(.0172)	4.6(5.3)
Total	.4187(.3169)	.4108(.3299)	.4148(.3234)	

* significant difference between treatment means at 0.05 level of probability.
All weights are in grams of air-dried roots. Tap root of level one is not included.
( ) denotes compacted treatment
Unbracketed denotes non-compacted treatment.

Table 13b. Average root weights (air-dried, in grams) of colored Black Turtle Soup and San-Fernando strains at six soil profile levels on two levels of soil compaction on September 9, 1979 at the Bean and Beet Research Farm.

Soil Profile Level	BTS	San-Fernando	Average	Percent
1	.1972(.2126)	.1114(.1445)	.1543(.1786)	44.3(47.9)
2	.0776(.0938)	.0936(.0650)*	.0856(.0794)	24.6(22.9)
3	.0457(.0484)	.0665(.0525)*	.0561(.0510)	16.1(13.7)
4	.0259(.0242)	.0215(.0265)	.0237(.0254)	6.8(6.8)
5	.0175(.0150)	.0110(.0308)	.0143(.0229)	4.1(6.1)
6	.0171(.0151)	.0110(.0167)	.0141(.0159)	4.1(4.3)
Totals	.3813(.4031)	.3150(.3360)	.3482(.3726)	

* Significant difference between treatment means at 0.05 level of probability
All weights are in grams of air-dried roots. Tap root of level one is not included
( ) denotes compacted treatment
Unbracketed denotes non-compacted treatment

Figure 4. Seafarer plants from non-compacted and compacted plots 25 days after emergence, June 28, 1979, grown on the Bean and Beet Research Farm.

Figure 5. Black Turtle Soup from non-compacted and compacted plots 25 days after emergence, June 28, 1979, grown on the Bean and Beet Research Farm.

Figure 4.

Figure 5.

Figure 6. Plants of San-Fernando from non-compacted and compacted plots 25 days after emergence, June 28, 1979, grown on the Bean and Beet Research Farm.

Figure 7. Plants of NEP-2 from non-compacted and compacted plots 25 days after emergence, June 28, 1979, grown on the Bean and Beet Research Farm.

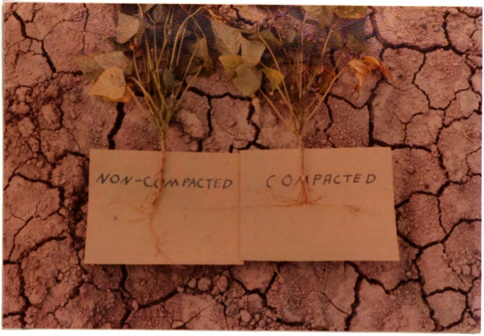


Figure 6.

Figure 7.

2.0 Above Ground Vegetative Growth (Parameter)

2.1 Plant Population

Plant populations were determined fifteen days after emergence. Mean numbers of plants are shown in Table 14. Thirty-two plants per three meters of row were considered as 100 percent germination. Soil crusting was of no consequence in either treatment. No significant differences were found between compaction treatments. Highly significant differences were found between strains with an LSD (.05) of 3.7 plants. Poor emergence of NEP-2 was due to poor seed quality, rather than treatment effects.

Table 14. Comparisons of plant populations of Seafarer, Black Turtle Soup, San-Fernando, and NEP-2 strains at two levels of soil compaction at the Bean and Beet Research Farm on June 2, 1979.

	Non-oompacted		Compacted	
	Number of Plants per 3 meter row	Germination Percent	Number of Plants per 3 meter row	Germination Percent
Seafarer	25.3	.78	24.6	.77
Black Turtle Soup	28.3	.88	26.6	.81
San-Fernado	27.7	.87	27.3	.85
NEP-2	19.0	.59	8.3	.57

LSD (.05) = 3.7 plants between strain means
LSD (.05) - 5.6 plants between two strain means at the same treatment

2.2 Dry Matter Accumulation

Dry matter accumulation was measured at time of flowering, mid-pod filling, and physiological maturity. Comparisons of means determined at flowering show no significant differences between strains. LSD (.05) was 2.6 grams for strains (Table 15). Black Turtle Soup showed it's superiority with the highest dry matter weights. NEP-2's lighter dry matter weights reflect lower plant densities.

Table 15. Shoot dry matter accumulations at flowering of Seafarer, Black Turtle Soup, San-Fernando, and NEP-2 strains at two levels of soil compaction on July 12, 1979 at the Bean and Beet Research Farm.

Strain	Non-compacted	Compacted	Non-compacted Advantage
Seafarer	11.5	12.9	-1.4
Black Turtle Soup	14.7	15.3	-0.6
San-Fernando	10.7	10.6	0.1
NEP-2	8.4	8.6	-0.2
Average	11.3	11.9	-0.6

Figures are in grams of air-dried plants per 0.5 m of row
LSD (.05) = 3.7 grams between strains at the same treatment

Comparison of dry matter accumulation at the mid-pod filling stage showed hihgly significant differences between treatment means (Table 16). The LSD (.05) is 7.29 grams with a coefficient of variation of 12,3 percent. San-Fernando showed the widest range between treatments (Table 16). All compacted means were smaller than non-compacted means for corresponding strains.

Comparisons between dry matter data at flowereing (Table 15) and at mid-pod filling (Table 16) indicate that NEP-2, even with lower plant population, was able to increase dry matter accumulation to within 9.2 g and 7.4 g of Black Turtle Soup and San-Fernando, respectively, on non-compacted sites. There is a marked increase in the difference between treatments at mid-pod filling, as compared at flowering. At flowering, soil compaction affects on dry matter accumulation were not evident, but they were evident at mid-pod filling.

Table 16. Shoot dry matter accumulation at mid-pod filling of Seafarer, Black Turtle Soup, San-Fernando, and NEP-2 strains at two levels of soil compaction on July 31, 1979 at the Bean and Beet Research Farm.

Strain	Non-compacted	Compacted	Non-compacted Advantage
Seafarer	52.6	46.0	6.6
Black Turtle Soup	73.1	48.3	24.7
San-Fernando	71.3	27.2	44.1
NEP-2	63.9	37.9	26.0
Average	65.2	39.9	25.3

Figures are in grams of air-dried plants per 0.5 m of row
LSD (.05) = 7.3 grams between treatment
LSD (.05) = 8.7 grams between two treatments at the same or different strains.

At physiological maturity, dry matter accumulation means were significant between treatments, with an LSD of 42.5 grams. Black Turtle Soup, Sna-Fernando, and NEP-2 showed 49.1 g, 121.6 g, and 57.8 grams more dry matter produced on non-compacted plots, than on compacted plots. Seafarer showed no significant difference (Table 17).

Differences between strains and the interaction of strains x treatment were both highly significant. Seafarer didn't produce nearly as much dry matter as the other three strains. After a rainfall of 9.2 cm on July 11, there were 5 days during which the mean temperature ranged from 23 to 24 C . Seafarerer suffered severly, losing more than 50 percent of its leaves from bacterial blight and ozone damage. The other three stains were affected very little (Table 17).

Table 17. Shoot dry matter accumulation at physiological maturity for Seafarer, Black Turtle Soup, San-Fernando, and NEP-2 at two levels of soil compaction on September 9, 1979 at the Bean and Beet Research Farm.

Strain	Non-compacted	Compacted	Average	C/NC Ratio
Seafarer	75.3	87.5	81.4	0.86
Black Turtle Soup	170.9	121.8	146.4	1.40
San-Fernando	228.3	106.7	167.5	2.14
NEP-2	213.6	155.8	184.7	1.37
Average	172.0	117.9		

Figures in grams of air-dried plants per 0.5 m of row
LSD (.05) = 42.5 grams between two treatments means
30.6 grams between two strain means
43.3 grams between two strain means at same treatment
31.5 grams between two treatment means at same or different strains.

2.3 Plant Canopy Height

Height of the plant canopy was measured on July 18 for over-all growth. Significant differences were found both among treatment and strain means (Table 18). Black Turtle

Soup showed greater height on non-compacted sites, whereas there were essentially no differences between strains on compacted plots. Figures 8 through 17 show the canopy for each strain at each treatment.

Table 18. Height of plant canopy at 46 days from emergence of Seafarer, Black Turtle Soup, San-Fernando, and NEP-2 at two levels of soil compaction on July 18, 1979 at the Bean and Beet Research Farm.

Strain	Non-compacted	Compacted	C/NC Ratio
Seafarer	37.0	35.3	1.04
Black Turtle Soup	46.3	34.6	1.34
San-Fernando	39.0	32.7	1.19
NEP-2	36.0	33.7	1.07
Average	39.6	34.1	

Figures in cm
LSD (.05) = 1.5 between treatment means
3.7 between strain means
5.3 between two strain means at same treatment
3.8 between two treatment means at the same or different strains

2.4 Starch Rating of Roots

Starch ratings in roots increased from the flowering to mid-pod filling, stages of plant development in all four strains (Table 19). No difference was noted at mid-pod filling between treatments in the black-seeded strains, but significant differences were noted between treatments among the white-seeded strains. Root starch ratings of Seafarer and Black Turtle Soup decreased from mid-pod filling to physiological maturity, except Black Turtle Soup on the compacted site. Starch ratings in roots of San-Fernando and NEP-2 increased to physiological maturity.

Figure 8. Seafarer on non-compacted plots 40 days after emergence, July 13, 1979, grown on the Bean and Beet Research Farm.

Figure 9. Seafarer on compacted plots 40 days after emergence, July 13, 1979, grown on the Bean and Beet Research Farm.

Figure 8.

Figure 9.

Figure 10. Black Turtle Soup on non-compacted plots 40 days after emergence, July 13, 1979, grown on the Bean and Beet Research Farm.

Figure 11. Black Turtle Soup on compacted plots 40 days after emergence, grown on the Bean and Beet Research Farm, July 13, 1979.

Figure 10.

Figure 11.

Figure 12. San-Fernando on non-compacted plots 40 days after emergence, July 13, 1979, grown on the Bean and Beet Research Farm.

Figure 13. San-Fernando on compacted plots 40 days after emergence, July 13, 1979, grown on the Bean and Beet Research Farm.

Figure 12.

Fgiure 13.

Figure 14. NEP-2 on non-compacted plots 40 days after emergence, July 13, 1979, grown on the Bean and Beet Research Farm.

Figure 15. NEP-2 on compacted plots 40 days after emergence, July 13, 1979, grown on the Bean and Beet Research Farm.

Figure 14.

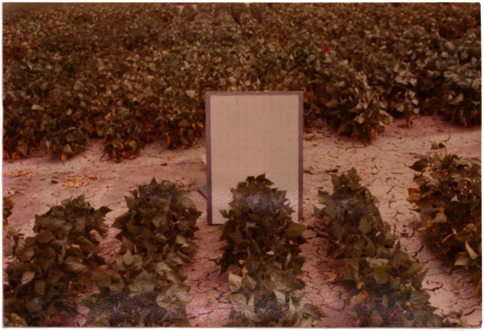


Figure 15.

Figure 16. Seafarer at flowering on non-compacted plots 45 days after emergence, July 18, 1979, grown on the Bean and Beet Research Farm.

Figure 17. Seafarer at flowering on compacted plots 45 days after emergence, July 18, 1979, grown on the Bean and Beet Research Farm.

Figure 16.

Figure 17.

Table 19. Starch ratings in roots at flowering, July 12; mid-pod filling, July 31; and physiological maturity, September 9, 1979 of Seafarer, Black Turtle Soup, San-Fernando and NEP-2 strains at two levels of soil compaction on the Bean and Beet Research Farm.

Date	Treatment	Seafarer	Black Turtle Soup	San-Fernando	NEP-2	LSD(.05)
Flowering	N-C	1.0	1.0	1.0	1.0	.2 treatment
	C	1.1	1.4	1.3	1.0	.2 strain
Mid-pod Filling	N-C	1.5	3.2	2.1	1.4	.7 treatment
	C	2.7	3.2	2.2	2.2	.6 strain
Physiological Maturity	N-C	1.1	1.9	3.2	3.8	----
	C	1.0	3.1	3.5	3.5	1.2 strain

N-C non-compacted
C compacted
Scale: 1 = no visible staining
5 = near cpmplete staining

2.5 Starch Rating of Stems

There were no differences in starch levels of stem at flowering as compared with mid-pod filling. Seafarer and Black Turtle Soup showed evidence of the largest treatment differences with a rating difference of 1.1, indicating more starch in plants on compacted treatment. Black Turtle Soup did not decrease as much on the compacted site. San-Fernando and NEP-2 increased in stem starch rating to physiological maturity (Table 20).

There is similarity between root and stem starch ratings among strains and treatments. Treatment differences at mid-pod filling indicate the lack of a large enough sink in plants on compacted site for carbohydrates being produced; thus more sugars were stored in the stem and root as starch. Black Turtle Soup, NEP-2 and San-Fernando are later maturing varieties and they produce and retain more starch than Seafarer.

3.0 Plant Reproductive Parameters

3.1 Pod Length Measurements

Comparisons of pod length measurements are shown in table 21. Neither moisture deficit or heat stress were noted when these data was taken. Seafarer displayed the largest treatment differences of 0.9 cm , with Black Turtle Soup and San-Fernando showing a difference of 0.8 cm at the fourth measurement. NEP-2 revealed the least treatment difference

Table 20. Starch rating in stems at flowering, July 12; mid-pod filling, July 31; and physiological maturity, September 9, 1979 of Seafarer, Black Turtle Soup, San-Fernando and NEP-2 strain at two levels of soil compaction on the Bean and Beet Research Farm.

Date	Treatment	Seafarer	Black Turtle Soup	San-Fernando	NEP-2	LSD(.05)
Flowering	N-C	1.0	1.1	1.0	1.0	---
	C	1.0	1.3	1.2	1.0	---
Mid-pod Filling	N-C	1.2	1.7	1.3	1.4	.9 treatment
	C	2.3	2.8	1.6	1.5	.7 strain
Physiological	N-C	1.4	1.4	2.3	2.9	---
	C	1.2	2.2	2.5	2.4	---

N-C non-compacted
C compacted
Scale: 1 = no visible staining of the cross section
5 = almost complete staining of the cross section

Table 21. Pod length, in cm , at two day intervals of Seafarer, Black Turtle Soup, San-Fernando, and NEP-2 strains at two levels of soil compaction on the Bean and Beet Research Farm.

Strain	Measurements			
	1	2	3	4
Seafarer	1.9(1.5)	3.3(2.3)	4.8(3.6)	6.4(5.3)
Black Turtle Soup	1.4(1.6)	4.0(4.0)	6.9(6.5)	9.1(8.3)
San-Fernando	1.3(1.4)	2.2(2.3)	5.2(4.6)	7.1(6.3)
NEP-2	1.2(1.2)	2.8(2.7)	4.2(3.9)	6.5(6.8)
LSD (.05) treatment	NS	.1	.2	.5
LSD (.05) strain	.1	.3	.5	.4
Two strain means at same level of Tmt.	.2	.4	.7	.6
Two treatment means at the same or different level of strains	.2	.4	.6	.3

Figure = non-compacted (compacted)

Twenty pods per replication were measured at the first date in Table 21; the same pods were measured at sequential two-day periods. Pod Abscission was evident when these measuremts were taken.

Pod abscission data are shown in table 22. Plants on compacted treatments lost significantly more pods than plants on the non-compacted treatments, except for the NEP-2 strain. Seafarer lost more than the other varieties, 15 and 35 percent on non-compacted and compacted plots, respectively. Pods were 1.5 to 1.9 cm long or longer before abscission occurred.

Table 22. Percent pod abscission of Seafarer, Black Turtle Soup, San-Fernando, and NEP-2 strains at two levels of soil compaction on the Bean and Beet Research Farm.

	Non-Compacted	Compacted
Seafarer	15	35
Black Turtle Soup	8	20
San-Fernando	2	13
NEP-2	5	5

LSD (.05) treatment 3.
LSD (.05) strain 3.

3.2 Days from Emergence to Flowering and Physiological Maturity.

No significant treatment differences were evident at flowering or at physiological maturiyt. Seafarer flowered eight days before the other strains. NEP-2 had the longest pod-filling period of 46 days, which should increase it's yield potential over other strains with a shorter pod-filling periods (Table 23).

Table 23. Days from emergence to flowering and to physiological maturity, for non-compacted and compacted treatment, respectively, for Seafarer, Black Turtle Soup, San-Fernando and NEP-2 strains on the Bean and Beet Research Farm.

Strain	Flowering	Physiological Maturity
Seafarer	35.7(36.7)	76.3(76.6)
Black Turtle Soup	43.3(42.7)	84.3(80.0)*
San-Fernando	44.5(43.7)	83.3(80.0)*
NEP-2	44.3(47.0)*	90.7(92.3)*
LSD (.05)	.7 days	.8 days
Two strains at same level of treatment	1.0 days	1.2 days
Two treatment means at different level of strain	1.5 days	1.4 days

* ( ) denoted compacted treatment
Unbracketed denote non-compacted treatment

3.3 Seed Size

Comparisons of seed size are shown in table 24. Significant differences were found only between treatments with and LSD (.05) of 1.3 grams. Difference in seed size did not contribute to yield differences between non-compacted and compacted treatments of the same strains.

Table 24. Seed weight in grams of one hundred seeds of Seafarer, Black Turtle Soup, San-Fernando, and NEP-2 strains grown at two levels of soil compaction on the Bean and Beet Research Farm in 1979.

Strain	Non-compacted	Compacted
Seafarer	18.3	16.1
Black Turtle Soup	19.6	19.9
San-Fernando	18.6	17.9
NEP-2	17.3	17.5

LSD (.05) between strains, 0.7 grams
between two strains at the same level of treatment, 0.9 grams
between two treatments at the same or different levels of strain, 1.2 grams

3.4 Economic Yield

Economic yield comparisons indicates plants on non-compacted plots out yielded plants on compacted plots for all strains (Table 25). The yields of white-seeded lines, Seafarer and NEP-2 were not significant between treatments. Seafarer had the lowest yield, on non-compacted plots which may have been due in part to bacterical blight and ozone, causing a premature loss of leaves.

Table 25. Economic (seed) yield in kg/ha of Seafarer, Black Turtle Soup, San-Fernando, and NEP-2 strains at two levels of soil compaction in 1979 at the Bean and Beet Research Farm.

Strain	Non-compacted	Compacted	Non-compacted Advantage
Seafarer	1644	1552	92
Black Turtle Soup	2127	1085*	1042
San-Fernando	2405	1530	875
NEP-2	2927	2680	47
Average	2276	1712	564

LSD (.05) between treatments, 321 kg/ha
between strains, 320 kg/ha
between two strain means at the same or different strain, 503 kg/ha

* All BTS replications were consistently low in this test, and markedly lower than this variety on other compacted plots in other experiments.

The black-seeded lines did not respond in economic yield on the compacted plots as expected. Black Turtle Soup yielded 1042 kg/ha lower and San-Fernando yielded 875 kg/ha lower on compacted than on non-compacted plots. Yields were closely related to number of days from emergence to physiological maturity for each strain.

3.5 <u>Yield Components</u>

The following equation shows components of yield; (seed size x seed per pod x pods per plant x number of plant/ unit area = yield). Earlier data indicated no significant differences between treatments for seed size (except Seafarer) or number of plants per unit area. Thus differences in seeds per pod and pods per plant must have been largely responsible for yield differences. Little difference was noted in length of pods, indicating small differences in seed per pod; thus number of pods per plant would be the important component in yield differences between treatments. Figure 18 illustrates the greates number of pods on the plant from a non-compacted site than from the compacted site.

4.0 Economic (seed) Yield of Seafarer, Black Turtle Soup, San-Fernando, and NEP-2 Strains in other Test.

The four strains discussed here were grown in other secondary experiments at the same location. Soil type, tillage, and planting operations were the same as previously stated. Both compacted and non-compacted treatments were used in the same experimental design. Soil compaction data were the same as that collected on the June 27 soil samples. Mean values for each treatment and for differences between means are shown in table 26.

In the primary tests, Seafarer yielded 281 kg/ha below and 233 kg/ha above the averaged yields of the secondary tests on non-compacted and compacted sites, respectively. These yield figures of 1644 kg/ha and 1552 kg/ha are well within the yield range of the other tests. There is no immediate explanation for the low yield, (1085 kg/ha) of Black Turtle Soup on the compacted site, except standing water on these plots after the July 11 rain. Two of the three replications gave a low yield causing the 1530 kg/ha value for San-Fernando on the compacted site. NEP-2 yielded higher on both treatments by 499 kg/ha on the non-compacted and 440 kg/ha on the compacted site. Water stood on the Black Turtle Soup and San-Fernando plots longer than on NEP-2 plots, which may lead to conclusion that lower economic yield was due to lack of sufficient O_2.

Figure 18. Seafarer plants from non-compacted and compacted plants approaching physiological maturity, August 8, 1979, grown on the Bean and Beet Research Farm.

Figure 18.

Table 26. Seed yield data in kg/ha on Seafarer, Black Turtle Soup, San-Fernando, and NEP-2 strains at two levels of soil compaction in secondary experiments in 1979 on the Bean and Beet Research Farm.

Test	Seafarer		Black Turtle Soup		San-Fernando		NEP-2	
	NC	C	NC	C	NC	C	NC	C
9101	1846	1081	1808	2170				
9102	1551	1011	1968	1810				
9103	2195	1012					2680	2450
9104	2054	1267	2500	1720	2710	2167	2841	2424
9105	2098	1133	2668	1367			2535	2151
9106	1514	1292	2266	1830				
9107			2174	1718				
9108	2009	1637					1863	2521
9109	2177	1008	2191	1573				
9110			2414	1276	2384	2089	2339	1910
9111							2307	1983
9112	2118	2142	2182	2139				
9113	1690	1602						
9114			2139	1959				
1	1925	1319	2231	1756	2547	2128	2428	2240
2	606		475		419		188	
3	1644	1552	2127	1085	2405	1530	2927	2680
4	92		1048		873		247	
5	281	-233	104	671	142	598	-499	-440

1. Average yield for all experiments
2. Non-compacted advantage of average yields for all experiments
3. Yield data means from Table 25
4. Non-compacted advantage of yields from Table 25
5. Average yields for experiments minus yield means from Table 25

5.0 Economic Yield of Seven Pairs of Near-Isolines

With respect to the performance of seven pairs of white and black seeded near-isolines on non-compacted and compacted treatments, the F statistic for treatments was very high compared to F-values for stains, color, and their interaction (Table 27). Treatments and strains effects were both highly significant, and all two-way interactions were also satistically significant. Color differences were not significant in this test. Large treatment differences apparently have influenced the two-way interactions. Thus, a closer look at the two and three-way interaction is necessary (Table 28).

Table 27. Analysis of variance for economic yield of seven pairs of near-isolines of dry beans grown in 1979 at two levels of soil compaction on the Bean and Beet Research Farm.

Source	Degree of Freedom	F
Treatment	1	416.9**
Error 1 = rep rep x tmt	4	
Strain	6	5.725**
Color	1	.5579
Strain x color	6	2.591*
Tmt x Strian	6	2.375*
Tmt x Color	1	5.883*
Tmt x Strain x Color	6	1.915
Error	52	

Table 28 shows the San-Fernando pair, consisting of San-Fernando as black-seeded and NEP-2, its EMS mutant, as white-seeded, yielding the highest over both treatments. The Black Turtle Soup pair yielded highest of all strains on non-compacted plots. The 62271 pair yielded lowest in both compacted and non-compacted sites. The difference between treatment means of 644 kilograms per hectare is highly statistically significant.

Table 28. Economic (seed) yield in kg/ha of seven pair of near-isolines of dry beans; two-way table strain vs treatment. Grown in 1979 at two levels of soil compaction on the Bean and Beet Research Farm.

Strain	Non-compacted	Compacted	Means[2]
61328	2343	1673	2008 B
61061	2367	1722	2045 AB
B T S	2413	1420	1915 B
N203a*	2128	1750	1938 B
N203b*	2278	1529	1903 B
62271	2078	1366	1722 C
San-Fernando	2366	2003	2180 A
Means	2282	1633	

LSD (.05) difference between two strains means, 170 kg
LSD (.05) difference between two treatment means, 148 kg
1 Figures are in kilograms per hectare
2 Means followed by same letter are not significantly different
* Two white mutants from N203 were used in this test; the black seeded N203 was paired with each white mutant.

White seeded strains on non-compacted soil out-yielded white-seeded strains on compacted plots by 753 kilograms per hectare (Table 29). Black-seeded strains on non-compacted soil out-yielded black on compacted soil by 534 kilograms per hectare.

White-seeded strains out-yielded pigmented seeded strains by 143 kg/ha on non-compacted plots, but the colored strains out-yielded the white-seeded on the compacted site by 76 kg/ha, indicating a treatment x seed color interaction. More important are the 32 percent and 24 percent reductions in yields of white and black seeded lines, respectively, due to averse effects of soil compaction.

Table 29. Two-way interaction of soil compaction treatment vs seed color in seven pairs of near-isolines of dry beans grown in 1979 on the Bean and Beet Research Farm.

Treatment	White	Black	Means
Non-compacted	2353	2210	2282
Compacted	1600	1676	1638
Percent decrease due to Compaction	32*	24*	28*

Color differences were not significant
LSD (.01) difference between treatment means, 145 kg
Figure are in kilograms per hectare
* Figures are in percent

The three-way table 30 illustrates the color vs treatment interaction with each strain. Among the white-seeded lines, white-seeded variants of strain 61328 and N203b were depressed the most by soil compaction among the blacks, Black Turtle Soup and 62271 were depressed most. White-seeded strains of 61328, 61061, and Black Turtle Soup yielded the highest on non-compacted plots. Performance of five of the seven strains indicated that yields on non-compacted plots were about the same, regardless of seed color, but on compacted plots, yield of white-seeded strains were depressed more than their black-seeded isoline counterparts.

Percent decrease in yield due to adverse effect of soil compaction is shown in table 30. Black Turtle Soup had the greatest percent reduction (47 percent). 61328 white, and N203b, the white mutant and had their yields reduced 39 percent by soil compaction. San-Fernando had the lowest reduction due to soil compaction in this test. More important is the 28 percent overall yield reduction in yield for all strains, both white and colored (Table 29).

Table 30. Economic (seed) yield in kg/ha of seven pairs of near-isolines of dry beans (black and white seeded) grown at two levels of soil compaction at the Bean and Beet Research Farm 1979.

Three-way Table

Strain	Color	Non-compacted	Compacted	% decrease due to compaction
61328	white	2430	1425	41
	black	2255	1925	15
61061	white	2440	1695	31
	black	2295	1750	24
B T S	white	2410	1560	35
	black	2420	1280	47
N 203a	white	2090	1745	17
	black	2165	1755	19
N 203b	white	2375	1395	47
	black	2180	1660	24
62271	white	2386	1465	39
	black	1770	1260	29
San-Fernando	white*	2345	1910	19
	black	2385	2090	12
Means	white	2353	1600	32
	black	2210	1676	24

LSD (.05) Difference between means of two strains (color) at same level of treatment, 240 kg
Difference between two treatments at the same or different level of strain (color) - 250 kg
Figures are in kilograms per hectare

* The white mutant of San-Fernando is NEP-2

6.0 Comparisons on seed yield of 65 cultivars across two levels of soil compaction in 1979, 1980 and the two year average.

Results of seed yields of 65 cultivars on non-compacted and compacted treatments are listed in table A2, A3, and A4 for the years 1979, 1980 and the average over both years, respectively. Columns A and B on table A2, A3, and A4 have either a plus or a minus depending on whether the yield for that cultivar at a particular level of soil compaction is above or below the average yield for treatment and year. This is summarized in Table 31.

Table 31. Comparisons of seed yield, above and below the average yield, across two levels of soil compaction, on 65 dry bean cultivars grown in 1979 and 1980 at the Bean and Beet Research Farm.

	Number above the average*		Percent of Cultivars in both groups
Year	Non-compacted	Compacted	
1979	35(2811)	36(2296)	56.9
1980	34(2878)	39(2650)	76.9
Two year average	33(2843)	33(2472)	76.9

* Only the above the average groups are shown
( ) denote average yields for year at a level of soil compaction.

In 1979 thirty seven 56.9 percent cultivars matched for yields above or below the average across two levels of soil compaction. In 1980 and the two year average of 50 cultivars or 76.9 percent matched for yield across levels of soil compaction. Cultivars were more stable in yields across levels of soil compaction in 1980 than in 1979. Detrimental effects of soil compaction on yield were greater for 1979, 515 kg/ha or 18.3 percent reduction than in 1980, 228 kg/ha or 7.9 percent reduction. This data indicates that high yielding cultivars tend to yield high for both levels of soil compaction.

Since medium yielding cultivars would be more prone to mismatch more than high or low yielding cultivars, cultivars were divided into three groups of 1 (high); 2 (meium); and 3 (low) yielding. Data is in table A2, A3, and A4 under columns headed "Group" and is summarized in table 32.

Table 32 indicates, in 1979, repeatability of high yielding, group 1, cultivar is higher, 65 percent, than low yielding, group 3 cultivar, 37 percent, across the two levels of soil compaction. In 1980, 78 percent, 18 out of 23 high yielding cultivars were common to group 1 on the non-compacted and compacted soil treatments. Thirteen of 18 cultivars for the low yielding group 3, were in the yielding group for both levels of soil treatment. Genotype tended to be more stable over soil treatments in 1980 than in 1979.

Figure 19 indicates data average over two years, all cultivars in group 1 (high yielding) of non-compacted treatment were not below the average in the compacted treatment. Similiarly cultivars in group 3 of the non-compacted treatment were not above the average yield for the compacted treatment. Since cultivars selection would usually select the higher yielding lines, selection of superior yielding genotype can be accomplished without testing at different levels of

Table 32. Comparisons of seed yields of 65 cultivars in high or low yielding group across two levels of soil compaction at the Bean and Beet Research Farm in 1979 and 1980.

Year	High Yielding				Low Yielding			
	NC	C	A	B	NC	C	E	F
1979	20(>2974)	20(>2498)	13	65	19(<2650)	16(<2093)	7	37
1980	23(>3115)	21(>2853)	18	78	18(<2641)	18(<2447)	13	72
G	10(>2829)	8(>2532)	5	50	12(<2247)	10(<1893)	8	67

NC = Non-compacted
C = Compacted
A = Number of cultivars common to both NC and C high yielding group
B = percent of cultivars common to both NC an C high yielding group
E = Number of cultivars common to both NC and C low yielding group
F = Percent of cultivars common to both NC and C low yielding group
G = Two year average
(   ) Seed yield in kg/ha

soil compaction.

Simple correlation between yields average over two years on these 65 cultivars on non-compacted and compacted soil treatments was calculated with r = 0.84. This is significant with 63 degrees of freedom. This supports the concept that high yielding cultivars tend to yield high across different levels of soil compaction normally found in field conditions.

Analysis of variance table for these cultivars is shown in table 33. Using the three-way, entry x year x compaction as the error term, all main and two-way interactions are highly significant, except the cultivar x compaction interaction. Thus, the interaction between yield of cultivars at different levels of soil compaction was not significant and high yielding cultivars would tend to yield high for both levels of soil compaction and low yielding cultivars would tend to yield low for both levels of soil compaction.

Table 33. Seed yield analysis of variance for 64 cultivars grown for two years at two levels of soil compaction in 1979 and 1980 at the Bean and Beet Research Farm.

Source of Variation	d.f.	MS
Compaction (C)	1	6098430**
Year (Y)	1	4246175**
C x Y	1	888777**
Cultivars	63	541380**
Cultivars x C	63	47642 n.s.
Cultivars x Y	63	222552**
Cultivars x Y x C	63	40119

** Significant at 1 percent level
n.s. = Not significant

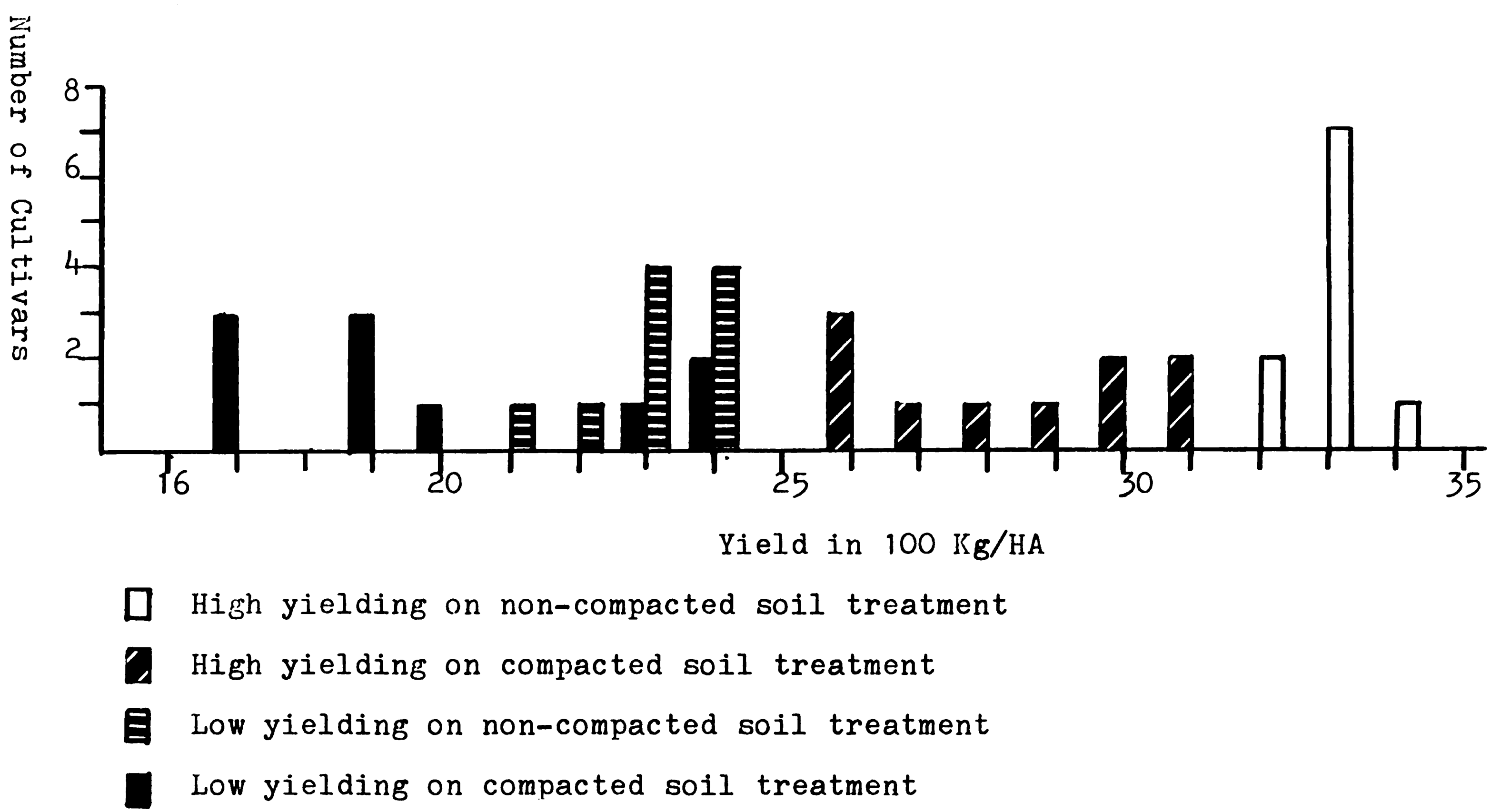


Fig. 19. Comparing the two year averaged yield on the compacted soil treatment of the ten highest and ten lowest yielding cultivars on non-compacted soil treatment averaged over two years on the Bean and Beet Research Farm in 1979 and 1980.

Figure 20 indicates how yield results of three cultivars of dry beans on four environments, two years at two levels of soil compaction. The line with slope, b = 1, passes through the mean yield for each enviornment. Cultivar, 790248, has a less than average yield over all environments. Its yield response increased is nearly equal (b = 0.91) to the average yield increase in more favorable environments. Mean square deviations from regression were small for it's yield response line and r^2 was 0.89 which is significant (Table A7). This indicates a stable yielding cultivar over environments, but would not select 790248 on yield alone, since it yields are below the average.

The yield response line (b = 0.28) for the cultivar, Sanilac, is way below the average yield for all environments, and does not response with increase yields in more favorable environments. It has low mean square deviations from regression, but r^2 is only 0.22. One would not select this cultivar on this data.

The cultivar, 62036, is above the average for all environments. With more favorable environments its yield potential increase, (b = 1.13). Mean square deviations from regression for the yield response line are 128, the smallest of all cultivars tested and r^2 is 0.99 which is highly significant. With above average yield performance, slope of yield response line near 1 and low mean square deviations for regression and highly significant r^2, 62036 would be highly favorable cultivars for further testing.

The main fault with these comparisons, as I have presented here, are the few, (4) environments from which the data was taken. If the number of environments could be increased to 10 or higher, we could get a better indication of the true yield response over environments for each cultivar. Projection of the slope line below or above the most unfavorable and most favorable environments could lead to very unrealistic yield comparisons.

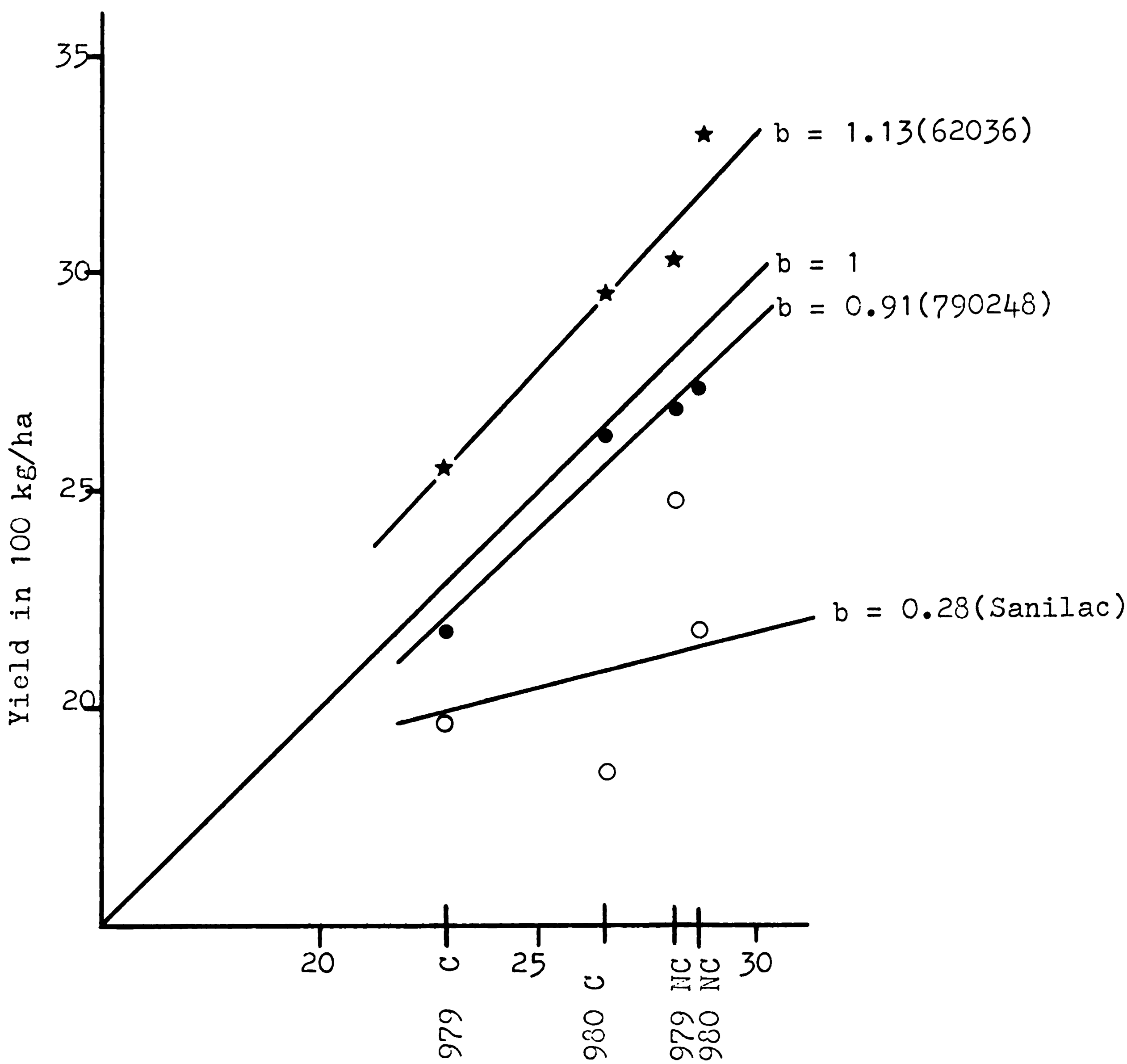


Fig. 20. Stability of yield of three cultivars over four environments, at two levels of soil compaction and two years grown on the Bean and Beet Research Farm in 1979 and 1980.

SUMMARY AND CONCLUSIONS

Soil parameters and growth response of dry bean (<u>Phaseolus vulgaris L.</u>) strains were investigated at two levels of soil compaction. This experiment was conducted on a Charity clay soil at the Saginaw Bean and Beet Research Farm near Saginaw, Michigan.

Soil samples taken on June 27, 1979 had bulk densities values of 0.14 and 0.08 g/cm^3 less on non-compacted plots, than on compacted plots at depths of 6.4 and 24 cm , respectively. These differences in soil bulk densities were highly significant. Soil moisture expressed as percent volumetric moisture increased as soil bulk density increased. Percent air pore space comprised of air was highest for the non-compacted 6.4 cm level, but in no soil profile level, 6.4, 14, or 21.6 cm , at either treatment level at soil compaction, was the percent air saturation below the 0.1 critical value indicated by Brake (1976).

Weight of roots collected on July 6 decreased with depth at both levels of soil compaction. Plants from compacted plots had a higher percentage of their roots in the 6.4 cm soil profile level. Correlations between average root weights were significant and negatively correlated with bulk density.

At physiological maturity of the beans, soil bulk density increased from 1.15 g/cm^3 in soil profile level one to 1.35 g/cm^3 in level four on non-compacted plots, and 1,37 g/cm^3 in level one to 1.42 g/cm^3 in level four of compacted plots.

Level five and six were not significantly different with respect to bulk density. Percent soil moisture was always higher on compacted plots. On non-compacted plots the soil lost moisture more readily and showed an increase in air-filled porosity.

Root weights at physiological maturity decreased with soil depth. Compacted plots had 45.1% of dry root weights in level one, whereas level one of non-compacted plots had only 37.5% of total collected root dry weights. Among commerical strain, Seafarer showed the greatest difference in root weights at level two and three, between non-compacted and compacted treatments.

No significant differences were found between plant populations on non-compacted and compacted plots. NEP-2 had the lowest germination, 58 percent. Dry matter accumulation at mid-pod filling indicated a significant difference between treatments for all strains, except Seafarer. Plant weights on the non-compacted plots were greater on the compacted plots by an average of 25.3 grams (38.8 percent). San-Fernando on compacted plots produced the lowest dry matter yields, 27.1 grams per 0.5 m of row at mid-pod filling.

At physiological maturity, Seafarer produced the least dry matter of any strain, at either level of soil compaction. San-Fernando produced the most dry matter accumulation on non-compacted plots and its white-seeded mutant NEP-2 produced the most dry matter accumulation on the compacted

Compaction reduce dry matter at physiological maturity by 31.4 percent.

Plant heights showed significant differences between soil treatments and between strains. All plant heights on non-compacted plots were higher than for plants on compacted plots. Black Turtle Soup was highest of all strains (46.3 cm) on non-compacted and shortest on the compacted plots (32.7 cm).

Both root and stem starch ratings generally increased as age of plants increased for San-Fernando and NEP-2. San-Fernando and it's white-seeded mutant NEP-2 had a relatively strong tap root and hypocotyl, which stayed viable longer than Seafarer and Black Turtle Soup. Seafarer's starch rating increased to mid-pod filling, then decreased at physiological maturity, but decreased less on compacted plots.

Seafarer showed the largest difference in pod length between the two levels of soil compaction, whereas NEP-2 revealed the least difference. Pod abscission was significantly higher on compacted plots, except for NEP-2. Seafarer had highest abscission rates of 15 and 35 percent on non-compacted and compacted plots, respectively. A higher rate of pod abscission of plants on compacted plots caused a decreased sink for photosynthate, thus more starch was retained in plants on compacted plots.

Low yields of Seafarer (1644 kg/hs) on the non-compacted plots were due to bacterical blight and ozone, causing a premature loss of leaves. NEP-2 yielded highest of the four varieties across both levels of soil compaction. The low yield of San-Fernando (1530 kg/ha) and Black Turtle Soup, (1085 kg/ha) on the compacted plot is contrary to other reports. San-Fernando and Black Turtle Soup should have yielded 25 and 50 percent better on the compacted plots.

Water covered the San-Fernando and Black Turtle Soup on compacted plots more than 24 hours after the July 11 rain, whereas the NEP-2 compacted plots were not flooded. It is difficult to say whether the stronger rooting system of NEP-2 or a less detrimental effect of soil compaction produced it's superior yields.

Comparisons of yield data of seven pairs of isolines indicated a black and white-seeded interaction with compaction treatment. On non-compacted plots, white-seeded strains out-yielded the black-seeded strains. All yields were reduced on the compacted plots by 28 percent, but the black-seeded strains out-yielded the white-seeded strains on compacted plots.

In comparisons of seed yields with these same varieties in secondary experiments on the same Charity clay soil under similar non-compacted and compacted treatments, the two black-seeded varieties, San-Fernando and Black Turtle Soup, were 598 and 671 kg/ha higher, respectively, on compacted plots in the secondary experiments, than on compacted plots in the primary tests. NEP-2 seed yields in the primary study were 499 kg/ha on non-compacted plots, and 440 kg/ha on compacted plots, above the yields in the secondary experiments.

Seafarer in the primary tests was 281 kg/ha below its average in secondary tests on the non-compacted plot and 233 kg/ha above its average on the compacted plots of the secondary test.

All strains had reduced yields on compacted plots (18.5 percent), when compared to non-compacted plots. The commercial strain, Seafarer, had it's yield lowered the most by compaction. Black Turtle Soup and San-Fernado yields were reduced similarly by compaction, although San-Fernando out-yielded Black Turlte Soup at both levels of compaction.

Indications from this study are that there are differences between strains of dry beans, both white and black-seeded, in their response to compaction. The low yields of Black Turtle Soup and San-Fernando on compacted plots in my experiments compared to yields in other experiments on similar compacted plots on the same Charity clay, indicates that some other factor besides just the increase in soil bulk density was limiting yields.

The relatively high rate of repeatability of high yielding cultivars at both levels of soil compaction, plus a correlation of 0.84 between yield averaged over two years at both levels of soil compaction, and non-significance of the two-way cultivars x compaction interaction strongly indicate that high yielding lines would tend to yield high at both levels of soil compaction. Thus, testing at more than one level of soil compaction is not essential for selection of superior genotypes. This would reduce labor and cost of testing large numbers of early generation genotypes of dry beans. However, the evaluation of commercial cultivars of various seed classes for specific fitness to compacted soils of differnet soil types may be very important; and should be continued until or unless contrary evidence is obtained.

APPENDIX

Table Al. Record of climatic conditions for the months of April thru September.

Date	Temperature			Precipation	Pan Evapor.	
April	Max.	Min.	Mean		Add	Remove
1	35	31	33			
2	42	30	36	.12		
3	48	28	38		.13	
4	40	32	36	.25		
5	45	14	30	.15		
6	30	15	23	T		
7	38	16	27	T		
8	31	27	29	.22		
9	41	24	33			
10	47	20	34			
11	42	30	36			
12	64	34	49	.41	.09	
13	61	47	54	.05		
14	54	36	45	T		
15	47	39	43	T	.43	
16	57	35	46		.13	
17	62	32	47		.21	
18	57	29	43		.18	
19	65	27	46		.16	
20	70	35	53		.17	
21	66	48	57	.14		
22	70	46	58		.27	
23	74	38	56		.19	
24	71	37	54	.10		.01
25	69	56	63	.25		.25
26	63	44	54	.43		.34
27	56	39	48		.07	
28	44	38	41	.05		.13
29	55	27	41		.02	
30	45	36	41	.34		
Total				2.51	2.05	.73

Table A1. Continued.

Date	Temperature			Precipation	Pan Evapor.	
May	Max.	Min.	Mean		Add	Remove
1	53	31	42	T	.11	
2	65	39	52	T	.22	
3	57	48	53	.67		.38
4	53	34	44		.05	
5	46	25	36	.04		
6	72	46	59	T	.28	
7	82	46	64		.44	
8	89	60	75		.51	
9	89	60	75		.37	
10	86	56	71	T	.21	
11	85	56	71	.24		.04
12	55	46	51	.18		
13	64	38	51	T	.15	
14	69	42	56	T	.23	
15	62	40	51	T	.21	
16	66	36	51		.32	
17	73	43	58		.40	
18	82	55	69		.22	
19	81	51	66	T		
20	75	47	61		.78	
21	64	44	54	T	.26	
22	65	34	50		.28	
23	69	50	60	T	.22	
24	55	46	51	T	.28	
25	59	48	54		.21	
26	52	44	48			.04
27	59	46	53	.23		
28	62	48	55	T	.08	
29	69	40	55		.16	
30	67	40	54		.14	
31	80	49	65		.27	
Total				1.36	6.40	.46

Table A1. Continued

Date	Temperature			Precipation	Pan Evapor.	
June	Max.	Min.	Mean		Add	Remove
1	77	56	67		.15	
2	79	40	60			
3	83	50	67			
4	87	39	63		.31	
5	71	58	65	.05	.15	
6	80	49	65	.05	.22	
7	84	63	74		.25	
8	88	65	77	.02	.12	
9	87	67	77		.24	
10	83	51	67	1.39		
11	69	50	60	T	.18	
12	69	45	57		.26	
13	75	42	59		.31	
14	84	53	69		.37	
15	88	68	78		.35	
16	88	68	78			
17	79	59	69			
18	67	55	61		.36	
19	80	44	62		.55	
20	85	61	73	.48		.14
21	82	66	74		.35	
22	70	48	59		.15	
23	56	44	50			
24	64	41	53		.56	
25	75	34	56		.26	
26	80	45	63		.36	
27	84	62	73	.26		.04
28	78	51	65		.29	
29	74	59	67	.64		.62
30	62	51	59	.70		.70
Total				3.59	5.79	1.5

Table A1. Continued

Date	Temperature			Precipation	Pan Evapor.	
July	Max.	Min.	Mean		Add	Remove
1	64	58	61	.28		.28
2	77	56	67		.11	
3	67	45	56	T	.04	
4	74	54	64	.14	.14	
5	73	45	59		.25	
6	78	44	61		.10	
7	82	48	65		.58	
8	80	52	66			
9	78	63	71	T	.18	
10	84	54	69	.63		.38
11	83	63	73	3.61		
12	86	60	73		.18	
13	88	65	77		.06	
14	84	67	76		.58	
15	87	64	76			
16	79	59	69		.28	
17	73	53	63		.18	
18	78	46	62		.24	
19	81	47	64		.21	
20	83	51	67		.12	
21	85	52	69		.62	
22	88	57	73			
23	86	61	74		.17	
24	83	66	75		.22	
25	79	70	75	.87		.65
26	72	62	67		.12	
27	84	55	70		.42	
28	83	65	74	.11		
29	84	56	70			
30	79	59	69	T	.11	
31	86	70	78	T	.23	
Total				5.64	5.14	1.03

Table Al. Continued

Date	Temperature			Precipation	Pan Evapor.	
August	Max.	Min.	Mean		Add	remove
1	75	63	69			.21
2	80	61	71	.30	.23	
3	80	54	67	.10		
4	84	58	71			
5	82	59	71	.42		.02
6	75	54	65		.22	
7	89	58	74		.21	
8	77	60	69	T	.06	
9	74	49	62	T	.13	
10	80	56	68	.75		
11	67	49	58			
12	73	41	57		.45	
13	69	58	64	T	.18	
14	66	49	58		.19	
15	71	48	60		.21	
16	73	38	56		.20	
17	62	53	58	.25		
18	74	57	66	.05		
19	77	53	65		.17	
20	75	54	65		.11	
21	82	53	68		.24	
22	78	53	66	T	.11	
23	81	64	73	.19		.07
24	75	63	69		.09	
25	73	52	63			
26	78	47	63		.36	
27	73	54	64	.04	.03	
28	74	63	69	T	.06	
29	80	59	70	T	.10	
30	85	59	72		.18	
31	84	53	69		.15	
Total				2.10	3.68	.30

Table Al. Continued

Date	Temperature			Precipation	Pan Evapor.	
Sept.	Max.	Min.	Mean		Add	Remove
1	83	60	72		.40	
2	81	62	72	.08		
3	79	55	67		.18	
4	81	52	67		.15	
5	85	53	69		.17	
6	83	54	69		.19	
7	63	49	56	T	.06	
8	64	38	51		.27	
9	71	38	55	T		
10	75	55	65	.02	.06	
11	74	44	59		.18	
12	85	51	68		.15	
13	78	60	69	T	.15	
14	70	51	61		.10	
15	63	42	53		.46	
16	78	46	62			
17	79	45	62		.21	
18	78	52	65		.24	
19	64	34	49		.18	
20	74	35	55		.16	
21	70	50	60	T	.09	
22	65	39	52		.36	
23	66	31	49			
24	73	34	54	T	.17	
25	76	44	60		.19	
26	82	39	61		.20	
27	82	42	62		.21	
28	80	45	63		.18	
29	83	48	66		.17	
30	78	46	62		.19	
Total				.10	5.07	0.0

Table A2. Seed yields of 65 entries on non-compacted and compacted plots in 1979 grown on the Bean and Beet Research Farm.

	Non-compacted				Compacted			
Entry	Yield	**Rank**	Group	a	Yield	Rank	Group	b
4044	3408	1	1	+	2587	15	1	+
61065	2866	25	2	+	2096	49	2	-
61068	3281	8	1	+	2881	4	1	+
61341	2934	23	2	+	1934	54	3	-
61356	2667	44	2	-	1640	61	2	-
61380	2810	31	2	+	2158	45	2	-
61612	3335	5	1	+	2138	47	2	-
61618	2804	32	2	+	2619	14	1	+
61622	3378	3	1	+	2583	17	1	+
61690	3350	4	1	+	2878	5	1	+
62036	3014	17	1	+	2559	18	1	+
62038	2799	33	2	+	2316	34	2	+
62041	3301	7	1	+	2189	41	2	-
62267	2498	54	3	-	1906	56	3	-
72220	2546	50	3	-	2326	33	2	-
790001	2538	52	3	-	2169	43	2	-
790007	2371	60	3	-	2290	36	2	-
790047	2511	53	3	-	2261	39	2	-
790087	3055	15	1	+	2164	44	2	-
790089	2666	45	2	-	2442	24	2	+
790092	2790	36	2	-	2000	51	3	-
790097	2854	27	2	+	2026	50	3	-
790124	2729	40	2	-	2405	26	2	+
790126	3307	6	1	+	2380	29	2	+
790127	2866	26	2	+	1942	53	3	-
790129	2843	29	2	+	1934	55	3	-
790130	2799	34	2	+	2206	40	2	-
790131	2632	47	3	-	2147	46	2	-
790137	3057	14	1	+	2777	8	1	+
790248	2677	43	2	-	2188	42	2	-
790254	2733	38	2	-	2627	13	1	+
790255	2794	35	2	+	2355	31	2	+
790329	2936	22	2	+	1671	60	3	-
790332	2953	21	2	+	1877	57	3	-
790334	2723	41	2	-	2273	37	2	-
790339	3009	19	1	+	1813	59	3	-
790340	2998	20	1	+	2128	48	2	-
790454	2854	28	2	+	2335	32	2	+
790456	2913	24	2	+	2736	10	1	+
790457	2731	39	2	-	2759	9	1	+
790458	2773	37	2	-	2511	20	1	+
790459	2600	48	3	-	2389	27	2	+
790460	2834	30	2	+	2661	11	2	+

Table A2. Continued.

	Non-compacted				Compacted			
Entry	Yield	Rank	Group	a	Yield	Rank	Group	b
790481	2416	58	3	-	2587	16	1	+
790488	2498	55	3	-	2267	38	2	-
790489	2338	63	3	-	2470	23	2	+
790491	2542	51	3	-	2483	22	2	+
790494	2256	64	3	-	2355	30	2	+
790498	2470	57	3	-	2514	19	1	+
790521	3130	12	1	+	2837	7	1	+
790522	3111	13	1	+	2313	35	2	+
790523	2576	49	3	-	2406	25	2	+
790525	3254	9	1	+	3044	2	1	+
790527	3184	11	1	+	2490	21	2	+
790532	3380	2	1	+	3054	1	1	+
790536	2658	46	2	-	2383	28	2	+
790537	3048	16	1	+	2643	12	1	+
790538	3010	18	1	+	2981	3	1	+
Seafarer	2347	62	3	-	1483	63	3	-
BTS	2380	59	3	-	1214	65	3	-
Tuscola	1883	65	3	-	1360	64	3	-
NEP-2	3232	10	1	+	2859	6	1	+
Sanilac	2485	56	3	-	1962	52	3	-
Riso 23	2355	61	3	-	1528	62	3	-
San Fernando	2692	42	2	-	1712	58	3	-

a Non-compacted; +, above average yield, - below average yield
b Compacted; +, above average yield; - below average yield
c Yields are in kg/ha

Table A3. Seed yields of 65 entries on non-compacted and compacted plots in 1980 grown on the Bean and Beet Research Farm.

	Non-compacted				Compacted			
Entry	Yield	Rank	Group	a	Yield	Rank	Group	b
4044	3023	27	2	+	2612	43	2	-
61065	2815	41	2	-	2377	51	3	-
61068	2864	35	2	-	2734	30	2	+
61341	3091	24	2	+	2898	19	1	+
61356	2690	47	2	-	2650	39	2	+
61380	3133	21	1	+	2616	42	2	-
61612	2927	33	2	+	2786	27	2	+
61618	3361	11	1	+	2961	12	1	+
61622	3437	9	1	+	2915	18	1	+
61690	3154	18	1	+	3054	8	1	+
62036	3301	14	1	+	2942	15	1	+
62038	2995	28	2	+	2827	23	2	+
62041	3260	15	1	+	2832	22	2	+
62267	2758	45	2	-	2445	49	3	-
72220	2946	31	2	+	2420	50	3	-
790001	2257	54	3	-	1883	61	3	-
790007	2510	50	3	-	2554	45	2	-
790047	2854	37	2	-	2883	21	1	+
790087	2517	49	3	-	2304	54	3	-
790089	2774	44	2	-	3105	6	1	+
790092	2384	53	3	-	1883	32	2	+
790097	2020	64	3	-	2655	38	2	+
790124	2824	40	2	-	2658	37	2	+
790126	3033	26	2	+	2887	20	1	+
790127	2099	61	3	-	1860	63	3	-
790129	1967	65	3	-	1899	60	3	-
790130	2593	48	2	-	2064	57	3	-
790131	2030	63	3	-	1627	65	3	-
790137	2855	36	2	-	2776	28	2	+
790248	2726	46	2	-	2633	40	2	-
790254	2906	34	2	+	2718	34	2	+
790255	3119	23	1	+	2704	35	2	+
790329	2992	29	2	+	2761	29	2	+
790332	3143	19	1	+	2971	11	1	+
790334	3058	25	2	+	2790	26	2	+
790339	2957	30	2	+	2721	33	2	+
790340	3212	16	1	+	2601	44	2	-
790454	2906	43	2	-	2631	41	2	-
790456	3406	10	1	+	3123	5	1	+
790457	3360	11	1	+	3060	7	1	+
790458	3915	1	1	+	3642	1	1	+
790459	3500	6	1	+	2446	48	3	-
790460	3209	17	1	+	2922	17	1	+

Table A3. Continued.

Non-compacted					Compacted			
Entry	Yield	Rank	Group	a	Yield	Rank	Group	b
790481	2944	32	2	+	2723	31	2	+
790488	3549	4	1	+	3052	9	1	+
790489	3330	13	1	+	3041	10	1	+
790491	3449	8	1	+	2930	16	1	+
790494	2831	39	2	-	2554	46	2	-
790498	2033	62	3	-	2189	56	3	-
790521	3495	7	1	+	2955	14	1	+
790522	3556	3	1	+	2791	25	2	+
790525	2130	60	3	-	2370	52	3	-
790527	2429	51	3	-	2360	53	3	-
790532	2843	38	2	-	2961	13	1	+
790536	2243	56	3	-	2471	47	2	-
790537	3592	2	1	+	3296	3	1	+
790538	3530	5	1	+	3308	2	1	+
Seafarer	2134	59	3	-	1869	62	3	-
B T S	2809	42	2	-	2826	24	2	+
Tuscola	2252	55	3	-	1985	58	3	-
NEP-2	3141	20	1	+	2663	36	2	+
Sanilac	2170	58	3	-	1857	64	3	-
Rico 23	2184	57	3	-	1928	59	3	-
San-Fernando	2417	52	3	-	2258	55	3	-

a Non-compacted; +, above average yield; -, below average yield
b Compacted; +, above average yield; -, below average yield
c Yields are in kg/ha

Table A4. Seed yields of 65 entries on non-compacted and compacted plots, averaged over two years grown on the Bean and Beet Research Farm.

	Non-compacted				Compacted			
Entry	Yield	Rank	Group	a	Yield	Rank	Group	b
4044	3216	9	1	+	2600	25	2	+
61065	2841	34	2	-	2236	50	2	-
61068	3073	17	2	+	2808	9	2	+
61341	3012	23	2	+	2416	41	2	-
61356	2679	48	2	-	2124	55	2	-
61380	2972	26	2	+	2388	43	2	-
61612	3131	14	2	+	2462	34	2	-
61618	2939	30	2	+	2790	12	2	+
61622	3408	1	1	+	2749	18	2	+
61690	3252	8	1	+	2966	5	1	+
62036	3158	13	2	+	2751	17	2	+
62038	2898	31	2	+	2751	17	2	+
62041	3332	4	1	+	2572	27	2	+
62267	2628	49	2	-	2176	53	2	-
72220	2746	41	2	-	2373	44	2	-
790001	2398	59	3	-	2027	56	3	-
790007	2440	56	3	-	2422	39	2	-
790047	2683	46	2	-	2573	26	2	+
790087	2786	39	2	-	2234	51	2	-
790089	2721	42	2	-	2773	14	2	+
790092	2587	51	2	-	2361	46	2	-
790097	2437	57	3	-	2341	48	2	-
790124	2777	40	2	-	2531	30	2	+
790126	3170	11	2	+	2633	24	2	+
790127	2483	54	3	-	1872	62	3	-
790129	2406	58	3	-	1917	59	3	-
790130	2696	44	2	-	2136	54	2	-
790131	2332	60	3	-	1887	61	3	-
790137	2956	29	2	+	2777	13	2	+
790248	2702	43	2	-	2411	42	2	-
790254	2819	37	2	-	2672	21	2	+
790255	2956	28	2	+	2530	31	2	+
790329	2964	27	2	+	2216	52	2	-
790332	3048	19	2	+	2424	38	2	-
790334	2891	32	2	+	2531	29	2	+
790339	2983	25	2	+	2267	49	2	-
790340	3105	16	2	+	2365	45	2	-
790454	2827	36	2	-	2483	33	2	+
790456	3160	12	2	+	2930	6	1	+
790457	3046	20	2	+	2910	7	1	+
790458	3344	2	1	+	3077	2	1	+
790459	3050	18	2	+	2418	40	2	-
790460	3017	22	2	+	2792	11	2	+

Table A4. Continued.

Non-compacted					Compacted			
Entry	Yield	Rank	Group	a	Yield	Rank	Group	b
790481	2680	47	2	-	2656	23	2	+
790488	3023	21	2	+	2660	22	2	+
790489	2835	35	2	-	2755	16	2	+
790491	2996	24	2	+	2707	19	2	+
790494	2544	53	2	-	2455	35	2	-
790498	2252	63	3	-	2352	47	2	-
790521	3313	6	1	+	2897	8	1	+
790522	3334	3	1	+	2553	28	2	+
790523	2854	33	2	+	2798	10	2	+
790525	2693	45	2	-	2707	20	2	+
790527	2807	38	2	-	2425	37	2	-
790532	3112	15	2	+	3008	3	1	+
790536	2451	55	3	-	2427	36	2	-
790537	3320	5	1	+	2970	4	1	+
790538	3270	7	1	+	3144	1	1	+
Seafarer	3241	64	3	-	1676	64	3	-
B T S	2595	50	2	-	2020	57	3	-
Tuscola	2065	65	3	-	1673	65	3	-
NEP-2	3186	10	1	+	2761	15	2	+
Sanilac	2328	61	3	-	1892	60	3	-
Rico 23	2270	62	3	-	1727	63	3	-
San Fernando	2554	52	2	-	1985	58	3	-

a Non-compacted; +, above average yield; -, below average yield
b Compacted; +, above average yield; -, below average yield
c Yields are in kg/ha

Table A5. Average performance of 22 high yielding cultivars grown in 1979 and 1980 at the Bean and Beet Research Farm.

Cultivar	Yield	b	S^2d	r^2	r	F
NEP-2	2974	0.40+-0.44	33978	.29	.54	NS
4044	2908	0.77+-0.86	128821	.28	.53	NS
61068	2941	0.51+-0.61	66572	.00	.06	NS
61618	2865	0.94+-0.25	11466	.86	.93	NS
61622	3079	1.35+-0.45	35607	.82	.90	NS
61690	3109	0.48+-0.39	26338	.43	.66	NS
62036	2955	1.13+-0.27	128	.99	.99	**
62041	2922	1.86+-0.53	49284	.86	.93	NS
790126	2902	1.10+-0.66	76016	.58	.76	NS
790137	2867	0.16+-0.33	18639	.11	.33	NS
790456	3045	0.48+-0.30	16076	.84	.91	NS
790457	2978	0.84+-0.49	42640	.59	.77	NS
790458	3211	2.02+-1.03	185195	.66	.81	NS
790460	2905	0.80+-0.20	7201	.89	.94	**
790488	2841	1.85+-0.75	97916	.75	.87	NS
790491	2852	1.37+-0.65	72933	.69	.83	NS
790521	3105	0.98+-0.30	16162	.84	.92	NS
790522	2944	1.90+-0.27	12967	.96	.98	*
790523	2826	1.05+-0.71	88510	.52	.72	NS
790532	3060	-0.23+-0.58	58628	.07	.27	NS
790537	3145	1.41+-0.33	18845	.90	.95	*
790538	3207	0.78+-0.40	28655	.65	.80	NS

Table A6. Average performance of 20 medium yielding cultivars grown in 1979 and 1980 at the Bean and Beet Research Farm.

Cultivar	Yield	b	S^2d	r^2	r	F
61065	2539	1.39+-0.30	13517	.92	.96	*
61341	2714	1.01+-0.39	23722	.93	.96	*
61380	2680	1.55+-0.32	15876	.92	.96	*
61612	2797	1.82+-0.54	43851	.85	.92	NS
62038	2735	1.09+-0.27	10794	.89	.94	*
790007	2431	1.19+-0.46	32799	.77	.87	NS
790087	2510	1.13+-0.75	86120	.53	.73	NS
790089	2747	0.50+-0.69	71813	.21	.46	NS
790092	2474	1.04+-0.70	74013	.52	.73	NS
790124	2654	0.70+-0.85	1098	.97	.99	**
790254	2746	0.37+-0.19	5481	.66	.81	NS
790255	2743	1.15+-0.33	16804	.86	.93	NS
790334	2711	1.18+-0.40	21887	.83	.91	NS
790340	2735	1.85+-0.27	11572	.96	.98	*
790454	2655	0.91+-0.10	1566	.98	.99	**
790459	2734	1.33+-1.11	186232	.42	.65	NS
790481	2668	0.21+-0.61	55861	.06	.24	NS
790489	2795	0.75+-1.20	220606	.16	.40	NS
790525	2700	-0.72+-1.40	30360	.12	.34	NS
790527	2616	0.54+-1.00	152177	.13	.36	NS

Yield = average seed yield of 4 environments in kg/ha
b = slope of regression line +- standatd deviation
S^2d = sim pf squared deviations from the mean

Table A7. Average performance of 22 low yielding cultivars grown in 1979 and 1980 at the Bean and Beet Research Farm.

Cultivar	Yield	b	S^2d	r^2	r	F
Seafarer	1959	0.45+-0.16	4183	.80	.89	NS
B. T. S.	2308	2.88+-0.46	32641	.95	.97	*
Tuscola	1869	0.39+-0.41	26372	.31	.55	NS
Sanilac	2110	0.28+-0.37	21774	.22	.47	NS
RicO 23	1999	1.03+-0.68	71528	.53	.73	NS
San-Fernando	2270	1.17+-0.78	95589	.53	.72	NS
61356	2402	1.87+-0.53	43323	.86	.92	NS
62267	2402	1.35+-0.25	9479	.94	.97	*
72220	2560	0.81+-0.49	37441	.58	.76	NS
790001	2123	3.00+-1.39	304785	.70	.84	NS
790047	2628	4.27+-2.21	768234	.65	.81	NS
790097	2389	3.18+-2.03	622614	.55	.74	NS
790127	2178	-1.85+-0.78	94256	.74	.86	NS
790129	2162	-1.66+-0.54	45318	.83	.91	NS
790130	2416	0.38+-0.90	126275	.08	.29	NS
790131	2110	-0.45+-1.09	188412	.08	.29	NS
790248	2557	0.91+-0.22	7960	.89	.94	*
790329	2590	2.24+-0.65	65728	.86	.92	NS
790339	2625	1.92+-0.71	79782	.78	.88	NS
790494	2500	0.70+-0.49	38313	.50	.71	NS
790498	2302	-0.78+-0.31	15396	.75	.87	NS
790536	2439	-0.12+-0.47	34790	.03	.18	NS

Yield = Average seed yield of 4 environments
b = Slope of seed response line +- standard deviation
S^2d = Mean square deviation from seed response line

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