FIELD PERFORMANCE OF WEATHERED SPRING WHEAT AND BARLEY

By

Harry Witika Ngoma

A Thesis

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In Partial Fulfilment of the Requirements

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DEDICATION

To my parents, brothers and sisters, and grandparents, in particular, Ambuya analume (Kasauka) who passed away in my absence on 9 June, 1990; M.S.R.I.P.) for their love, support, and giving my life a meaning. I love you all so dearly.

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LIST OF ABBREVIATIONS

BCT=Barley under conventional tillage

BFR=Barley under conventional tillage with Fortress herbicide applied in the previous fall.

BZT=Barley under zero tillage

WCT=Wheat under conventional tillage.

WFR=Wheat under conventional tillage with Fortress herbicide applied in the previous fall.

WZT=Wheat under zero tillage

Seedlot 1=Unweathered seed - control treatment

Seedlot 2=Slightly weathered seed

Seedlot 3=Severely weathered seed.

Cond=Seedbed condition (Conventional tillage, conventional tillage with Fortress herbicide, and zero tillage).

TKW=Thousand kernel weight

NSA=Number of spikes (heads) per unit area

HLW=Hectolitre weight

ABSTRACT

Field performance of weathered spring wheat and barley.

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In Western Canada harvesting is sometimes delayed by adverse weather, during which seed damage due to weathering may occur. Studies on this subject have often been confined to laboratory evaluations of weathering effects on seed quality characteristics but few have actually assessed field performance of weathered seeds. This study examined the effects of weathered seed of spring wheat (Triticum aestivum L. cv. Katepwa) and spring barley (Hordeum vulgare L. cv. Heartland) on emergence, plant development, and grain yield at Portage la Prairie in 1990 and 1991. Unweathered, moderately weathered, and severely weathered seedlots were seeded at 25, 50, and 75 mm seeding depths under conventional tillage, conventional tillage with fall applied Fortress herbicide, and zero tillage.

In both years, field weathering had no significant effect on any of the growth parameters of wheat. However, emergence of severely weathered seed compared with unweathered seed appeared to be lower at 75 mm. Unweathered barley seed had 33% more seedlings than weathered seed at 75 mm depth in 1990. No significant differences in seedling emergence could be detected at shallow seeding (25 mm) in either crop or year. Weathered seed appeared to have a faster emergence index rate

compared with unweathered seed, especially at the shallow seeding depth. Field weathering had no significant effect on subcrown internode length, dry matter production, or leaf area index in either wheat or barley.

Weathering had no significant on 1000-kernel weight, hectolitre weight or number of spikes per unit area in neither crop nor year. Comapred with unweathered seed, the severely weathered barley seed resulted in lower grain yield under Fortress area in 1990. In 1991, the weathered barley seed produced equal or higher grain yields compared with unweathered seed. Differences in yields observed between the 2 years were attributed to variation in the degree of seed weathering and to weather conditions between the 2 years.

Seedling emergence was consistently reduced with deep seeding in both crops and years under all the 3 seedbed conditions (8% and 10% for wheat and barley, respectively). Deep seeding also delayed emergence by 3 days in both crops and years. When grain yields for the 2 years were averaged, deep seeding reduced yields by 6% in wheat and 8% in barley.

This study shows that light to moderately weathered seed does not significantly reduce seed vigour and subsequent plant performance. If conditions for seed germination are stressful, severely weathered seed may reduce seedling emergence. Under favourable germination conditions, weathered seed appears to enhance seedling emergence and subsequent plant growth and yield.

CHAPTER 1.0: INTRODUCTION

Stand establishment is a critical factor in successful crop production. To achieve the desired plant population often calls for use of pedigreed seed, among other factors. In Canada, the use of certified seed assures varietal purity and a guaranteed minimum percentage germination (Anonymous 1, 1991). However, recent studies have shown that certified wheat (Triticum aestivum L.) and barley (Hordeum vulgare L.) seed produced by different seed growers exhibits significantly different levels of field performance and grain yield (>10%) when grown under similar conditions (Empey, 1992; Sonntag et al., 1989). This variability in field performance was attributed to differences in seed vigour.

There are reports which indicate that a major reason for seed vigour loss in Western Canada is field weathering during the seed maturation period from physiological maturity to harvest moisture. Although seed vigour is normally at its peak at physiological maturity (about 30 to 40 % kernel water content-KWC), it is not harvested until it attains "harvest moisture" (12 to 16 % KWC), a safe moisture content at which mechanical injury to the seed is minimised. Adverse weather during the dry-down period may expose seed to cycles of wetting and drying (weathering) from either rain or high atmospheric humidity. The detrimental effects of allowing crops to remain under these adverse conditions is well known (Tekrony et al., 1980; Czarnecki and Evans, 1986; Wytinck et al., 1991). The extent of weather damage on seeds depends on the amount and duration of rain (Czarnecki and Evans, 1986; Wytinck, 1991), mean air temperature, and mean minimum relative humidity (Tekrony et al., 1980; Suresh et al., 1991).

Field weathering is reported to alter both the physical and physiological properties of the seed. Weathering has been shown to reduce test weight (Czarnecki and Evans, 1986; Wytinck et al., 1991). Weathering reduces seed density, kernel mass, and kernel hardness (Czarnecki and Evans, 1986; Wytinck et al., 1991). Field weathering causes kernel bleaching and premature enzyme activation (Czarnecki and Evans, 1984), especially alpha-amylase activity (Clarke et al., 1984; Wytinck et al., 1991). Weathered seed are also more susceptible to mechanical damage (Dilday, 1989) and to disease infection (Harrison and Perry, 1976; Whytock and Powell, 1986; Wytinck, 1991).

Although the impact of weathering on seed quality parameters of both wheat (Clarke et al., 1984; King and Richards, 1984; Czarnecki and Evans, 1986; Wytinck et al., 1991) and barley (Christensen and Legge, 1985; Wytinck et al., 1991) are documented, little effort has been directed toward investigating the implications of using weathered seed on field performance of these crops.

This study was established to determine the implications of planting weathered seed on (i) seedling emergence, (ii) plant development, and (iii) grain yield of spring wheat and barley. Several seeding depths and different seedbed conditions were used to determine the effect of stress on the performance of weathered spring wheat and barley seed.

2. LITERATURE REVIEW.

2.1: General.

2.1.1 Growth and development of wheat and barley.

An understanding of the general structure, growth and development of wheat and barley is essential for maximum crop production. The seed is the reproductive unit that assures survival of all plant species. Germination is the emergence and development from the seed embryo of those essential structures which, for the kind of seed in question, are indicative of the ability to produce a normal plant under favourable conditions (AOSA, 1983).

There are two kinds of germination; 1) epigeal germination, where the cotyledons are raised above the ground, e.g. beans; and 2) hypogeal germination; where the cotyledons or the storage organs remain beneath the soil while the plumule pushes upward and emerges above the ground, e.g. grasses. Regardless of their above-ground or below-ground positions, the cotyledons or comparable storage organs continue to provide nutritive support to the growing points throughout germination. In grasses, such as wheat and barley, the coleoptile provides protection and rigidity to the plumule as it emerges above the ground (Lersten, 1987).

The essential requirements of germination are water, oxygen, and temperature. Some species require exposure to light before germination. The major events of germination are water imbibition, enzyme activation, initiation of embryo growth, rupture of the seed coat and emergence of the seedling (Copeland and McDonald, 1985). During the first few days, the germinating seedling undergoes a net loss in dry weight due to the high respiration rate and some exudation and leakage through the seed coat.

The seedling starts to establish itself when it begins water uptake and photosynthesis. Before this it is entirely dependent on the seed reserves (endosperm). Small grains have two root systems; the seminal roots that emerge directly from the seed, and the nodal (crown) roots that emerge from the coleoptile node and the first four leaves (Klepper, et al., 1984). Seminal roots grow mainly in a downward direction, where as crown roots grow more laterally at first and then downward.

The shoot is a short rhizome bearing several axillary leafy culms (tillers). The number of culms varies with cultivar, seeding depth and density, and environmental conditions.

The inflorescence is a condensed branch system that bears the spikelet. The spikelet bears florets which develop into seed (Lersten, 1987).

2.1.2 Grain Yield Components.

Grain yield of cereals is a product of three components: the number of heads or spikes per unit area, number of kernels per head or spike, and kernel weight (Frank et al., 1987;

Black and Aase, 1982; Power and Alessi, 1978). The number of heads per unit area is a function of total number of tillers produced and the proportion which survives to produce an ear (Innes et al., 1981; Power and Alessi, 1978).

Although the maximum number of kernels per head is set at time of apex initiation, environmental conditions during the apex reproductive phase affect the number of kernels formed (Frank et al., 1987). The environment, as defined by the plant breeder includes the integrated influence of all non-genetic variables affecting phenotypic expression of various genotypes (Saeed and Francis, 1984). In cereal crops, weather factors such as temperature and moisture have the greatest influence on key physiological and developmental processes which determine yield.

Frank et al. (1987) suggest that temperature and water strongly influence the reproductive development phase in spring wheat. They reported that higher air temperature (26 C) from about 6 to 8 days prior to apex double ridge through terminal spikelet formation (4.5 to 5.5 Haun stage scale) reduced the number of spikelets per spike. The same study also showed that water stress starting 12 days after seedling emergence resulted in fewer spikelets per spike.

In sorghum, variation in temperature and rainfall accounted for more than half of the environment and genotype interaction sum of squares for seed number and seed weight components of yield (Saeed and Francis, 1984). In peas, high air temperatures from about 6-12 days after the flower opened reduced the number of seeds per pod (Jeuffroy et al., 1989). The reduction in number of seeds per pod at high temperatures was attributed to flower abortion.

Other factors influencing number of spikes per unit area include seeding density (Black and Aase, 1982) and nutrition (Black and Aase, 1982; Black, 1970). Depending on moisture availability, high seeding rates can increase or decrease the number of spikes/unit area. In a study done at Sidney, Montana, with above average season rainfall, all plots with a high seeding rate had about 20% more heads than plots with a low seeding rate (Black and Aase, 1982). Nitrogen fertilizer alone increased the number of head-producing stems by 30%. However, number of kernels/head was lower at high population density regardless of nitrogen levels.

Reports by Innes et al. (1981) showed that drought 5 weeks prior to anthesis reduced the final number of ears of winter wheat lines with higher tillering capacity by 14% compared to the low tillering lines. Early drought reduced tiller survival for both high and low tillering lines by 8%. Early drought also reduced the number of grains per ear for both high and low tillering lines.

Black (1970) reported that the number of tillers per plant in wheat were positively correlated with adventitious roots per plant which were also influenced by phosphorous and nitrogen rates. The greatest yield contribution per plant comes from the main stem in wheat (Gan et al., 1992; Power and Alessi, 1982).

In general, grasses such as wheat and barley have compensatory characteristics. It is well known that if environmental conditions are unfavourable for tillering during the first three weeks of growth cycle of cereals, few tillers are produced. If favourable conditions are present later in the season, the plants will compensate for the reduced number of tillers by producing more kernels per head (Knapp and Knapp, 1980) and/or larger kernels.

2.2 Definition and Measurement of Seed Vigour

2.2.1 Definition of seed vigour

There are numerous concepts of seed vigour which in the past have caused confusion. In 1980 the Association of Official Seed Analysts (AOSA) defined **seed vigour** as all those seed properties which determine the potential for rapid, uniform emergence, and development of normal seedlings under a wide range of field conditions.

2.2.2 Measurement of seed vigour.

Seed vigour tests may be direct or indirect. Direct vigour tests are those in which an environmental stress expected in the field is reproduced in the laboratory and the percentage and rate of seedling emergence is recorded (AOSA, 1983). The cold germination test (Morrison et al., 1989; Sonntag et al., 1988) is one example. Indirect tests are those in which other characteristics of the seed which have proved to be correlated with an aspect of field performance are measured (AOSA, 1983). Examples of these are respiration rate (Harrison and Perry, 1976) and conductivity test.

It is now generally accepted that the standard germination test is a determination of seed viability and not seed vigour (Morrison et al., 1989; Sonntag et al., 1989; Wytinck et al., 1991). It must also be noted that a vigour test is not a test for field response per se. Field response of a particular seed lot may more closely correlate with a vigour test or the ordinary standard germination test depending on the field conditions under which the crop is planted. Therefore, a **vigour test** is an examination under specific environmental conditions to provide a means of detecting differences which are not detected in a standard germination test (AOSA, 1983). No single method will satisfy all requirements and a method or combination of methods should be chosen to suit the crop or environment into which it will be sown.

In Western Canada, field conditions at planting in spring are sometimes sub-optimal due to low soil temperatures. The cold germination test (conducted at 4 to 5 °C) may be more indicative of how different seed lots will perform in the field under a cold stress than the standard germination test. Cold germination tests have been used extensively to determine the vigour of cotton (Christensen, 1963), corn (Martin et al., 1988), wheat (Sonntag et al., 1988, Morrison et al., 1991) and barley (Sonntag, 1988). Low temperatures reduce the germination rapidity and uniformity of seeds (Lafond and Baker, 1986a), thus allowing for differences in vigour to be better expressed.

2.3 Factors affecting seed vigour.

The principal known causes of variation in the level of seed vigour include : (1) genetic constitution (2) environment and nutrition of the mother plant, (3) stage of maturity at harvest, (4) seed size, weight or specific gravity (Gan et al., 1992; Kaufman and McFadden, 1960), (5) mechanical integrity (Vyn and Moes, 1986; Bourgeois et al., 1992), (6) deterioration and aging (Harrison and Perry, 1976; Dell'Aquilla and Trotto, 1991) and (7) pathogens (Christensen, 1972; Harrison and Perry, 1976; Wytinck et al., 1991).

The most commonly described seed characteristics related to seed vigour include seed size or seed weight, bulk density, kernel density, protein content and enzymatic activity. Seed deterioration (i.e. loss of capacity for germination - failure to reproduce a normal seedling) may be preceded by negative changes in one or more of these seed characteristics.

2.3.1 Seed size.

Seed size, measured as diameter or mass per seed, is the most commonly measured seed quality characteristic (Evans and Bhatt, 1977; Boyd et al., 1971; Kaufmann and McFadden, 1960; Tekrony et al., 1987; Spilde, 1989; Gan et al., 1992). The positive influence of seed size on plant establishment and grain yield is well documented. Cornish and Hindmarsh (1988), reported that seed size influences coleoptile length of wheat. Their data showed that coleoptile length declined by 0.37 mm per mg reduction in seed weight. A positive relationship between seed weight and coleoptile length has also been found in barley (Radford, 1987b). A strong positive relationship between seed size and coleoptile length would mean farmers could grade seed to increase coleoptile length when desirable, e.g. for deep seeding.

Large seeds are more vigorous than small seeds because they have larger seed reserves. Evans and Bhatt (1977) showed a positive correlation between seed size, protein content and seedling vigour. Large seeds had a higher protein content than small seeds. Peterson et al. (1982 and 1989), looking at the contribution of seed reserves to seedling development of winter wheat reported that the amount of reserve material (endosperm) affected seedling development more than embryo size. Freyman (1978) reported that winter wheat plants from large seeds were more cold tolerant than those from small seeds. McDaniel (1969), also found that seedling weight, protein content and mitochondrial biochemical activity were positively correlated with seed weight. Thus seedlings from large seeds have a greater potential for growth than seedlings produced from small seeds.

Seed size is reported to have a positive effect on growth and development of wheat and barley (Gan et al., 1992; Kaufmann and McFadden 1960; Austenson and Walton, 1970; Spilde, 1989). Lafond and Baker (1986) reported that wheat plants grown from small seeds emerged faster but accumulated less dry weight than those from large seeds. In the same study, seed size accounted for 50% of the variation in seedling shoot weight of spring wheat.

In a recent study conducted at Portage la Prairie, Manitoba, it was reported that large seeds of spring wheat have a faster emergence rate than small seeds particularly at deep seeding (75 mm) (Gan et al., 1992). Total seedling emergence for small seeds also tended to be lower compared to large seeds at deep seeding. Under the stress of deep seeding, large seeds are more vigorous than small seeds. Improved stand establishment from using large seeds has also been observed in sorghum (Maranville and Clegg, 1977).

The effects of seed size have also been expressed in grain yield. Barley plants grown from large seeds produce superior grain yield (>10 %) than plants grown from small seeds (Kaufmann and McFadden, 1960). Their data showed that higher yield from large seeds resulted mainly from a greater number of heads on plants from large seeds. Gan et al. (1992), using precision planting and labelling the stem and tillers showed that wheat grain yield differences between large and small seeds were mainly due to differences in the grain yield of the tillers. Tillers from large seeds produced more grain yield than tillers from small seeds. There were no differences in main stem grain yield of large and small seeds. Spilde (1989) also observed yield reductions (4% and 5%) associated with small seeds in barley and wheat, respectively. Similar results were also reported for spring wheat by Austenson and Walton (1970). On the contrary, Duczek and Piening (1982) reported no seed size effect on spring barley grain yield.

2.3.2 Protein content

A high seed protein content (mg/seed) has been shown to increase seed vigour (Bulisani and Warner, 1980; Schweizer and Ries, 1969; Lowe et al., 1972; Ries and Everson, 1973; Torres and Paulsen, 1982). In growth chamber experiments, Bulisani and Warner (1980) showed that seedling vigour was significantly increased by seed weight and percent protein. The amount of N in the seed and not the percent protein or seed weight per se was the most important factor influencing seedling vigour. These workers also showed that the vigour differences were reduced if exogenous nitrogen was supplied during the first 3 days after planting.

Positive effects of seed protein upon grain yields have also been reported for wheat (Scheizer and Ries, 1969 and Lowe et al., 1969). Schweizer and Ries (1969) reported grain yield increase of 21 to 42 % when seed protein content was chemically increased. Bulisani and Warner (1980) reported no advantages in either rate of emergence or grain yield of wheat from seed with high protein content. Variations in seed protein are unlikely to have a significant effect on seedling vigour or yield under field conditions (Bulisani and Warner, 1980; Welch, 1976; Ries and Everson, 1973) because the environment becomes the dominant factor influencing plant growth and development after emergence.

2.3.3. Bulk density

The other seed characteristic related to seed vigour is test weight or bulk density. Test weight, usually expressed in kilograms/hectolitre, is the mass of grain which fills a specified volume under standard packing conditions. It is routinely assayed by millers because it provides an indication of potential flour yield.

Test weight is a function of density and packing characteristics of the seed (Fiona and Bingham, 1975). Seed samples with large test weights have been correlated with large seedlings, faster maturity and heavier kernels in oats (Frey and Wiggins, 1957). McDaniel (1969), reported that as seed weight increased from light, medium to heavy seed classes of barley, the respiratory activity of mitochondria also increased. Their data also showed that seedlings from the lowest test weights weighed only 50% as much as those from the higher test weights 2 weeks after planting. However, plant weights from light test weight seed reached the same weight as those from heavy seed sometime before maturity. In the same study the light test weight seed tended to produce grain that weighed less. A negative correlation between test weight and protein content has also been observed (Tkachuk and Kuzina, 1979; Ghaderi et. al., 1971), showing that low test weight can actually indicate higher protein.

2.3.4 Other factors.

Other factors which may reduce seed vigour are mechanical threshing (Vyn and Moes, 1986; Bourgeois et al., 1992) and presence of degradative microflora (Anonymous 2; Christensen, 1972). In field studies conducted at Ridgetown, Ontario, increases in corn seed breakage during threshing were associated with increased plant densities and increased drying temperatures (Vyn and Moes, 1986).

Some kernel physical characteristics have been implicated as factors in breakage susceptibility; (1) size; with larger kernels reported to be more susceptible to breakage than smaller kernels (Leford and Russell, 1985; Bourgeois[1], personal comm.); (2) shape, with breakage being greatest for large round kernels and lowest for flat kernels of various sizes (Vyn and Moes, 1988; Martin et al., 1987); (3) weight, with breakage susceptibility being negatively correlated with kernel weight (Bauer and Carter, 1986); and (4) kernel density, with dense kernels being more susceptible to breakage (Leford and Russell, 1985).

Recent studies show that the type of combine (Bourgeois et al., 1992) and cylinder speed (Bourgeois et al., 1992; Entz et al., 1991) affect seed vigour. Field studies by Bourgeois et al. (1992) indicated that although threshing efficiency increased with higher cylinder speed, seed vigour was adversely affected. The study further showed that rotary

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[1]Graduate student at University of Manitoba.

combines (in which material flow is parallel to the axis of the cylinder) caused less damage to seeds than conventional combines (in which material flow is tangential to the cylinder). In addition to visible cracking, mechanical damage may increase the incidence of invisible cracks (Vyn and Moes, 1988). Such cracks could affect seed viability or may increase seed disease incidence (Harrison and Perry, 1976).

Another factor which may reduce seed vigour is the presence of degradative microflora (Christensen, 1972; Wytinck, 1991). 'Field' and 'storage' fungi are the most common sources of seed degradation. The field fungi invade seeds developing in the field or after the seeds have matured and the plants are still standing or are cut and swathed, awaiting threshing (Wytinck, 1991).

After harvest, sound seed may be invaded by a variety of fungi during storage and have been designated "storage fungi" (Christensen, 1972). Regardless of their group, these fungi produce mycotoxins which are known to have inhibitory effects on germination (Harrison and Perry, 1976). The fungal invasion have been shown to reduce germination percentage of seeds (Christensen and Stakeman (1935) - in Christensen, 1972). Generally, these microflora thrive under the same conditions conducive for seed quality loss (Halloin, 1986; Wytinck et al., 1991). Wytinck et al. (1991) reported greater levels of Fusarium spp. infection on severely weathered wheat seed compared with unweathered seed. No differences in the level of infection by Fusarium spp. were observed between weathered and unweathered barley seed.

Decline in vigour and viability of seeds occurs during storage and has been shown to depend on duration of storage and on seed moisture content (Harrison and Perry, 1976; Nath et al., 1991). Harrison and Perry (1976) reported that seed viability of barley decreased with increasing storage time for all moisture treatments above 16%. Seedling vigour decline was more rapid at 22% moisture content. All seeds stored at 24% moisture content lost viability 21 days after storage and the loss was associated with invasion of the seeds by fungi.

Nath et al. (1991) reported that a 2 h pre-storage hydration at 25 C followed by drying allowed maintenance of germinability in storage. However, longer hydration treatments before storage severely increased the susceptibility of wheat seeds to deterioration.

2.4. Effects of field weathering on seed vigour.

2.4.1 Effects on physical seed characteristics

Field weathering has been shown to alter both the physical and physiological properties of seeds. Weather damage to seeds can occur when the seed is still on the plant. Although seed vigour is normally at its peak at physiological maturity (approximately 30 to 40 % kernel water content-KWC), the seed is not harvested until it attains "harvesting moisture" (12 to 16 % KWC), a safe moisture content at which mechanical injury to the seed is minimized (Bourgeois et al., 1992). Adverse weather during the dry-down period, especially rainfall and high relative humidity, increases the dry-down period (Christensen and Legge, 1984) and may expose seeds to cycles of wetting and drying (weathering). The detrimental effects of allowing crops to remain under these adverse weather conditions are well defined (Tekrony et al., 1980; Czarnecki and Evans, 1986; King, 1984; Wytinck et al., 1991).

In a study conducted at University of Manitoba, it was reported that moderate amounts of rain caused a 5% reduction in test weight of wheat (Czarnecki and Evans, 1986). The loss in test weight was attributed to a decrease in kernel density, kernel weight, and parking efficiency. Changes in kernel shape or roughening of the seed coat after weathering have also been implicated as factors that influence parking efficiency, which in turn affects bulk density (Ghaderi et al., 1971; Tkachuk and Kuzina, 1979; Czarnecki and Evans, 1986). Reduction in bulk density after weathering is also due to an irreversible increase in seed volume after water imbibition (Pushman, 1975).

Field weathering may cause a reduction in kernel density (Milner and Shellenberger, 1953; Czarnecki and Evans, 1986) or has no effect at all (Wytinck et al., 1991). Czarnecki and Evans (1980) reported that wheat exposed to field weathering during delayed harvest resulted in an average of 2.4% reduction in density. Reduction in kernel weight due to weathering is also inconsistent (Czarnecki and Evans 1986; Christensen and Legge, 1984; Wytinck et al., 1991). Czarnecki and Evans (1986) reported an increase in kernel weight after one wetting and drying cycle but reported a decrease in seed weight after the second cycle, although moisture content at harvest was similar. Christensen and Legge (1984) reported decreases in "Klages" barley kernel weights due to weathering, but drying method had no effect. In a recent study done at the University of Manitoba, no differences in kernel weight could be detected between weathered and nonweathered wheat and barley seed (Wytinck, 1991). Czarnecki and Evans (1986) speculated that dry matter loss associated with weathering may have resulted from the leaching or oxidation of the seed constituents.

Weathering may also reduce kernel hardiness (Czarnecki and Evans, 1986). Such kernels are more subject to fracture during harvesting (Dilday, 1989; Czarnecki and Evans, 1986) and to disease infection e.g. in barley (Harrison and Perry 1976).

Field weathering of seed may also result in staining or bleaching of the seed and is often the degrading factor in the grading of cereals in Canada, (Christensen and Legge, 1984a; Czarnecki and Evans, 1986). In a study done at Beaverlodge, Alberta, two cultivars of barley were down-graded by the Canadian Grain Commission to No. 1 Canada feed because of staining or bleaching due to the wet conditions during harvest of 1980 (Christensen and Legge, 1984a). No staining or weather damage of seed was reported in 1981 when the weather conditions at harvest were hot and dry. Down-grading of wheat in 1980 at Beaverlodge, Alberta, was also due to mildew, green kernels, and sprouting (Christensen and Legge, 1986). Bleaching of kernels due to weathering has also been observed by Czarnecki and Evans (1986), and Wytinck, (1991). Wytinck (1991) attributed the down-grading of wheat and barley seed to weathering of seed that occurred as a result of the large amounts of natural precipitation 3 weeks after physiological maturity in 1989.

2.4.2. Physiological effects of Field Weathering.

Field weathering has also been shown to alter the physiological properties of the seed. Premature enzyme activity, particularly alpha-amylase activity, is the most important (Moss et al., 1972; Czarnecki and Evans, 1986; Wytinck et al., 1991). Falling number, a starch-paste viscosity test for evidence of alpha-amylase activity (Moss et. al., 1972), is often used as an indicator of sprouting damage or alpha-amylase activity (Clarke et al., 1984; Wytinck et al., 1991). The lower the falling number, the greater the alpha-amylase activity (Matheson and Pomeranz, 1978).

In field studies conducted at the University of Manitoba, it was demonstrated that weathered wheat seeds exhibited higher levels of alpha-amylase activity as indicated by the falling number test (Czarnecki and Evans, 1986). Data reported by Wytinck et al. (1991), supported earlier studies that wet periods during harvest cause premature enzyme activity. In his studies, Wytinck observed significantly higher amounts of alpha-amyalse activity in the severely weathered wheat seed compared to unweathered seed. Low-falling numbers have also been observed in weathered barley seed (Wytinck, 1991; Christensen and Legge, 1985).

Another factor which may reduce the physiological performance of seed is the presence of degradative microflora (Christensen, 1972; Harrison and Perry, 1976; Anonymous ...). Since many microflora species flourish under the same conditions conducive for seed quality loss (Harrison and Perry, 1976), adverse weather conditions during harvest would also enhance disease development. Wytinck et al. (1991), demonstrated that exposing wheat and barley seed to field weathering increased incidence of fungal infections. Mildew reported on wheat harvested at Beaverlodge in 1980 was because of exposure of seed to weathering (Christensen and Legge, 1984a). If such seeds are not treated, their field performance is marginal (Anonymous ...).

Several studies have shown that the extent of the physical and physiological seed damage by field weathering depend on environmental factors. (1) The amount and duration of rain (Czarnecki and Evans, 1986; Tekrony et al., 1980; Wytinck et al., 1991), the higher the amount of rain and longer the wet period persists, the greater the damage. (2) Mean air temperature (Suresh et al., 1991; Tekrony et al., 1980; Wytinck et al., 1991), the hotter and drier it is, the lower the damage. (3) relative humidity (Tekrony et al., 1980; Wytinck et al., 1991; Suresh et al., 1991), the higher the relative humidity, the greater the damage.

Other factors associated with field weathering are harvest management (Christensen and Legge, 1984 and 1985; Clarke et al., 1984; Wytinck et al., 1991) and ear characteristics (King, 1984; King and Richards, 1984). Both of these factors are related to the physical-chemical aspects of water imbibition by the grain. Since germination can be slowed by restricting the water supply to grain, in-ear sprouting should be reduced if water uptake is restricted. For example, Clarke et al. (1984) observed more weathering in windrowed compared with direct combined wheat. The greater weathering susceptibility of the windrowed than that of standing wheat was attributed to higher moisture contents and slower drying following rains in windrowed compared to standing wheat. Results reported by Christensen and Legge (1984) and Wytinck et al. (1991) supported the earlier findings that windrowing increases the susceptibility of seed to weathering.

Genotype variation in water imbibition rates of seeds explains some of the differences in weathering susceptibility among cultivars (King, 1984). Ear characteristics, particularly the awns and their associated structures, accounted for some of the varietal differences in water uptake of wheat (King and Richards, 1984). These researchers observed that wheat cultivars with awns absorbed up to 30% more water, sprouting in the ear was enhanced by 40%, and water penetrated more quickly to the grain ears of awned lines. The awned characteristic had little influence on the loss of free water during the drying period. Pubescence and glaucousness (waxy/low wax) had no effect on ear wetting. It is unclear how the structure of the ear of awned varieties enhances water capture, since removal of the awn itself did not affect ear wetting (King and Richards, 1984).

King (1984) reported that water uptake by mature (post-dormancy) wheat grains in 50 cultivars differed up to two-fold. Neither grain colour, pericarp or testa thickness, grain hardness nor protein content was correlated with grain water uptake or germination. Reports by Clarke and Depaw (1989) that rate of water imbibition of wheat kernels was not associated with kernel colour supported the conclusions of King (1984). However, in contrast with King's report, these authors observed a positive correlation between water uptake rate and protein content. They also observed that water uptake was negatively correlated with kernel weight and kernel hardness.

Milner and Shellenberger (1952) reported that weathered wheat seed imbibed water faster than unweathered seed. They attributed these differences in water uptake to fissuring of the endosperm of the weathered seed during the wetting and drying cycles. On the contrary, Clarke and De Pauw (1989) observed faster rates of water uptake in non-weathered wheat (0.0136 $gg^{-1}h^{-1}$) compared with weathered seed (0.0130 $gg^{-1}h^{-1}$). These workers argued that samples used by Milner and Shellenberger (1953) were artificially weathered by soaking followed by a rapid oven drying at 50 C which could have influenced the degree of fissuring. Ambient field drying rates are unlikely to be this high.

Clarke (1984) concluded that windrowing of cereals can lead to increased weathering damage, particularly in weathering susceptible cultivars. Precipitation on swathed barley or wheat may also increase pick-up losses by causing the windrows to settle through the stubble, particularly under low-yielding crops (Clarke et al., 1984; Clark, 1989).

2.4.3 Effects on emergence

The effects of field weathering on emergence and stand establishment and their consequences on grain yield is limited and inconsistent. Many studies have emphasized the relationship of weathering to seed quality characteristics. Murray and Kuiper (1988) demonstrated that weathering reduced the germination of some wheat cultivars. The reduction in vigour of weather-damaged seeds was further increased by stresses caused by azole fungicide seed treatments, deep seeding (80 mm), and low soil moisture content. Their data also showed that weathered seed had reduced coleoptile lengths when compared with sound seed, but this difference may have been due to different seed sources.

Tekrony et al. (1980) showed that weathering reduced emergence of soybean. The decline in seed vigour of soybean following harvest maturity was associated with high temperatures and/or high levels of moisture. Data reported by Harrison and Perry (1976) on mechanisms of barley deterioration also demonstrated that seed deterioration was correlated with temperature and moisture content during seed storage.

In a study done at the University of Manitoba, Morrison et al. (1991) reported reduced seedling emergence for low vigour wheat seed under higher levels of trifluralin. The low vigour seed was suspected to have been weathered during harvest.

Tekrony et al. (1989) reported consistently lower emergence for low vigour than high vigour corn seeds in both zero tillage and conventionally tilled plots. The differences in emergence between the low and high vigour seeds were particularly larger under stress conditions (lower soil temperatures) that occurred in two of the three years. However, these workers did not explain the sources of seed vigour differences in their samples. Therefore, these results may not be related to weathering effects of seeds.

The effects of weathering on seed may not be detected by the ordinary germination test (Wytinck, 1991). Standard germination tests done on weathered and non-weathered seedlots of wheat and barley showed no differences in total germination percentage. However, the severely weathered seed generally had lower cold germination than the unweathered seed. Whether these differences detected by the cold germination test would correlate with field emergence will depend on seedbed environment. Johnson and Wax (1970) reported that for soybean, the cold germination test gave high correlations with field emergence.

2.4.4. Effects on grain yield.

There is little information on the relationship of weathering, to crop yield. Most studies examined vigour effects on germination and stand establishment. Generally, the few studies that considered final yield showed that lower seed vigour due to weathering reduced seedling emergence and yields if less than critical plant populations were obtained (Tekrony et al., 1989a and 1989b). DasGupta and Austenson, (1972) reported that wheat yields at Saskatoon in 1968 were correlated with test weight, 1000 kernel weight, and seedling dry weight. They suggested that these differences in seed vigour may have been due to weathering of seed harvested in 1968. Tekrony et. al., (1989b) showed that corn seed vigour had no direct effect on grain yields. However, low vigour seed had reduced seedling emergence and consequently lowered grain yields.

Tekrony and Egli (1991) concluded that seed vigour effects on yield depended on when the crop is harvested. Crops harvested during vegetative growth (e.g. cabbage) or early reproductive growth (e.g. tomato) showed a consistently positive relationship between seed vigour and yield. Those harvested at full reproductive maturity (e.g. cereals) generally showed no relationship between seed vigour and yield under normal cultural conditions. However, high seed vigour frequently increased yield when plant densities were less than those required to maximize yield.

The physiological basis for the effects of seedling vigour on plant development and potential yield has been attributed to photosynthetic efficiency. Until a seedling has produced enough photosynthetic capacity, its survival and vigour depends on food reserves present in the kernel. Early seedling vigour is most desirable under stress growth conditions e.g. in soils with residual herbicides (Morrison et al., 1991), and under cold growth conditions (Lafond and Baker, 1988; Freyman, 1978). In drought prone areas early seedling vigour is desirable for a quick ground cover thereby reducing water loss by evaporation.

2.5 SEEDING DEPTH AND PLANT PERFORMANCE.

2.5.1 Effects on emergence and growth.

Deep seeding, commonly practised when seed beds are deficient in moisture, causes poor emergence and establishment of crop stands (Sunderman, 1964; Austenson and Walton, 1970; Torres and Paulsen, 1982; Radford 1987a and 1987b; Loeppky et al., 1989). Several workers have used seeding depth to stratify seed vigour differences because of the clearly marked effects of seeding depth on plant performance (Torres and Paulsen, 1982; Sunderman, 1964).

In general, results of seeding depth studies indicate that wheat and barley cultivars show reduced seedling populations when planted deep because the coleoptiles are shorter than the seeding depth (Sunderman, 1964; Austenson and Walton, 1970; Radford, 1987a, 1987b). Data from Radford, (1987a and 1987b), indicated that tall wheat and barley cultivars generally have longer coleoptile lengths than the semi-dwarf cultivars. In his experiments with barley, Radford, (1987b) observed that barley cultivars with short coleoptiles suffered the largest reductions in establishment when seeded deep (110 mm). Similar results were reported for wheat (Whan, 1976), where semi-dwarf wheats with short coleoptiles had a lower total emergence than tall cultivars.

Deep seeding also influences the rate of seedling emergence. Data reported by Kaufmann (1968), showed that barley is generally more sensitive to deep seeding (75 mm) than either oats or wheat. Gul and Allan (1976) observed that the emergence index rate of winter wheat was lower at deep seeding (103 mm) than at shallow sowing (80 mm). Studies by Loeppky et al., (1989) showed lower emergence and increased variability in seedling emergence of winter wheat at deep seeding (25 to 50 mm) than at shallow seeding depth (10 to 25 mm). Gan et al. (1992) confirmed earlier reports that deep seeding increases emergence time. In their studies done in 1989 and 1990, they observed that seedlings from 75 mm emerged 3 to 4 days later than those from 25 mm depth.

Seeding depth has also been known to affect plant root growth and development (Loeppky et al., 1989; Hunt et al., 1983). Plant root growth and development affect the total supplies of water and nutrients available to the plant and also control the rates at which these supplies are extracted from the soil profile. Deep seeding results in longer subcrown internode lengths than shallow seeding (Loeppky et al., 1989). Although the longer sub-crown internode length at deep seeding results in shallow placement of crown roots, the roots are not as shallow as those from shallow seeding (Loeppky et al., 1989).

Temperature is another important environmental factor affecting the position of crown roots in the soil (Loeppky et al., 1989; Hunt et al., 1983). These studies found that the subcrown internode tends to elongate to a greater extent under warm, compared with cool temperatures (Hunt et al., 1983 loeppky et al., 1989). It is unlikely, however, that soil temperatures within the top 10 cm will vary considerably to affect the sub-crown internode lengths of plants.

Stand establishment at deep seeding can be enhanced by using high vigour seed (Gan et al., 1992; Ries and Everson, 1973; Torres and Paulsen, 1982; Radford 1987b; Cornish and Hindmarsh, 1988; Marranville and Clegg, 1977). In studies done at the University of Manitoba in 1990, Gan et al. (1992) reported that total seedling emergence at deep seeding was improved when large seeds were planted compared with using small seeds. Cornish and Hindmarsh (1988), reported that coleoptile length of wheat was positively correlated with seed size. Consequently, small seeds have poor emergence because they have shorter coleoptiles. Similar relationships have been found in barley (Radford, 1987b), wheat (Radford, 1987a), and sorghum (Marranville and Clegg, 1977).

Stand establishment is influenced by many environmental factors. A number of studies have reported on the interactive effects of soil temperature, soil water potential and /or seeding depth on the emergence of winter wheat (Gul and Allan, 1976; Loeppky et al., 1989; Lindstrom et al., 1976; Lafond and Fowler, 1989) and spring wheat (deJong and Best, 1979). In all these studies, time to emergence increased as soil temperature and soil water potential decreased. Increasing seeding depth increased time to emergence and variability in total plant stand.

2.5.2 Effects on grain yield.

There are several reports of effects of seeding depth on grain yield (Hadjichristodoulou et al., 1977, Duczek and Piening, 1982; Loeppky et al., 1989, Gan et al., 1992;). Most of these studies showed that yield decreases with increasing seeding depth. Reductions in grain yield at deep seeding have been associated with reduced tillers and heads/M^2 at deep seeding (Hadjichristodoulou et al., Loeppky et al., 1989; Gan et. al., 1992), and increased incidence of root rot disease in barley (Duczek and Penning, 1982).

The depth of seeding will vary from environment to environment, depending on soil moisture, soil temperature and soil type. Radford (1987a), reported that the mean coleoptile length of wheat decreased from 10.8 cm at 15 C to only 3.1 cm at 35 C. Thus, Radford concluded that in warm soils shallow seeding is necessary for satisfactory stand establishment.

In summary, deep seeding usually produces weak seedlings that frequently fail to emerge, resulting in reduced plant stands and consequently low grain yields.

2.6 INFLUENCE OF TILLAGE SYSTEM ON PLANT PERFORMANCE.

Zero tillage is the practice of sowing a crop directly into the soil without prior cultivation, but commonly following the application of a knockdown herbicide. Zero tillage has a number of advantages when compared to conventional tillage. These include reduced soil erosion, increased soil water conservation, reduced fuel costs, and lower labour costs (Tekrony et al., 1989b; Hall and Cholick, 1989; Zenter and Lindwall, 1978; Malhi et al., 1988).

Adoption of zero tillage or high residue systems changes the micro-environment in which the young crop grows. In the absence of tillage, lower soil temperatures often result due to the effects of trash cover on the surface (Gauer et al., 1982; Wall and Stobbe, 1984; Aston and Fisher, 1986; Malhi and O'Sullivan, 1990). Gauer et al. (1982) reported that retaining straw on zero tillage plots resulted in lower soil temperatures, and removal of the crop residues resulted in increased soil temperature. The higher the amount of straw on the soil surface, the lower the soil temperature (Unger and Wise, 1979).

According to reports by Gauer et al. (1982), soil temperature differences between zero tillage and conventional tillage are not because of tillage per se but are due to presence or absence of trash on the soil surface. These studies done at the University of Manitoba, indicated no consistent soil temperature differences between conventional and zero tillage soils when the straw was burned.

The same study (Gauer et al., 1982) also demonstrated that differences in soil temperature between the two tillage systems are due to differences in maximum rather than minimum soil temperatures. Additionally, these soil temperature differences are greatest in the layers adjacent to the soil surface (2.5 cm to 5.0 cm) (Gauer et al., 1982; Wall and Stobbe, 1984; Malhi et al., 1990). The soil temperature differences in these layers could be as high as 0.5 C to 2.8 C (Malhi and O'Sullivan, 1990; Gauer et al., 1982).

Because of these lower temperatures and decreased radiation flux on the soil surface of zero tillage plots, the evaporation rate decreases, resulting in higher soil moisture (Gauer et al., 1982; Malhi and O'Sullivan, 1990). The greatest moisture advantage under zero tillage occurs early in the growing season, when evaporation is the dominant means of soil moisture loss (Gauer et al., 1982). Like soil temperature differences between zero and conventional tillage, moisture conservation due to the presence of straw is greatest in the surface layers of the soil (0-15 cm) Malhi and O'Sullivan, 1990), but could be up to a depth of 60 cm (Gauer et al., 1982).

Other than reducing evaporation, stubble mulch increases water use efficiency by decreasing surface run-off, by increasing infiltration, and by increasing the amount of trapped snow.

The benefits of zero tillage may be overshadowed by a lack of economical weed control (Parson and Koehler, 1984; Malhi et al., 1988) and low nitrogen availability (Malhi and Nyborg, 1990). In a study done at 4 locations in central Alberta, zero tillage on average was \$48.77 $ha.^{-1}$ less economical than conventional tillage. This loss was associated with the additional herbicide costs and lower grain yields in zero tillage.

Soil compaction (measured by penetration resistance), is consistently greater under zero tillage than in conventional tillage soil (Malhi and O'Sullivan, 1990; Lindstrom et al., 1984). Owing to this compaction, zero tillage plots usually have a larger number of small, poorly drained pores (Gowman et al., 1978). These small pores could reduce the degree of soil aeration. Soil compaction could also be expected to impede root penetration (Lynch et al., 1983), thereby affecting the ability of the crop to absorb nutrients (Malhi et al., 1988), which may consequently reduce plant performance.

On the contrary to the above discussed negative effects of zero tillage, studies done at Portage la Prairie and Carman, Manitoba, by Donaghy (1973) showed that weed control and root development appeared to be superior under zero tillage compared with conventional tillage. Recent work done at Portage la Prairie, Manitoba, by Martino (1991) indicated no significant differences in soil compaction between tillage treatments. Reports by Poppe (1991) further support earlier findings observed at Portage la Prairie and Carman that plant growth and development of wheat or canola is similar between zero and conventional tillage.

2.6.2 Effects on emergence.

Because root-zone temperatures exert a considerable influence on early plant growth, a difference in germination and early plant growth could be expected between zero tillage and conventional tillage, particularly if the seed was planted at a shallow depth (Aston and Fisher, 1986; Malhi and Nyborg, 1990; Lindwall and Anderson, 1981).

In a study conducted at the University of Manitoba, the number of days from sowing to 50% emergence was increased significantly (by 2 days) for corn grown under zero tillage (Wall and Stobbe, 1983). The delay in emergence was associated with lower soil temperature (1.5 C lower) under zero tillage compared with conventionally tilled plots. These workers also reported reduced plant stands in conventional compared with zero tillage plots in one of the two years. The poor plant stand under conventional tillage was attributed to moisture stress that occurred soon after planting. In a wet year, plant population was higher under conventional than zero tillage plots. Poor emergence under zero tillage corresponded to localized areas with high concentrations of straw on the soil surface which may have physically hindered emergence.

Rourke (1981) measured the performance of wheat under different tillage and straw management systems at Graysville, Manitoba. He reported greater emergence of wheat under zero tillage plots with straw removed by burning than zero tillage plots with straw spread or removed by raking. On the contrary, plots under conventional tillage with straw spread had the highest emergence, followed by raking and burning. Averaged across the two tillage systems, 13% more plants emerged on conventional than on zero tillage plots. Poor seed placement due to interference from straw during seeding was the major factor for lower emergence in zero tillage plots with straw.

Reduced soil temperatures experienced after seeding also influence early plant development. In a study by Aston and Fisher (1986), done in Southern Australia, it was observed that cooler soil temperatures under zero tillage treatments were associated with reduced early vigour of wheat as measured by dry weight per plant at the 4.5 Haun developmental growth leaf stage. Similar results were reported by Ciha (1982) who found that stress incurred by spring wheat under no-till reduced early growth. Once the early growth of plants was reduced, they never recovered resulting in a yield loss.

Rourke (1981) reported that although no significant differences were observed for dry matter accumulation between tillage systems, there was a tendency for dry matter weights to be higher in conventional than zero tillage treatments. However tiller survival was greater in the zero tillage compared with conventional tillage plots. The higher mortality rate of tillers under conventional tillage (34%) compared to 27% under zero tillage may have been due to greater competition in the former.

2.6.3 Effects on grain yield.

Yield responses of many crops to zero or reduced tillage system has been either negative, positive or neutral (Hall and Cholick, 1989; Rourke, 1981; Lindwall and Anderson, 1981; Malhi and Nyborg, 1990). Rourke (1981) reported no differences in wheat grain yield between zero and conventional tillage, although yields under the latter tended to be greater in one of the two years.

Donaghy (1973) evaluated the performance of four crops under two tillage systems in southern Manitoba. He found no significant differences in grain yield for wheat and barley between zero and conventional tillage, except at one location where zero tillage barley gave the lowest grain yield. Nitrogen fertilizer trials indicated that less soil nitrogen was available under zero tillage and may have explained the reduced barley grain yield reported. Hall and Cholick (1989) showed that wheat planted in no-till seed bed could increase, decrease, or not affect grain yield, depending on cultivar. Poppe (1991) reported no yield differences in either wheat or peas between zero till and conventional tillage.

Yield advantages obtained under zero tillage are mostly in those areas where moisture is limiting during the growing season (Unger and Wiese, 1979; Aston and Fisher, 1986; Lindwall and Anderson, 1981; Malhi and Nyborg, 1990). Since yield increase observed under zero tillage appears to respond to improved moisture conservation (Unger and Wiese, 1979; Rourke, 1981; Malhi and Nyborg, 1990), straw management is the most important factor. Unger and Wiese (1979) reported that unusually large amounts of straw than those obtained from dryland wheat were required to show this difference. In his study, wheat straw of 8 to 12 t/ha was required to substantially increase yields over those obtained with conventional stubble-mulch tillage.

Studies show that barley grain yields can equal those with conventional tillage provided that rates of nitrogen are relatively high (Donaghy, 1973; Malhi and Nyborg, 1990). Donaghy (1973) studied effects of nitrogen rates on crop performance under two tillage systems at Portage la Prairie and Carman, Manitoba. He reported that at high rates of nitrogen (101 to 269 kg/ha) crops under zero tillage outyielded crops grown under conventional tillage.

Recent studies by Malhi and Nyborg (1990) also support Donaghy's earlier conclusions that lower yields with zero tillage may be due to immobilization of applied N due to the presence of straw. This was evident because at high N rates (100 kg N/ha), the immobilization effect of straw in zero tillage treatments was overcome. Yield reductions in zero-till have also been associated with lower soil temperatures and root growth inhibition due to allelopathic effects of crop residues (Cohran et al., 1977; Hall and Cholick, 1989).

2.6 EFFECT OF TRIFLURALIN ON PERFORMANCE OF WHEAT AND BARLEY.

Trifluralin (α,α,α-trifluro-2,6-dinitro-N,N-diprophyl-P-toluidine) is a residual dinitroaniline herbicide applied as a pre-plant deep incorporated treatment for the control of grass weeds and broadleaf weeds in dicotyledonous crops such as canola (Darwent, 1980; O'Sullivan et al., 1985). Several reports indicate that trifluralin degrades slowly in the soil and can leave significant residues that carry over into the next crop year (Pritchard and Stobbe, 1980; Pchajek et al., 1983; Grover et al ., 1988). Pritchard and Stobbe (1980) showed that between 17 and 26 % of the applied herbicide remains in the soil up to 50 weeks under Manitoba conditions. These levels of trifluralin were reported to be potentially phytotoxic to susceptible crops.

Trifluralin is also registered in Canada as a shallow (5 cm) pre-emergence incorporated treatment for control of green foxtail (Setaria viridis) in wheat and barley (Olson and McKercher, 1985; O'Sullivan et al., 1985; Anonymous, 1990). However, several studies show that trifluralin is injurious to wheat (Morrison et al., 1989; O'Sullivan et al., 1984b; Olson and McKercher, 1985) and barley (O'Sullivan et al., 1984). The major phytotoxic effect of trifluralin on wheat is the inhibition of coleoptile elongation (Rahman and Ashford, 1970), decreased seminal root extension, swelling of root tips, and reduced root weight (Olson and McKercher, 1985; Olson et al., 1984, Morrison et al., 1989). The general trend was that crop injury increased as rate of trifluralin herbicide increased.

Data reported by O'Sullivan et al. (1984 and 1985), indicated that spring application resulted in more injury than the fall application. Injury was in the form of smaller plants that exhibited delayed growth. O'Sullivan et al. (1985) reported that trifluralin rates below 1.0 kg/ha. increased grain yield of spring wheat while higher rates caused a yield decrease compared to the control.

In other studies, trifluralin has been reported to increase percentage of calcium and magnesium and decreased percentage of nitrogen, phosphorous, and potassium in young (25-day-old) wheat seedlings (Olson et al., 1984). However, these differences could not be seen in 35-day-old plants, indicating that wheat seedlings were able to recover from trifluralin injury.

Morrison et al. (1989a and 1989b), reported reduced wheat densities (37%) and lower dry matter production (50%) at the early growth stage of wheat planted in trifluralin treated soil. However, the crop was able to recover before crop maturity and it was attributed to enhanced assimilation rates of surviving plants, increased tillering and greater dry matter production per plant. Yield reductions associated with trifluralin treatments in wheat were greater in low vigour seeds than in high vigour seeds (Morrison et al., 1989a).

The phytotoxicity of trifluralin is also influenced by environmental conditions. Pritchard and Stobbe (1980), reported that trifluralin phytotoxicity decreased with increasing organic matter. They also observed that the persistence of the herbicide increased with an increase in organic matter content of the soil.

The effect of temperature on the phytotoxicity of trifluralin is contradictory. Darwent (1980) showed that efficacy of trifluralin in controlling wild oats dropped at high temperature (7-20 C) but improved at low temperature (4 C). This improvement in performance was attributed to long periods of exposure to the chemical due to reduced plant growth rate at low temperature. On the contrary, Moyer (1979), concluded that trifluralin toxicity to barley and wild oats was unaffected by temperature.

3. MATERIALS AND METHODS

3.1 General

The main objective of the experiment was to determine the influence of field weathering on seedling establishment and grain yield of Katepwa wheat and Heartland barley grown under a wide range of soil conditions. Katepwa wheat is a commercial variety of hard red spring wheat grown extensively across the prairies. Heartland barley is a 6-rowed feed cultivar recommended for all cropping zones in Manitoba (Anonymous 1, 1992).

The experiment was done at University of Manitoba Plant Science Research Station at Portage la Prairie (49 ^{o}N latitude, 100 ^{o}W longitude) in 1990 and 1991. The soil type in both years was a Neuhorst clay loam composed of clay (31%), silt (44%), and sand (25%) with an organic matter content of 7.5% and a pH of 7.7.

Planting was done on 14 and 15 May 1990, and 15 May 1991 at a seeding rate of 200 seeds/m^2. Seeding was done using the Noble Hoe Press Drill equipped with a Hedge belt cone seed metering system. The row spacing was set at 20.32 cm. The initial subplot size seeded was 2.02 x 9 m but was later trimmed to 2.02 x 7.5 m about four weeks after seedling emergence to remove variation at the end of each plot. Prior to planting, 100 kg N/ha was broadcast on all plots and incorporated only in the tilled plots. At seeding, 8 kg N/ha and 40 kg P_2O_5 were drilled with seed each year. Appropriate pest control measures were done in each year (appendix 1).

3.2 Experimental treatments.

3.2.1 Seedlots

Weathered seeds were used to study the effect of field weathering on performance of spring wheat and barley. Seed lots used were those obtained from an earlier study which looked at the influence of field weathering on seed quality and vigour of Katepwa wheat and Heartland barley (Wytinck et al., 1991).

Wheat and barley seedlots were subjected to field weathering by rainfall or simulated rainfall or both after swathing in 1989 and 1990 (Wytinck, 1991). Alpha-amylase (determined by using the Falling Number test) and cold germination tests were conducted in the laboratory to determine vigour differences caused by field weathering. The cold germination and falling number test results showed that there were seed vigour differences among the different treatments (Table 3.1 and 3.2).

Prior to seeding, standard germination tests were done on both wheat and barley. Four replicates of 50 seeds of each seedlot were placed on Whatman no. 1 filter paper in 9 cm plastic petri dishes moistened with 6 mL of distilled water and placed in a germination cabinet set at 20 C. Germination counts were made from 3 days after planting until germination ceased (Table 3.3).

Table 3.1 Influence of field weathering on falling numbers of wheat and barley at Portage la Prairie.

Weathering Level	Wheat 1989	Wheat 1990	Barley 1989	Barley 1990
Check	335a†	409a	365a	338b
Moderate	167b	400a	276b	364a
Severe	88c	309b	63c	225c
LSD (.05)	55	47	19	16
C.V.	15	8	5	3

†Numbers in a column followed by different letters are significantly different at P<0.05 (LSD test). (source: Wytinck 1991).

Table 3.2 Cold germination test results (14 Days after planting) for wheat and barley.

weathering Level	Wheat 1989	Wheat 1990	Barley 1989	Barley 1990
	...........% Germination..........			
Check	93a‡	95a	95a	98a
Moderate	87b	94a	94a	97a
Severe	92ab	70b	83b	96a

‡Means with the same letter within each column are not significantly different at $P \leq 0.05$ LSD test. (Source: Wytinck, 1991).

Table 3.3 Standard germination test results for wheat and barley.

Weathering Level	Wheat 1989	Wheat 1990	Barley 1989	Barley 1990
	..........% Germination............			
Check	93a‡	96a	99a	99a
Moderate	98b	98a	94a	98a
Severe	98b	99a	81b	98a

‡Means with the same letter within each column are not significantly different at $P \leq 0.05$ (LSD test).

Seeds were considered germinated when the radicals were distinctly visible. Based on the thousand kernel weight for each seedlot, the amount of seed per plot was calculated and weighed prior to planting.

There were no significant differences among seedlots except in severely weathered barley and unweathered wheat which had the lowest standard germination percentage in 1989 (Table 3.3).

Official grain grades were determined on all seedlots by the federal grain inspectors at the Canadian Grain Commission (Anonymous 1989). All barley seedlots in both years were graded 1 CW (No. 1 Canada Western). The higher the grade number, the poorer the grade of the seed being evaluated. Only the severely weathered barley seed was sprouted (6%) in 1990. Heartland barley is a feed crop and therefore the grading quality standards are fairly low.

Wheat grades ranged from 1 CW to CW feed in 1989. The moderate and severely weathered wheat seed was given 3 CW and CW feed respectively, in 1989. Sprouting was also evident in these seedlots (4.5% in the moderately weathered and 14.0% in the severely weathered seed). In 1990, all weathered wheat seedlots were assigned 3 CW and no seedlot was sprouted. The unweathered seedlot was given 1 CW in 1989 and 2 CW in 1990.

In both years, each seedlot was obtained after mixing seed from four replicates. This composite sample was passed through a 5.5/64 x 3/4 inch sieve in order to remove very small seeds. The seed was then treated with Vitavax, a fungicide that offers protection to seedlings from fungal diseases. For every 2 kg of seed 6 mL of Vitavax was injected into an electrically rotated drum (Gustafson) to ensure uniform coating of the chemical onto the seed.

In 1990, five seedlots were used: seedlot 1 = unweathered, lot 2 = slightly weathered, lot 3 = moderately weathered, lot 4 = severely weathered, lot 5 = slightly weathered (but combined straight). Based on the results of 1990, these lots were reduced to three only in 1991 season: lot 1 = unweathered, lot 2 = moderately weathered, and lot 3 = severely weathered. The data presented here will be based on three seedlots: 1 = unweathered, 2 = moderately weathered (lot 3 in 1990), and 3 = severely weathered (lot 4 in 1990).

3.1.2 Seeding depth.

Each seedlot was planted at three depths in both years. Planting depth was at 25 mm (shallow), 50 mm (medium) and 75 mm (deep). The depth of seeding was estimated and adjusted on guard plots before actual seeding to ensure that seed placement was close to the desired sowing depth.

3.1.3 Seedbed condition.

Each experiment was repeated under three different seedbed conditions: 1) zero-tillage, 2) conventional tillage with a fall application of Fortress[2] herbicide and, 3) conventional tillage. The previous crop in all trials was canola (Brassica napus or B. campestris L.). In the zero tillage plots, the crop was planted directly into an untilled seedbed, while conventional tillage plots were tilled twice in the fall and again in the spring prior to seeding. In 1990, zero-till plots were on a separate location from the two conventional tillage plot areas.

In the conventional tillage, the Fortress treatment was applied in the fall prior to seeding in each year as granular Fortress at the recommended rate of 14 kg/ha (Anonymous 1990) of product with a pneumatic spreader. Immediately following application the herbicide was incorporated into the soil to a depth of 50 mm with a tandem disc set to cut 75 mm. The second incorporation was done 7 days later, at right angles to the first pass.

3.2 Experimental design.

The experiment was laid down as a split-plot design with seeding depth as main plot factor and seed lot as sub-plot treatment. Seedlots were randomized within each seeding depth. Seeding depths were also randomized within each replicate. Each experiment had five replicates in 1990 and six replicates in 1991.

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[2] Fortress, generic name: Triallate (10% active ingredient-a.i.) and Trifluralin (4% a.i. granular).

3.3 Observations.

After planting but before emergence, an area of 50 x 50 cm quadrant was marked with flags at the centre of each plot. The same row position was used in each plot to remove any variation from the seeding unit. This area contained three rows measuring 50 cm each. Daily emergence counts were conducted on these areas at about 10.00 am everyday until no new plants could be noted. Coloured wire rings were used to mark seedlings that emerged on a given day. Seedlings were considered emerged when the coleoptile was visible above the soil surface. Total emergence for each plot was calculated by summing up the daily emergence records.

Speed of emergence index was calculated using the method proposed by Maguire (1962) and Hall and Wiesner (1990):

Equation (1)

$$\text{Speed of emergence} = \frac{\text{Seedlings emerged on D1}}{\text{D1}} + \frac{\text{Seedlings emerged on D2} - \text{seedlings emerged on D1}}{\text{D2}} + \ldots \frac{\text{Seedlings emerged on Dn} - \text{seedlings emerged on Dn-1}}{\text{Dn}}$$

Where D1=First day of emergence count
D2=Second day of emergence count
Dn=n^{th} day of emergence count

Although the seeder was calibrated before planting, seed distribution may have differed among the ten drill runs. Therefore, the same row positions (7th, 8th, and 9th drills of the Noble Hoe Press Drill) were used for sampling in each year. In 1990, sampling was done across seeding depths only (Haun scale 5.4) and thus, all early growth measurements except leaf area index (LAI) gave an estimate of seeding depth effects. In 1991, sampling was on 10th June for all wheat treatments (Haun scale 5.2) and 11th June for all barley treatments (Haun scale 5.3). Sampling of plants for growth measurements in 1991 was done in all three seeding depths and all seedlots. However, seedlot samples were taken only from the 75 mm seeding depth. To sample seedlots at all the three seeding depths was physically unjustifiable in terms of labour requirements.

The excavated plants were kept in a refrigerator or deep freezer so that all the desired measurements could be made before the plants were dry. The number of plants (seedlings), subcrown internode length, coleoptile length, and Haun developmental growth stage were measured and recorded. The Haun developmental scale was chosen over the Zadoks scale because of its ease to apply and it is also a good indicator of speed of emergence (Lafond and Baker, 1986). Dry matter yield was determined by drying the above ground parts at 80 °C for 48 hrs.

Other observations recorded include leaf area index (LAI - the ratio of the upper leaf area surface of the crop canopy to the ground area occupied by the crop). The LAI was determined by measuring canopy light penetration using a light meter bar model Licor LAI 2000. By getting two light readings above the canopy and eight light readings below the canopy, a LAI for each plot was computed and stored in the microprocessing unit of the equipment.

Head counts were conducted on the flagged areas in both years. Grain yield was obtained from an area of 1.2 x 7 m. Prior to harvest, one or two outer rows were trimmed. Plot areas were measured individually to ensure correct yield estimates. In each year, seed was cleaned using the 5.5/64 x 3/4 inch sieve before TKW and HLW weights were determined.

In 1990, seed moisture content of all wheat treatments and all deep seeded barley were determined automatically by a moisture meter mounted on the combine harvester. Barley under 25 and 50 mm seeding depths was harvested before calibration of the moisture meter on the combine, therefore, seed moisture content was determined manually using a Labtronics moisture meter model 919. Calibration of the moisture meter on the combine was based on the Labtronics moisture meter. Moisture determinations in 1991 were all manually done using the moisture meter described above. Grain yields were adjusted to a moisture content of 13.8 % for wheat and 14.5 % for barley.

3.4 Statistical analysis.

All data of each year were subjected to analysis of variance procedures on the Statistical Analysis System (SAS Institute, 1985). Means were compared using the Fisher's Least Significant Difference (LSD) test if ANOVA was significant at probability of 5% or less. Simple correlation analyses were conducted to determine relationships between the various growth parameters and grain yield. Data for each year were analyzed separately because when combined together, the error variances were significantly different (Gomez and Gomez, 1984)

4. RESULTS AND DISCUSSION

4.1 Summary of weather data

Rapid and uniform emergence is an important pre-requisite for obtaining satisfactory stands and optimum growth. Early stress from either low water potential, low soil temperature, diseases, or deep seeding reduce plant establishment. These effects may be reduced in part by using high vigour seeds. The use of weathered seeds and its effects on seedling establishment, growth and grain yield were evaluated under field conditions at Portage la Prairie, Manitoba, in 1990 and 1991.

A summary of the rainfall, soil and air temperatures, for both years is presented in Table 4.1. Weather data was

Table 4.1 Long-term average and actual monthly temperature and rainfall at Portage la Prairie, Manitoba.

Month	Year	Air Temperature Max	Min	Mean	Soil temp. (10cm)	Rainfall (mm)
		....		°C.	....	
May	Normal	17.0	4.6	10.8	-	31.0
	1990	17.5	2.8	10.2	7.7	42.7
	1991	20.9	7.9	14.1	11.1	59.0
June	Normal	22.9	10.6	16.8	-	81.0
	1990	24.4	11.5	18.0	-	133.6
	1991	25.2	12.4	18.8	18.1	75.0
July	Normal	25.6	13.5	19.6	-	77.4
	1990	25.4	13.0	19.2	-	53.6
	1991	25.9	13.6	19.5	20.3	95.0
August	Normal	24.7	12.0	18.4	-	80.0
	1990	26.8	13.0	19.9	-	42.6
	1991	28.3	12.4	20.2	20.3	10.0

Long-term average temperature and rainfall at Portage (Source: Environment Canada).

obtained at the site of the experiment or from Agriculture Canada. Soil temperatures were measured at 10 cm depth under a sod cover. Thus, the actual soil temperatures in the field may have differed from those at the station due to differences in soil cover. However, a comparison between years was still valid even under such conditions.

Average minimum soil temperatures were warmer at planting in 1991 (11 °C) compared to 1990 (8 °C). Although total precipitation was similar between the 2 years, rainfall distribution varied (Fig 4.1). In 1990 soon after seeding, 37 mm of rain was received, and coupled with the low soil temperatures (Fig 4.2), seedling emergence was extended over 11 days. On the other hand, 1991 was relatively drier for 10 days after planting and together with the warm soil temperatures, seedling emergence was complete within 9 days. The cold soils of 1990 may have delayed emergence of seedlings but the final plant stand at shallow seeding was excellent. Seed germination and seedling emergence at shallow seeding were slightly reduced in 1991 because of the relatively drier and warmer soil conditions compared to 1990.

At the late grain filling stage in August, rainfall was well below normal particularly in 1991 compared with 1990. This lack of rainfall in 1991 may partly explain yield differences seen between the 2 years.

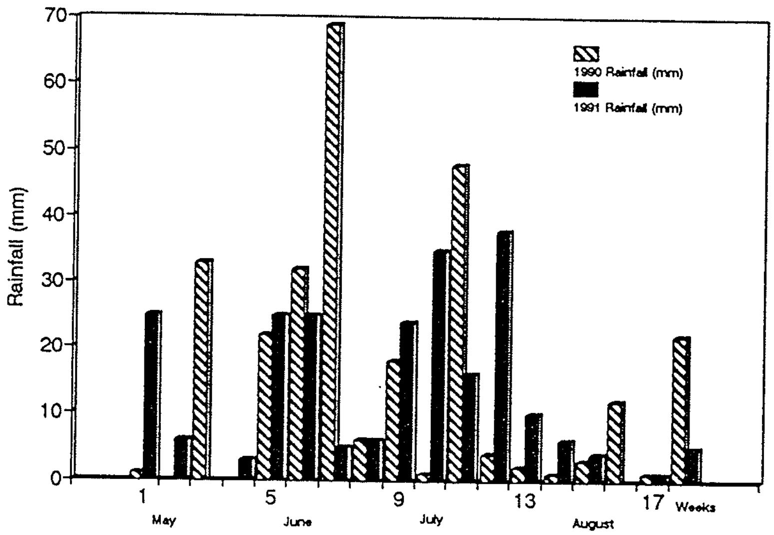


Fig 4.1 Rainfall distribution at Portage la Prairie in 1990 and 1991.

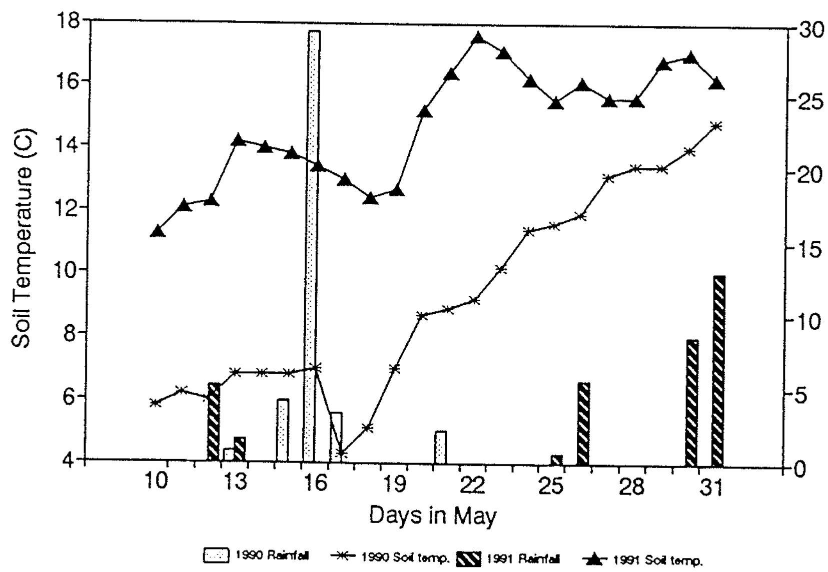


Fig 4.2 Soil temperature and rainfall in May at Portage la Prairie.

4.2 SEEDLING EMERGENCE.

The data was analyzed for both vigour and depth effects in each year (Appendix A4.1 and A4.2). Although interactions between seeding depths and seedlots for emergence and speed of emergence were not significant in all seedbed conditions, all data were further subjected to ANOVA at each seeding depth to check for patterns of crop performance at each depth.

4.2.1 Emergence of weathered spring wheat

The absence of a seedlot by seeding depth interaction for wheat seedling emergence indicated that all seedlots responded similarly to changes in seeding depth (Appendix A4.1). When averaged across depths no significant differences in seedling emergence were detected among wheat seedlots under any seedbed condition (Table 4.2).

Table 4.2. Wheat total seedling emergence (plants/0.25 m^2) for all three seeding depths. Each value represents the mean of 15 and 18 observations in 1990 and 1991, respectively.

Crop	Seedlot (1990)				Seedlot (1991)			
	1	2	3	C.V.(%)	1	2	3	C.V.
WCT	52	52	55	20	65	63	64	13
WFR	47	52	51	19	59	58	60	14
WZT	43	42	42	20	60	56	62	13

WCT=Wheat under conv-till; WFR=Wheat in conv-till with Fortress herbicide; WZT=Wheat under zero-till.

Even when seedlots were analyzed at each seeding depth, there were no trends to suggest that unweathered wheat seed had better emergence than weathered seed (Table 4.3).

Table 4.3 Wheat seedling emergence (plants/0.25 m^2) at three seeding depths. Each value is an average of 5 and 6 observations in 1990 and 1991, respectively.

Crop	Depth	Seedlot (1990)				Seedlot (1991)			
		1	2	3	C.V.(%)	1	2	3	C.V (%)
WCT†	25	56	60	62	14	60	65	59	11
	50	51	47	54	29	70	69	72	11
	75	51	48	49	17	64	56	60	16
WFR	25	54	61	54	16	63	59	63	15
	50	46	50	48	19	60	64	58	7
	75	40	46	50	23	52	52	58	19
WZT	25	52	47	47	21	61	60	64	9
	50	42	43	40	22	64	68	62	11
	75	33	35	40	16	53	52	56	20

†WCT=Wheat under conv-till; WFR=Wheat in conv-till with Fortress herbicide; WZT=Wheat under zero-till.

4.2.2. Weathering effects on emergence of barley

Total seedling emergence from the 3 seedlots was similar at the 3 seeding depths as shown by a nonsignificant seedlot by seeding depth interaction (Appendix A4.1-4.2). When all seeding depths were averaged, total emergence of unweathered barley seed was significantly higher (2.4% greater) than the severely weathered seed only under conventional tillage in 1990 (Table 4.4). In the same year, no significant differences in emergence could be detected among the three seedlots under the other two seedbed conditions (Zero tillage and Fortress treatments). In 1991, there were no significant differences in plant stands among seedlots under any seedbed condition.

Table 4.4. Emergence means (plants/0.25 m^2) of barley at Portage la Prairie. Each value represents the mean of 15 and 18 observations in 1990 and 1991, respectively.

Crop	Seedlot (1990) 1	2	3	C.V.(%)	Seedlot (1991) 1	2	3	C.V.
BCT*	56a†	54a	45b	13	59	60	58	14
BFR	46	44	47	22	54	53	55	19
BZT	41	39	36	25	59	58	54	15

†Means followed by different letters within each row and year are significantly different at $P< 0.05$ (LSD) test.
*BCT=Barley under conv-till; BFR=Barley under conv-till with fall applied Fortress herbicide; BZT=Barley under zero-till.

When analyzed by seeding depth, the unweathered seedlot had significantly higher emergence counts (26 and 33 % higher) at the 50 and 75 mm seeding depths, respectively, than severely weathered seed under conventional tillage in 1990 (Table 4.5). The severely weathered seed appeared to show reduced emergence at deep seeding in 1990 under all seedbed conditions. No significant differences in emergence counts were reported in 1991 at any seeding depth.

Lack of consistency in total seedling emergence between the 2 years may be attributed to differences among seedlots and to weather conditions. Seedlots used in 1990 showed lower falling numbers compared with 1991 (Table 3.1). This would suggest that the 1990 seedlots suffered weathering to a greater degree than the 1991 seedlots. The degree of weathering for severely weathered barley was particularly greater in 1990 than in 1991 as indicated by both falling numbers and cold germination tests.

Table 4.5 Barley seedling emergence (plants/0.25 m^2) at three seeding depths. Each value is an average of 5 and 6 observations in 1990 and 1991, respectively.

Crop	Depth	Seedlot (1990) 1	2	3	C.V.(%)	Seedlot (1991) 1	2	3	C.V.(%)
BCT*	25	63	65	59	11	67	72	63	12
	50	54a†	52a	43b	10	62	61	60	11
	75	50a	44ab	33b	18	47	47	52	19
BFR	25	58	70	72	12	61	62	65	15
	50	42	37	36	27	56	62	60	18
	75	38	34	26	37	44	41	36	25
BZT	25	41	42	45	25	64	65	66	15
	50	45	43	35	28	63	60	56	14
	75	37	33	29	18	49	49	43	16

†Means followed by different letters within each row and year are significantly different at $P < 0.05$ (LSD) test.
*BCT=Barley under conv-till; BFR=Barley under conv-till with fall applied Fortress herbicide; BZT=Barley under zero-till.

Moisture contents for different seedlots at time of harvest in 1989 were different. The unweathered wheat seed for example was harvested at 19% moisture content in 1989 compared with the 12% moisture content in 1990. Previous studies (Entz, et al., 1991) have shown that grains harvested at higher moisture content undergo greater internal damage during threshing than those threshed at ideal harvest moisture content. The seedlots used in 1991 were fan dried prior to threshing, ensuring a uniform moisture content before threshing.

As to which test best described the vigour of seeds, Wytinck (1991) suggested the cold germination test for wheat and falling number test for barley. Wytinck (1991) showed that the most differences in cold germination test between the unweathered and severely weathered wheat seed appeared about 10 to 12 days after planting. These differences were, however, markedly reduced after the germination period was over. This implies that most of the seeds do eventually germinate after sometime and therefore, total plant stand may not be affected for different seedlots at the end of the emergence period. The present study does not agree with either tests as predictors of field performance for spring wheat and barley. Field response of individual seedlots was not consistent with the laboratory tests as shown by data from the 2 years.

Responses to seedling emergence among the 3 seedlots were different for the 2 years in part due to weather differences. Cooler soil temperatures in 1990 may have caused a severe stress on germinating and emerging seedlings. The cold soils may have reduced emergence of the weathered seeds especially at deep seeding. On the other hand, soil temperatures at seeding in 1991 were warmer, providing close to "ideal" conditions for germination and emergence.

It has been previously reported that low vigour seed will reduce field emergence and crop performance if seeds are planted under poor soil conditions. However, under ideal soil conditions, the standard germination test accurately predicts field emergence, and seed vigour has less influence on final plant stand (Tekrony and Egli, 1977; Tekrony et al., 1987).

In this study all seedlots had standard germination percentages that exceeded the levels normally considered to be commercially acceptable (>80%). The soil conditions at planting in both years were closer to "ideal germination conditions", particularly at shallow seeding. These ideal conditions at the shallow seeding depth resulted in excellent emergence regardless of the initial seed vigour. In all experiments, the beneficial effect of sound seed seemed to be relatively greater at deep seeding than at the shallow depth, suggesting that the stimulatory effect of high vigour seed increased as the stress on the seedlings increased.

These results are generally in agreement with the findings of Murray and Kuiper (1988) who reported inconsistent differences in emergence of wheat seeds previously exposed to field weathering. Their data showed that weathering reduced the emergence of some cultivars of wheat but not all. Emergence of weathered seed appeared to be reduced especially in stress environments, e.g. at deep seeding (80 mm) and with the azole seed dressings.

In other studies, reduced seedling emergence has been associated with reduced soil temperature, decreased water potential and deep seeding in wheat (Khan et al., 1986; Lindstrom et al., 1976; Lafond and Fowler, 1989) and cold, wet soils in corn (Martin et al., 1988).

In terms of which seedbed condition gave the best estimate for vigour differences between weathered and unweathered seed, it can be concluded that it was conventional tillage since significant vigour differences were only observed in barley under conventional tillage in 1990. Zero tillage and Fortress areas consistently showed better emergence of the unweathered seed at deep seeding compared with weathered seed in 1990. This was attributed to the possible higher stress levels under these 2 seedbed conditions which may have lowered the potential for weathered seeds.

Although there was no replication for the seedbed conditions, the 2 years' data showed that Fortress treated soil reduced emergence of both crops compared with conventional tillage. For example, in 1990 emergence in conventional tillage was consistently higher than in the Fortress treated area in 2 out of the 3 seeding depths. The reduction in emergence appeared to be greatest at the 50 and 75 mm seeding depths especially in 1990. The cold and wet soil conditions that prevailed in 1990 may have increased the exposure period of the germinating seeds to the herbicide.

Emergence under zero-tillage can not be directly compared with the conventional tillage treatments because locations were different in 1990. But in 1991, all the seedbed conditions were on the same soil type and emergence of both crops was similar between zero and conventional tillage. Emergence under conventional tillage however, was always equal or better than that in either Fortress or zero-till. The zero tillage treatment resulted in consistently higher emergence than the Fortress treatment. Emergence data from the Fortress herbicide treated seedbed in 1990 support conclusions by Morrison et al (1991) that trifluralin reduces field emergence of wheat.

4.2.3. Weathering effects on speed of emergence

The rate of emergence determines how quickly seedlings emerge. Speed of emergence index as proposed by Maguire (1962) (Equation 1) was calculated for each seedbed condition and at each seeding depth. Generally, the higher the speed of emergence index value, the faster the emergence. Small emergence index values indicate slower emergence and lower plant stands.

Averaged across all seeding depths within each seedbed condition, severely weathered wheat seed gave significantly higher emergence index values than unweathered seed under conventional tillage (CT) (Table 4.6). The significant wheat seedlot by depth interaction for emergence index under CT in 1990 indicates that seedlots responded differently at the three depths (Appendix A4.3). Analysis of variance by depth showed that the severely weathered wheat seed had a significantly higher emergence index value than unweathered seed only at shallow seeding (Table 4.7). No significant differences in speed of emergence between weathered and unweathered could be detected at 50 and 75 mm seeding depths.

Table 4.6. Effect of weathering on speed of emergence index of wheat. Each observation is an mean of 3 depths replicated 5 times in 1990 and 6 times in 1991.

Crop	Seedlot (1990)				Seedlot (1991)			
	1	2	3	C.V.(%)	1	2	3	C.V.(%)
	...............emergence index rate...........							
WCT*	15b†	13b	17a	17	27	27	28	15
WFR	14	16	15	37	23	24	26	26
WZT	12	14	14	34	23	23	24	21

†Means followed by different letters within each row and year are significantly different at P<0.05 (LSD test).
WCT*=Wheat under conv-till; WFR=Wheat in conv-till with Fortress herbicide; WZT=Wheat under zero-till.

Table 4.7 Speed of emergence index of weathered wheat seed as affected by seeding depth. Each value is a mean of 5 and 6 observations in 1990 and 1991 respectively.

Crop	Depth	Seedlot (1990)				Seedlot (1991)			
		1	2	3	C.V.(%)	1	2	3	C.V.(%)
WCT	25	25b†	22b	31a	11	40	41	42	9
	50	10	10	11	29	24	25	27	20
	75	8	8	8	17	17	15	14	22
WFR	25	24	28	25	16	32	33	36	23
	50	9	10	10	24	19	20	20	15
	75	7	8	9	29	11	12	13	25
WZT	25	21	24	25	32	32	32	44	23
	50	9	10	10	14	20	26	22	8
	75	6	8	7	17	15	14	13	21

†Means followed by different letters within each row and year are significantly different at P<0.05 (LSD test).
*WCT=Wheat under conv-till; WFR=Wheat in conv-till with Fortress herbicide; WZT=Wheat under zero-till.

Averaged across all seeding depths within each seedbed condition, unweathered barley seed had lower emergence index values compared with moderately and severely weathered seed under Fortress treatment in 1990 (Table 4.8). A significant depth by seedlot interaction for speed of emergence index in barley under Fortress and zero tillage in 1990 and under zero tillage in 1991 (Appendix A4.3) indicate that seedlots responded differently at the 3 seeding depths .

Table 4.8 Effect of weathering on speed of emergence index of barley. Each value is a mean of 3 depths replicated 5 times in 1990 and 6 times in 1991.

Crop	Seedlot (1990)				Seedlot (1991)			
	1	2	3	C.V.(%)	1	2	3	C.V.(%)
	..................emergence index rate...............							
BCT*	23	20	20	37	24	26	26	25
BFR	15b	20a	20a	18	22	23	21	34
BZT	10	12	14	37	23	23	25	27

†Means followed by different letters within each row and year are significantly different at P<0.05 (LSD test).
*BCT=Barley under conv-till; BFR=Barley under conv-till with fall applied Fortress herbicide; BZT=Barley under zero-till.

Examination of seedlot performance at each depth showed no significant differences between unweathered and weathered seedlots under any seedbed condition, except in barley under conventional tillage in 1990 and under zero tillage in 1991 (Table 4.9). The unweathered and moderately weathered barley seed under conventional tillage exhibited higher emergence index values than the severely weathered seed at deep seeding in 1990. In 1991, severely weathered seed under zero tillage showed significantly greater emergence index values compared with unweathered and moderately weathered seed.

The speed of emergence index value for barley under conventional tillage at deep seeding may have been higher for the unweathered and moderately weathered seed compared with the severely weathered seed because of differences in vigour levels. The reduced vigour of the severely weathered seeds may have been due to oxidative and leaching losses.

The differences in rate of seedling emergence between weathered and unweathered seed in 1991 may be attributed to differences in stages of enzyme activation among seedlots. Field weathering initiated some of the germination processes which may have enhanced the speed of emergence in the weathered seed as shown by the alpha-amylase test (Table 3.1).

Table 4.9 Speed of emergence index of weathered barley seed as affected by seeding depth. Each value is a mean of 5 and 6 replicates in 1990 and 1991, respectively.

Crop	Depth	Seedlot (1990)				Seedlot (1991)			
		1	2	3	C.V.(%)	1	2	3	C.V.(%)
BCT*	25	46	40	43	27	36	42	40	27
	50	13	12	11	24	25	24	24	23
	75	9a†	8a	6b	21	12	12	14	20
BFR	25	30	46	45	24	37	38	35	25
	50	9	9	9	28	20	23	19	31
	75	7	5	7	47	10	8	9	28
BZT	25	15	19	26	33	35b	35b	49a	19
	50	10	10	9	41	23	21	21	29
	75	6	6	6	16	12	13	11	30

†Means followed by different letters within each row and year are significantly different at $P<0.05$ (LSD test).
*BCT=Barley under conv-till; BFR=Barley under conv-till with fall applied Fortress herbicide; BZT=Barley under zero-till.

Seed germination occurs in three phases: 1) moisture imbibition, 2) enzyme activation, and 3) nutrient mobilization from the endosperm to the embryo (Street and Opik, 1975). Weathered seeds may have been exposed to some or all of these processes as indicated by the alpha-amylase test (section

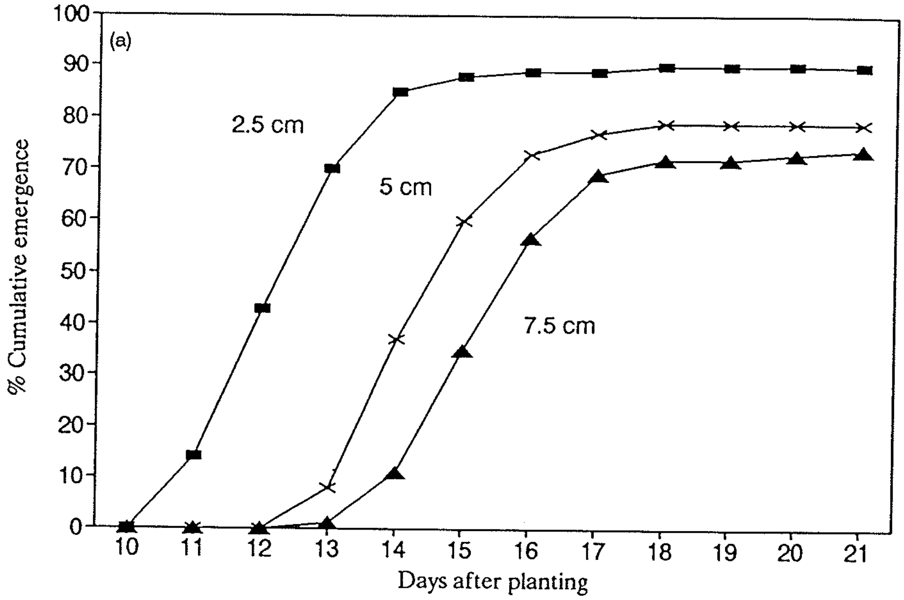
3.2.1.). This would generally reduce the time required for the seed to germinate and emerge.

Speed of emergence index values were generally higher in 1991 than in 1990. Once again, this difference may be attributed to soil temperature differences between the two years. Average soil temperature at time of seeding was much lower in 1990 (7 °C) than in 1991 (11 °C). Since temperature is an important component of seed germination and emergence, reduced soil temperatures at seeding time in 1990 delayed emergence by slowing down the physiological development rate of the germinating seedlings.

4.2.4 Depth effects on total seedling emergence.

The absence of a significant seedlot by depth interaction for total seedling emergence permitted the averaging of seedlot means for comparisons of differences due to seeding depth. In both wheat and barley, seedling emergence was significantly greater for shallow compared with deep seeded plants (Fig 4.3a-b and Fig 4.4a-b). These differences were significant at the 1% level of probability. Because total emergence per unit area exceeded the target population, percentage seedling emergence was computed based on the highest count at shallow seeding for each seedbed condition.

Emergence exceeded 80% in both crops and years at shallow seeding (Fig. 4.3a-b and Fig. 4.4a-b). Increasing seeding depth resulted in significantly lower plant populations for



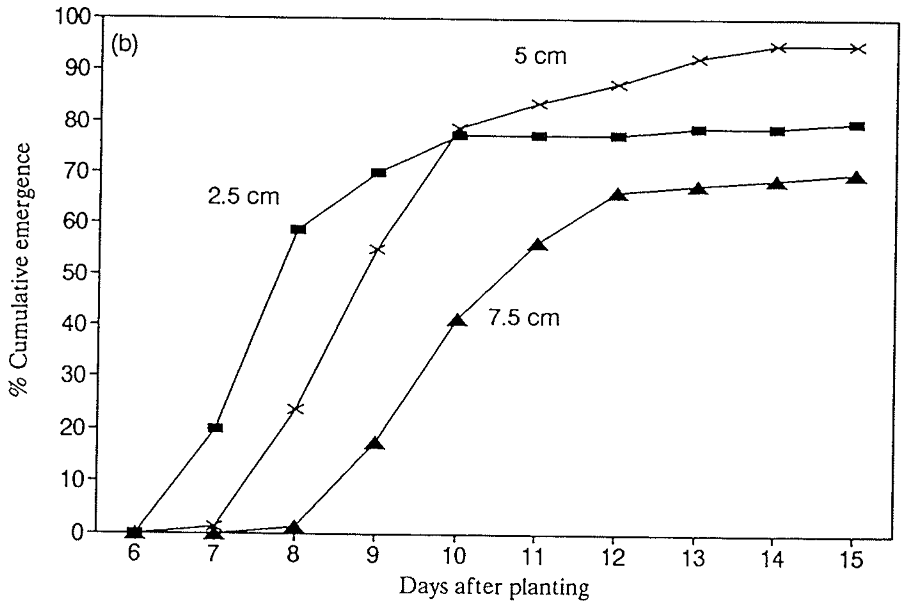


Fig. 4.3 Percent cumulative seedling emergence of Katepwa wheat as affected by seeding depth; (a) 1990 and (b) 1991. Each point is a mean of 3 seedlots and 3 seedbed conditions replicated 5 and 6 times in 1990 and 1991, respectively.

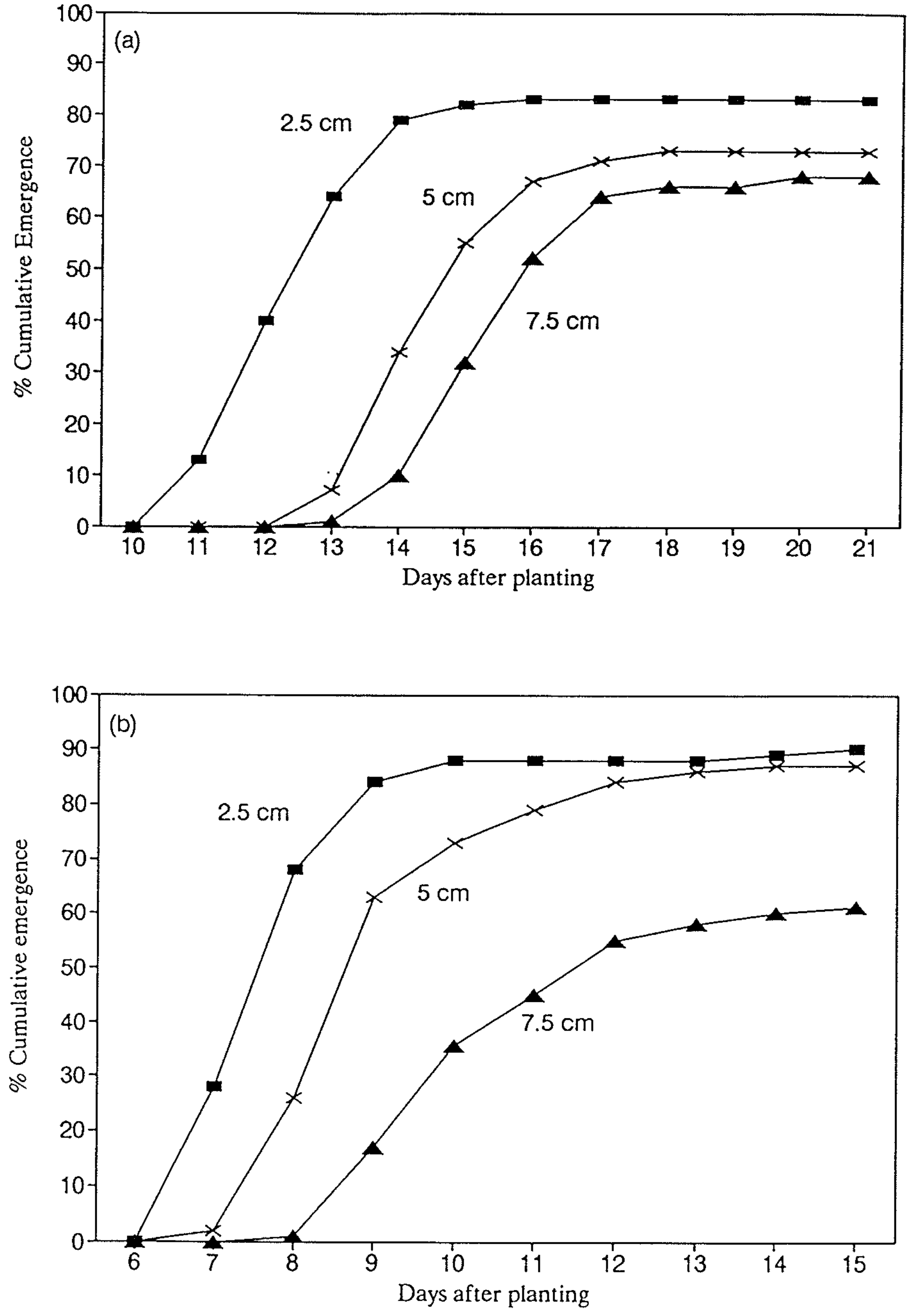


Fig. 4.4 Percent cumulative seedling emergence of Heartland barley as affected by seeding depth; (a) 1990 and (b) 1991. Each point is a mean of 3 seedlots and 3 seedbed conditions replicated 5 and 6 times in 1990 and 1991, respectively.

both crops and in both years. Averaged across the two years, deep seeding resulted in 8% and 10% plant stand reductions in wheat and barley, respectively.

Differences between the 25 and 50 mm seeding depths were less dramatic in 1991 than in 1990. This may have been due to the actual seeding depths which were less deep in 1991 than in 1990 (Data not shown). Moisture stress at the shallow seeding depth in 1991 may also have contributed to this observation. Deep seeding adversely affected barley more than wheat. When the unemerged seedlings were uncovered, it appeared that the coleoptiles had failed to reach the soil surface. The first two leaves had unfolded under the ground and were bound to die unless heavy rains washed off the top soil. Even when such seedlings managed to emerge, they appeared chlorotic and weak.

Reduction in seedling emergence due to deep seeding has been reported in winter wheat (Loeppky et al., 1989) and spring wheat (Gan et al., 1992). Murray and Kuiper (1988) reported a positive correlation between wheat seedling emergence and coleoptile length. Burleigh et al. (1964) concluded that tall wheat varieties have higher emergence because they have longer coleoptiles compared with dwarf cultivars. In other studies, decreased emergence with deep seeding has been attributed to increased root rot disease in spring barley (Duczeck and Piening, 1982) and to reduced soil temperature in winter wheat (Lafond and Fowler, 1989).

4.2.4 Effect of seeding depth on speed of emergence.

Results for both crops and years on effect of seeding depth on rate of seedling emergence are presented in Fig 4.5-4.6. Generally, as seeding depth increased from 25 to 75 mm, the rate of seedling emergence decreased for both crops. The reductions observed were large considering that depth of seeding only varied from 25 to 75 mm. Previous studies have shown that late emerging plants face more intense competition for light from earlier emerged plants, and consequently produce lower grain yield (Gan et al., 1992). Deep seeded plants were slower to emerge because their coleoptiles had to push through a longer soil column.

Deep seeding also delayed seedling emergence of both crops. Emergence time was increased by three days in both years when planting depth was increased from 25 to 75 mm. The time required to get 50% emergence at shallow seeding for both crops in 1990 was 12 and 16 days after planting at 25 and 75 mm planting depth, respectively. This increase in days to 50% emergence with deep seeding was true for all seedbed conditions. The same trend was observed in 1991, but the emergence period was generally reduced by about 3 days due to warm weather that prevailed during and after seeding in 1991.

This study supports earlier reports by Gan et al. (1992); Lindstrom et al. (1976); and Lafond and Fowler (1989) that deep seeding increases time to 50% emergence. The current Manitoba recommendation of seeding wheat at 40 to 80 mm depth

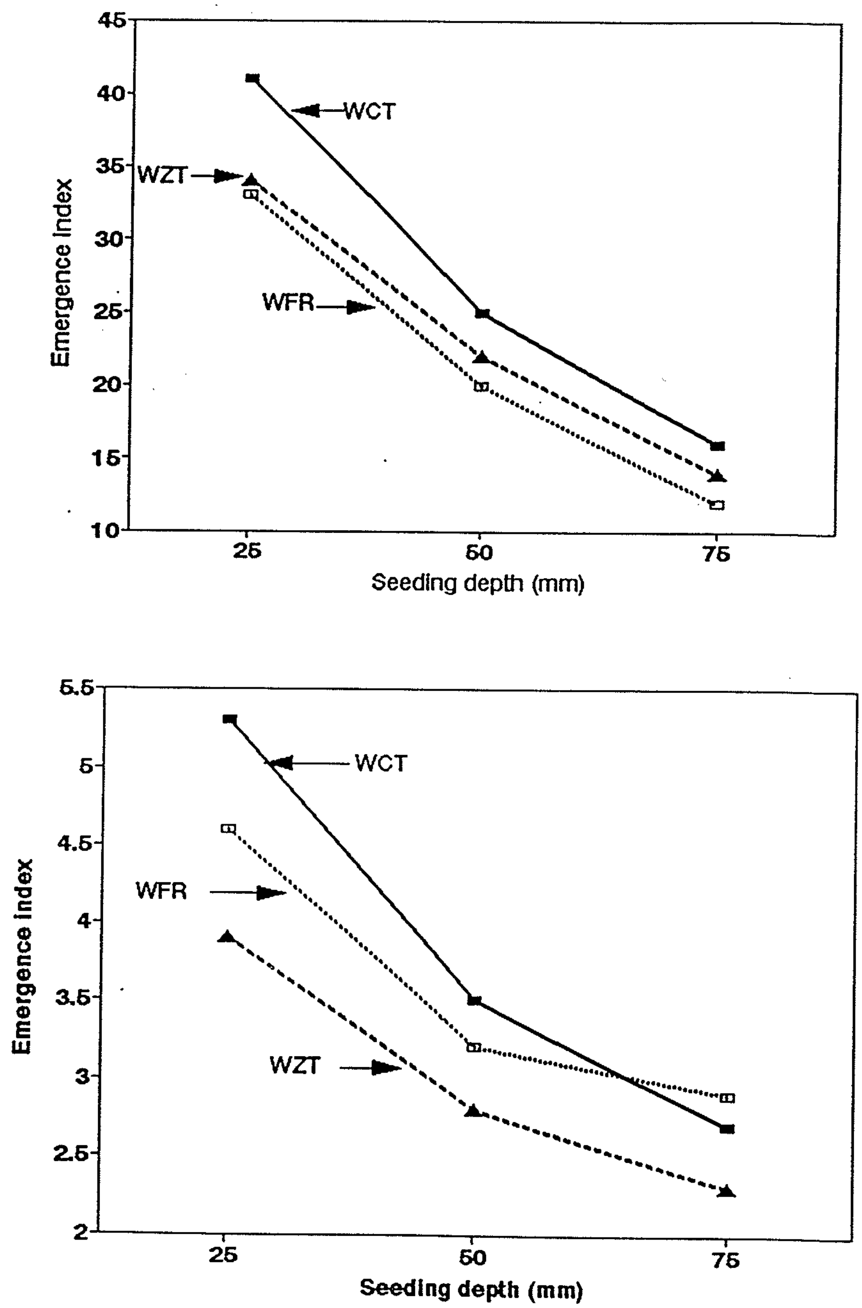
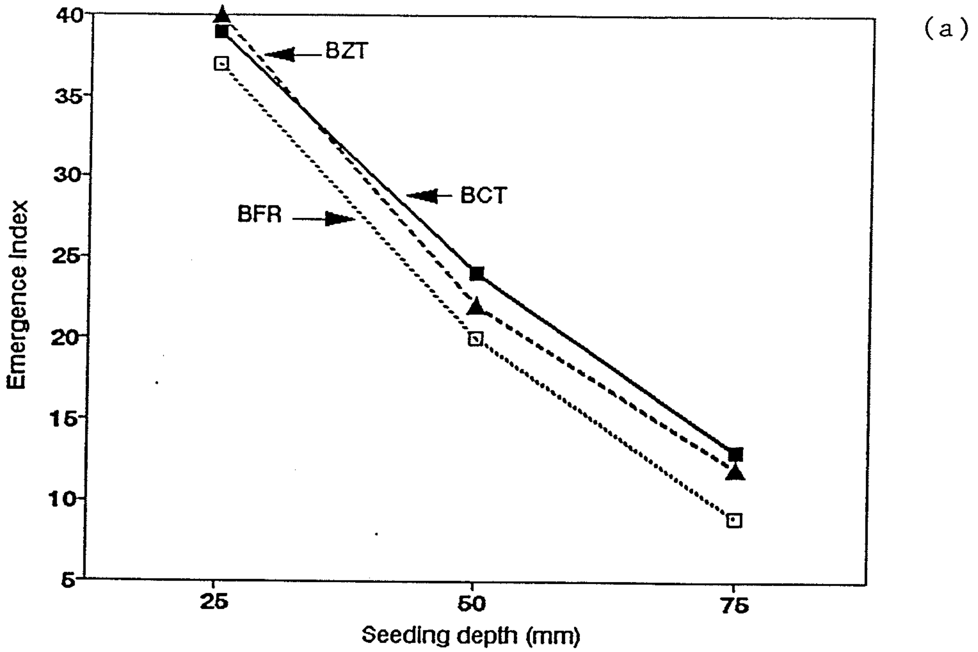


Fig 4.5 Speed of emergence index for wheat as affected by seeding depth; (a) 1990 and (b) 1991. WCT=Wheat under conventional tillage (CT); WFR=Wheat under CT with fall applied Fortress herbicide; WZT=Wheat under zero tillage.



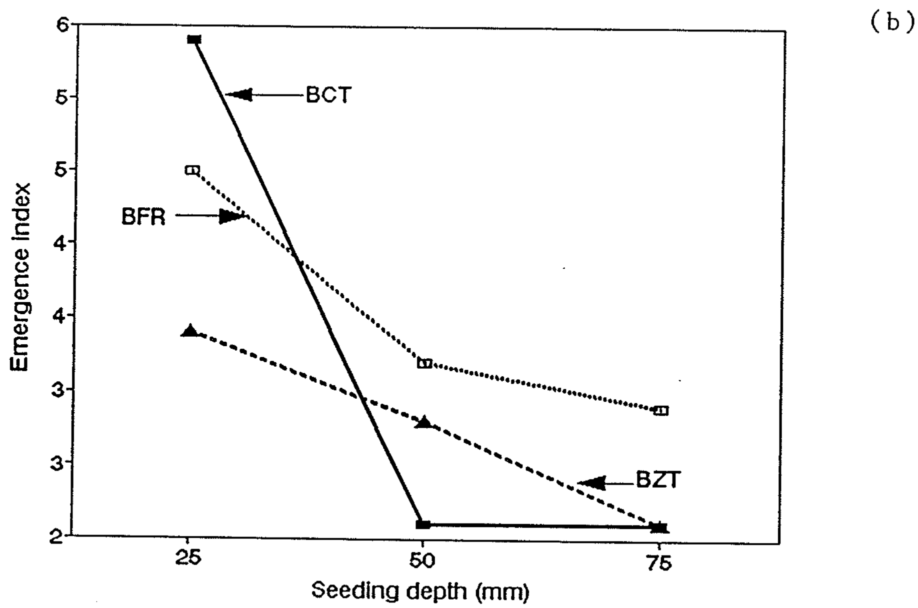


Fig 4.6 Speed of emergence index for barley as affected by seeding depth; (a) 1990 and (b) 1991. BCT=Barley under conventional tillage (CT); BFR=Barely under CT with fall applied Fortress; BZT=Barley under zero tillage.

(Anonymous 1988) needs to be reviewed in view of our results. The upper limit of seeding depth in wheat is too high and should be reduced to 50 mm. Our data showed that generally, shallow seeding had the highest emergence counts and fastest emergence rates.

Lafond and Fowler (1989) showed that as little as 9.5 mm of rain was sufficient to establish winter wheat successfully provided that seeding was shallow (18 mm). Lindstrom et al. (1976) reported that the lower limit or minimum water potential for wheat seedling emergence increased with increasing temperature. Gull and Allan (1976) observed wheat emergence at low water potentials of -14.4 bars (i.e. close to wilting point). Emergence period was however, extended over a long period of time at this low water potential. Lengthening of emergence time to such an extent in the field may cause poor stands due to chances of crust formation from rain after seeding and before emergence.

These results indicate that under Manitoba field conditions, non-uniform seeding depth due to deep seeding can result in variable emergence rates and low stands.

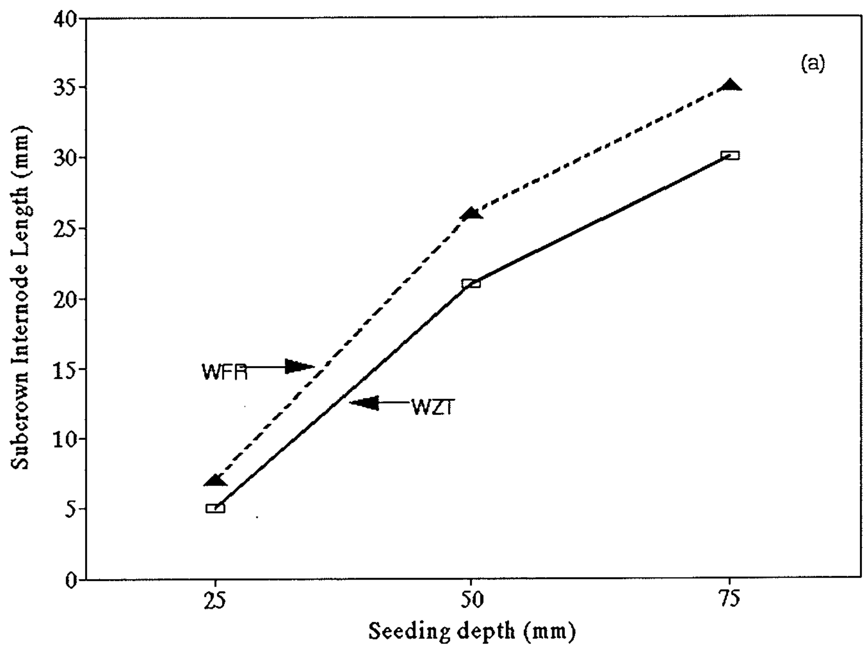
4.3 PLANT GROWTH AND DEVELOPMENT.

4.3.1. Subcrown internode length.

The state of a plant is determined by both growth and developmental processes. It is important to distinguish between the two because they are affected by different environmental variables. Development refers to the timing of critical events in the life cycle of a plant. Growth simply refers to the increase in weight, volume, length, or area of some part or all of the plant (Ritchie and NeSmith, 1991). The two terms are often used interchangeably because it is difficult to draw a line between them.

Subcrown internode length was measured to assess seeding depth effects on plant growth and development. The subcrown internode length was defined as the internode between the seed node (or first node) and the 2 node. There was no seedlot by seeding depth interaction, indicating that all seedlots responded similarly at different depths (data not shown). It was unlikely that weathering would cause differences in subcrown internode lengths since other variables taken earlier showed little or no response to weathering.

Seeding depth had a significant effect on the subcrown internode length of plants (Fig 4.7). In general, the subcrown internode length was found to increase with deep seeding. The average length of the subcrown internode length from shallow seeding was 6 mm for wheat and 14 mm for barley while deep seeded plants had a subcrown internode length of 25



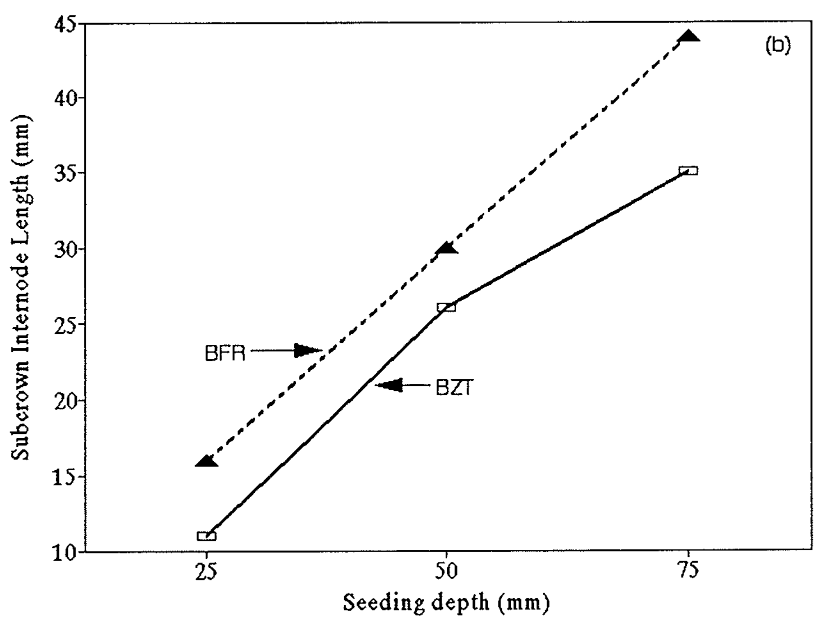


Fig. 4.7 Effect of seeding depth on subcrown internode length of (a) wheat and (b) barley in 1990. WFR=Wheat under conventional tillage with fall applied Fortress herbicide; WZT=Wheat under zero tillage; B=Barley, conditions as described for wheat.

and 30 mm for wheat and barley, respectively.

Plants from shallow seeding had shallower-placed crowns and more prostrate growth habit than those from deep seeding (Plate 1). Plants from deep seeding often had 3 nodes below the soil as opposed to a single compressed node in shallow seeded plants. Most of the crown roots in deep seeded plants developed at the last node near the soil surface, ensuring that the crown roots are as close to the soil surface as possible. These observations are consistent with previous reports (Loeppky et al., 1989; Newman and Moser, 1988) that the subcrown internode length tends to increase with deep seeding.

Development of crown roots is also dependent on the physical environment, especially soil moisture around the crown (Ferguson and Wright, 1968; Briggs, 1978; Martin et al., 1988). Under dry conditions, a deep crown placement is favoured over shallow placement due to moisture limitations at the latter depth (Martin et al., 1988). Soil temperature during germination, emergence, and seedling growth also have a considerable influence on the position of the crown in the soil (Martin et al., 1988; Loeppky et al., 1989). Martin et al. (1988) observed that cool soil temperatures produced shorter subcrown internodes in wheat and barley.

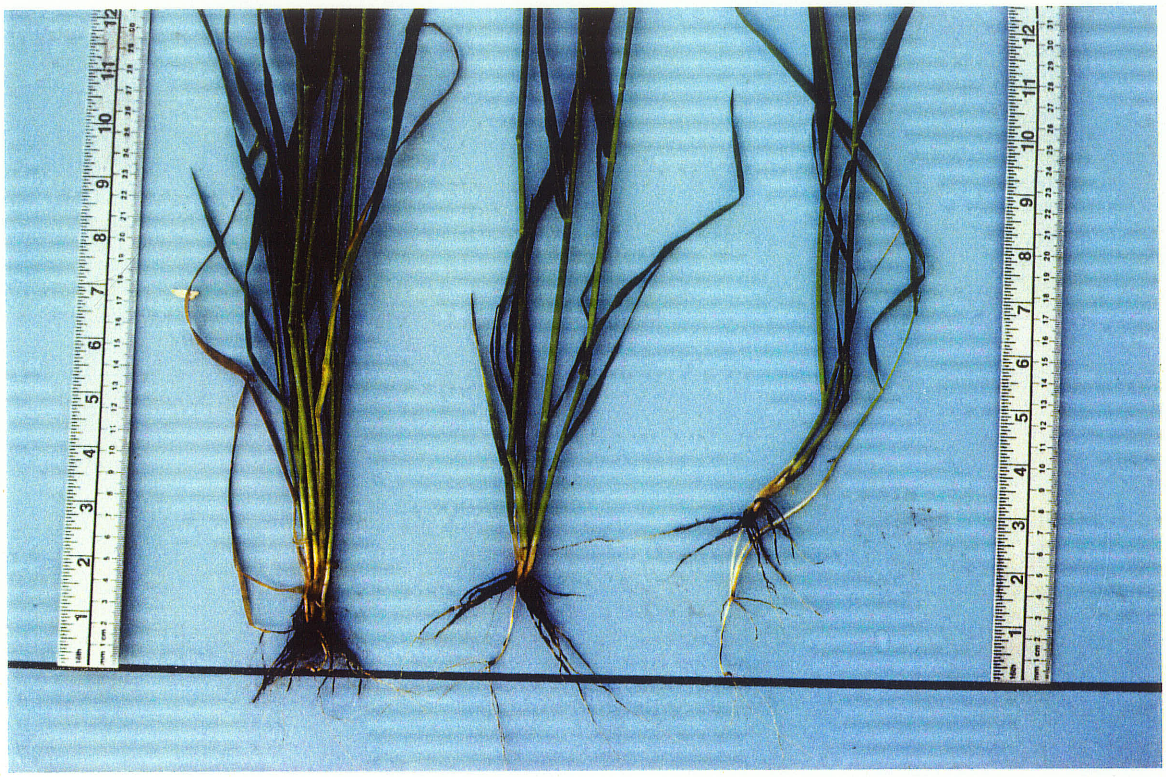


Plate 1. Effect of seeding depth on root development of wheat plants seeded at 25, 50 and 75 mm (from left to right). Deep seeded plants had fewer crown roots compared with shallow seeded plants.

4.3.2. Haun developmental growth stage values.

Haun developmental growth stage values were taken to evaluate differences in plant growth and development among seedlots and seeding depths. Data taken in 1990 measured plant growth and development among the three seeding depths only, but measurements done in 1991 considered both seedlots and depth effects.

4.3.2.1. Weathering effects on haun growth stage

No significant differences among seedlots could be detected at any depth or under any seedbed condition (data not shown). The lack of any significant seedlot by depth interaction for haun growth stage indicates that all seedlots responded similarly at each seeding depth. Since no significant differences in speed of emergence were observed among the three seedlots, it was unlikely to get differences in haun developmental growth stage values. These results further show that weathering of seed is not so critical on the subsequent growth and development of wheat or barley.

4.3.2.2. Depth effects on haun developmental growth stage

Seeding depth had a large influence on plant development. As seeding depth increased, plant growth was significantly decreased as shown by the haun developmental growth stage (Fig. 4.8). This observation was consistent under all seedbed conditions and in both crops and years.

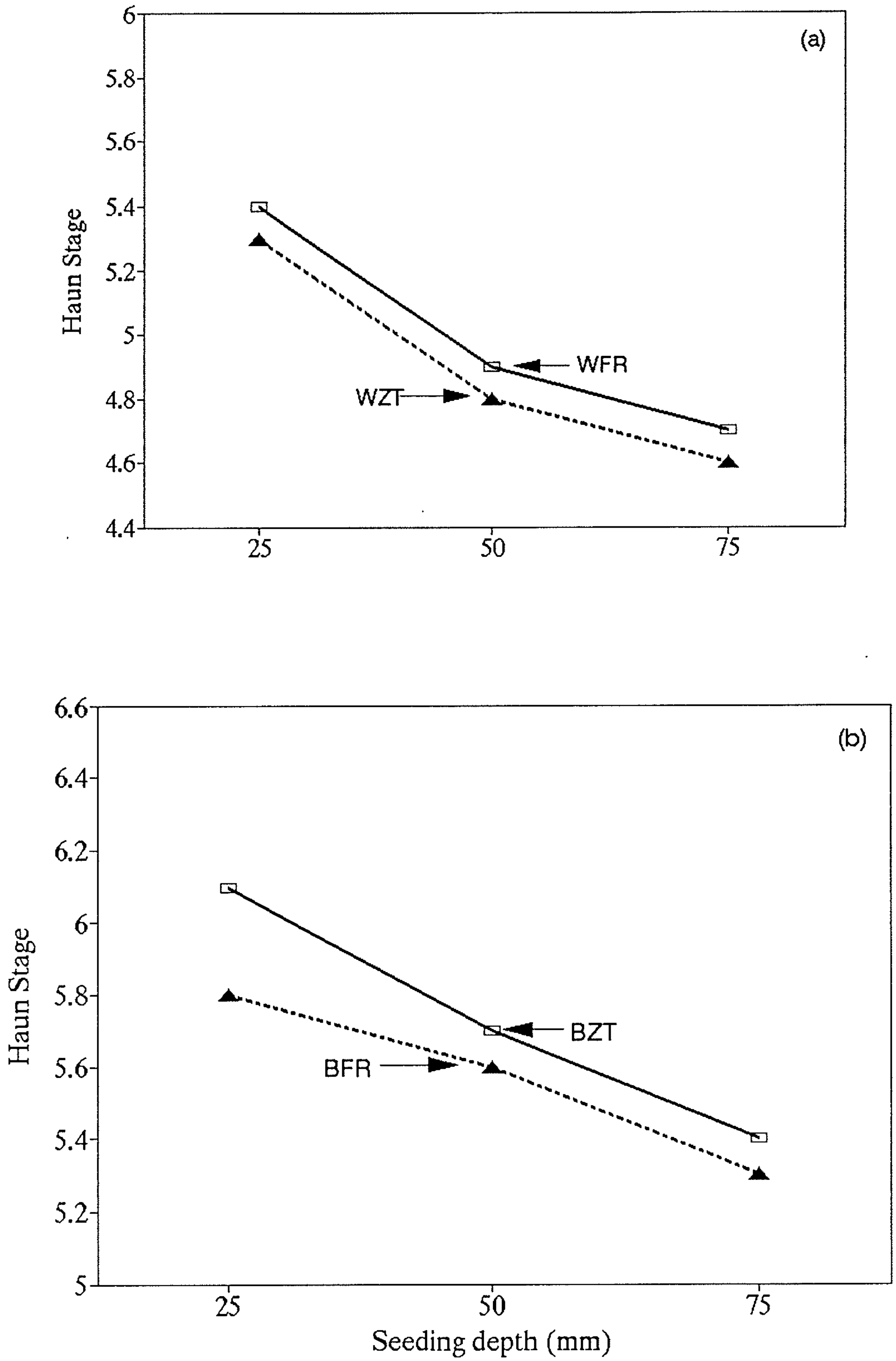


Fig. 4.8 Effect of seeding depth on Haun developmental stage of (a) wheat and (b) barley, 30 and 33 days after planting, respectively. WFR=Wheat under conventional tillage with Fortress herbicide; WZT=Wheat under zero tillage; B=Barley, conditions as described for wheat.

Growth rate was significantly faster at shallow seeding than at deep seeding. Physical examination of seedlings also suggested that even if the haun developmental growth stage values were sometimes similar among plants from the three depths, plant sizes were very different. Plants from shallow seeding appeared to have larger leaves and more robust in outlook (see dry matter - section 4.3.3 and LAI - section 4.3.4). These results generally support reports by Gan et al. (1992), who concluded that compared with deep seeding, shallow seeding in wheat results in faster plant growth and development.

4.3.3 Dry matter yield.

Plant growth and development was also assessed by measuring dry matter yield of individual seedlots at three seeding depths. There were no significant differences in dry matter yield amon the three seedlots (Table 4.10). Lack of significant differences in dry matter yield may be due to stage of plant growth when dry matter was determined.

It has been previously stated that differences due to seed vigour are most distinct at the early growth stage (Bulisani and Warner, 1980). May be the growth stage (Haun stage 4.6 to 6.0) at which we sampled was too late to detect seedling vigour differences. However, it should be noted that other measurements taken earlier also showed no significant differences among the three seedlots.

Table 4.10 Dry matter weights for wheat and barley seedlots at 5.5 Haun developmental growth stage (1991). Each value represents the mean of 6 observations .

Crop	Seedlot				Seedlot			
	1	2	3	C.V.(%)	1	2	3	C.V.(%)
	..........g/0.25 m2.....				........g/plant...........			
WCT*	17	18	19	14	.37	.42	.41	13
WFR	19	23	17	28	.47	.52	.36	26
WZT	13ab‡	10b	17a	32	.32	.28	.38	29
BCT	12	13	12	23	.23	.23	.22	20
BFR	11	14	12	36	.24	.23	.24	17
BZT	10	8	9	37	.20	.19	.18	23

‡Means followed by different letters are significantly different from each other at $P<0.05$ (LSD test).
*WCT=Wheat under conv-till; WFR=Wheat under conv-till with Fortress; WZT=Wheat under zero-till; BCT=Barley under conv-till; BFR=Barley under conv-till with fall applied Fortress herbicide; BZT=Barley under zero-till.

Although the number of seedlings that emerged from the 75 mm seeded plots was sometimes similar to plant stands from 50 and 25 mm seeding depths, dry matter weights from deep seeded plants were significantly lower (Table 4.11). The reduced dry matter weights associated with deep seeding were attributed to lower tillering and slender, weaker seedlings, as indicated by individual plant dry matter weights (Table 4.11). On the other hand, plants from shallow seeded plots were large and robust in appearance and had more tillers (data not shown) than deep seeded plants. These results agree with the findings of several other workers (e.g. Gan et al. 1992; Lafond and Fowler, 1989) who have reported that shallow seeding results in higher seedling dry matter weights than deep seeding.

Table 4.11 Dry matter production of wheat and barley at three seeding depths (at the 5.5 Haun developmental growth stage, 1991). Each value represents the mean of 6 observations.

Crop	Seeding Depth (mm)				Seeding Depth (mm)			
	25	50	75	C.V.(%)	25	50	75	C.V.(%)
	......g/0.25 m2.....				......g/plant......			
WCT*	36a‡	31b	17c	12	.66a	.53b	.37c	15
WFR	42a	30b	19c	14	.58	.61	.47	29
WZT	25a	20a	13b	21	.45a	.45a	.32b	13
BCT	17a	19a	12b	34	.31a	.26a	.23b	54
BFR	20a	16a	11b	22	.33a	.31a	.24b	12
BZT	17a	11b	10b	20	.29a	.24b	.20b	13

‡Means followed by different letters within each row are significantly different from each other at $P<0.05$ (LSD test).
*WCT=Wheat under conv-till; WFR=Wheat under conv-till with Fortress; WZT=Wheat under zero-till; BCT=Barley under conv-till; BFR=Barley under conv-till with fall applied Fortress herbicide; BZT=Barley under zero-till.

Frank et al. (1987), showed that the size of the spike (i.e. number of kernels per spike) of wheat is determined at the early vegetative stage (4.5 to 5.5 Haun developmental growth stage). Therefore, any stress that occurs during this early reproductive growth stage may result in reducing the number of spikelets per spike. In this study, deep seeding has been shown to reduce seedling vigour which may potentially reduce grain yield compared to shallow seeded plants.

4.3.4 Leaf area index (LAI).

LAI for each seedlot was measured only in the deep seeded plots, once or twice during plant growth. LAI was only determined in the 75 mm seeded plots because it was assumed that differences among seedlots would be greatest under deep seeding. Effects of seeding depth on LAI were assessed on guard plots in 1990 and on all plots with the unweathered seedlot in 1991.

4.3.4.1 Weathering effects

The data shown in Table 4.12 indicate that no significant differences in LAI were observed among seedlots. The LAI meter is not suitable for use in very thin canopies like in young wheat and barley seedlings because of increased experimental error. Therefore vigour differences between different seed lots may not be detectable by the LAI meter 2000 since most seedling vigour differences are greatest at early plant growth.

Table 4.12 Leaf area index (LAI) for wheat and barley as influenced by weathered seed 1991. Each value represents the mean of 6 observations.

Crop	Seedlot			
	1	2	3	C.V.(%)
	..........LAI............			
WCT*	4.2	4.4	3.7	12.4
WFR	4.3	4.4	4.6	7.8
WZT	4.5	4.2	4.4	12.0
BCT	4.9	4.7	4.8	26.0
BFR	5.0	5.1	4.9	4.9
BZT	3.8	3.7	3.6	12.0

*WCT=Wheat under conv-till; WFR=Wheat under conv-till with Fortress herbicide; WZT=Wheat under zero-till; BCT=Barley under conv-till; BFR=Barley under conv-till with Fortress herbicide; BZT=Barley under zero-till.

Previous workers have reported that it is unlikely to detect seed vigour differences after the seedling growth stage

(Tekrony et al., 1989; Bulisani and Warner, 1980) because the environment (e.g. nutrition and water) become the most important factors determining plant growth and development.

4.3.4.2 Seeding depth effects.

Differences in seeding depth were also reflected in LAI measurements (Fig 4.9). Deep seeding significantly reduced LAI compared with shallow seeding. These data simply confirmed the earlier observed differences in plant growth and development due to seeding depth.

Physical examination of plots in the field also showed that plant growth and development was greatest in shallow-seeded plants (Plate 2). Differences in LAI among plants from the three seeding depths may be due to tillering. Compared with deep seeding, shallow seeding resulted in more tillers (data not shown). Shallow-seeded plants also covered the ground much faster than did deep-seeded plants. A quick ground cover is desirable for weed control due to crop competition and may also reduce evaporative water loss.

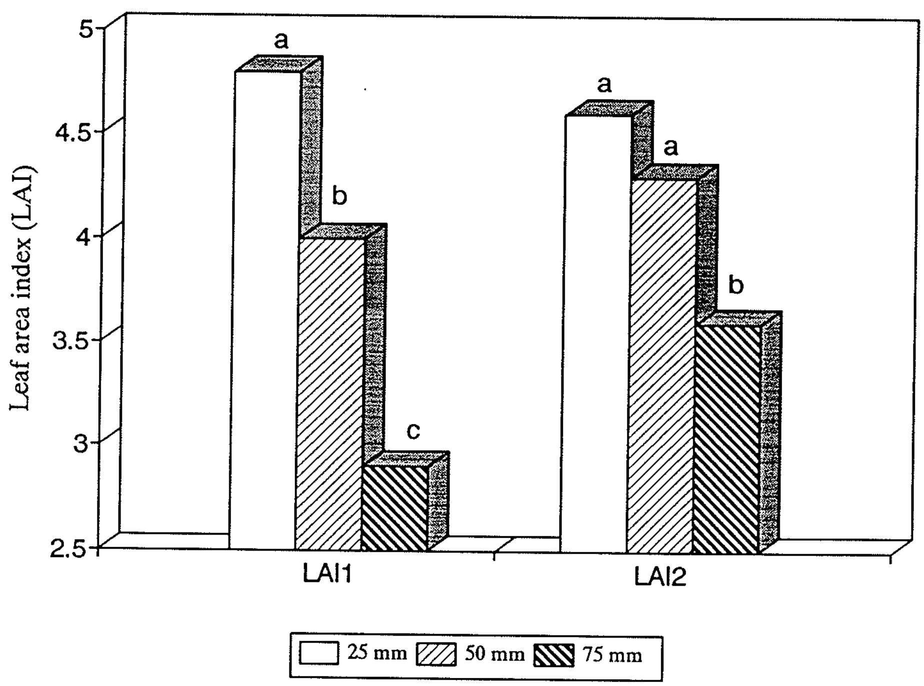


Fig. 4.9 Leaf area index of barley under conventional tillage as affected by seeding depth in 1991. LAI1 was measured at Zadok's growth stage 36 and LAI2 at growth stage 47 on the Zadok's scale.

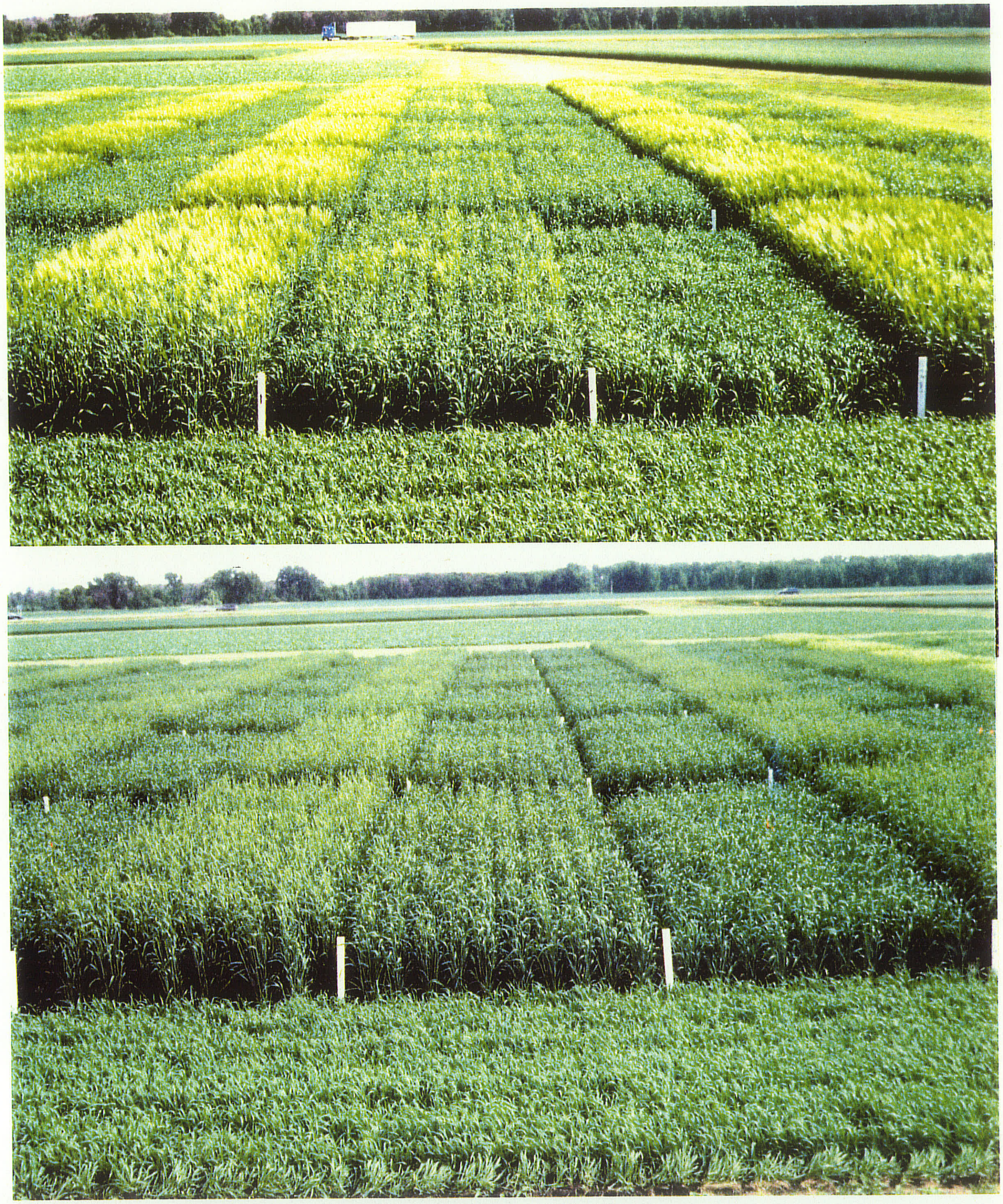


Plate 2. Effect of seeding depth on the development of barley (top) and wheat (bottom) in the Fortress treated area (1990). Heading in shallow seeded barley (left of peg) is 70%, the 50 mm seeded plants (left of middle peg) are only 20% headed, and the deep planted crop (left of the last peg) is almost 0 % headed. The same was true for wheat (left of first peg is shallow, followed by medium and deep seeding depths).

4.4 YIELD COMPONENTS.

Two grain yield components were measured, namely 1000-kernel weight (TKW) and number of spikes or heads per unit area (NSA). In addition, hectolitre weight (HLW) was also determined to check whether or not weathered seed affects HLW of the subsequent seed generation.

4.4.1 Thousand Kernel Weight (TKW)

4.4.1.1 Weathering effects.

The absence of a significant seedlot by seeding depth interaction for TKW in both crops indicates that all seedlots responded similarly at the three planting depths (Appendix A4.9). When all seeding depths were averaged for each seedlot, no patterns in TKW could be detected among the three seedlots (Table 4.13-4.14). The average TKW for all wheat seedlots in 1991 was 35.6 mg/seed and 34.7 mg/seed when grown under Fortress and zero tillage treatments, respectively. In barley, TKW averaged 34.9 mg/seed and 35.3 mg/seed when grown under conventional tillage and Fortress treatments, respectively. Generally, TKW was positively correlated with grain yield (Table 4.17). These results are not so surprising since it is very unlikely that the small vigour differences between seedlots could be expressed in seed weight of the next generation .

4.4.1.2 Depth effects on TKW

There was no significant effect of depth on TKW except in wheat under zero tillage and barley under conventional tillage in 1991 (Appendix A4.9). TKW for wheat under zero-till and in barley under conventional tillage planted at 25 mm was larger than TKW from either 50 or 75 mm seeded plots (Table 4.15 and 4.16). Generally, TKW declined with deep seeding under most of the seedbed conditions.

Table 4.13. Effect of weathering on yield components of wheat (1991). Each value is a mean of 6 observations.

Crop	Seed Lot	NSA	HLW	TKW
			..kg/hl..	..mg..
WCT*	1	692	78	36
	2	673	81	36
	3	660	78	36
C.V.(%)		14	10	3
WFR	1	755	-	-
	2	732	-	-
	3	723	-	-
C.V.(%)		13		
WZT	1	698	77	34.8
	2	658	77	34.7
	3	678	77	34.7
C.V.(%)		11	1	3

†Means followed by different letters within a column and seedbed condition are significantly different at P<0.05 (LSD test). *WCT=Wheat under conv-till; WFR=Wheat in conv-till with Fortress herbicide; WZT=Wheat under zero-till.

The reduction in TKW observed at deep seeding compared to shallow seeding could be attributed to differences in grain filling. Since shallow-seeded plants emerged faster (3 days earlier) than deep sown plants, it is likely that growth and

Table 4.14. Effect of weathering on yield components of barley in 1991. Each value is an average of 6 observations.

Crop	Seed Lot	NSA	HLW	TKW
			..kg/hl..	..mg..
BCT*	1	762	57	34.7
	2	722	57	34.9
	3	772	58	35.2
C.V.(%)		9	2	3
BFR	1	586b	59	35.4
	2	583b	56	34.8
	3	626a	59	35.5
C.V.(%)		9	13	5
BZT	1	664	-	-
	2	684	-	-
	3	646	-	-
C.V.(%)		13		

†Means followed by different letters within a column and seedbed condition are significantly different at P<0.05 (LSD test). *BCT=Barley under conv-till; BFR=Barley under Fortress herbicide; BZT=Barley under zero-till.

development of plants under shallow seeding was faster and plants reached maturity when growth conditions were still favourable. On the other hand, plants from deep seeding were delayed by 3-5 days in all phenological development stages (Plate 3). Reduced plant stand with deep seeding may have caused a longer tillering duration, which could also have contributed to the reduced TKW.

Plate 3. Effect of seeding depth on the development of barley under Fortress treated area (1990). Heading was up to 3 days earlier in shallow seeded plots (left) compared with deep seeded plants (centre).

4.4.2 Number of spikes per unit area (NSA).

4.4.2.1 Weathering effects on NSA.

There was no seedlot by seeding depth interaction for NSA in either crop (Appendix A4.9), indicating that all seedlots had a similar response at the 3 seeding depths. Further analysis by depth showed no significant differences in the number of spikes (heads) per unit area (NSA) in wheat under any seedbed condition (Table 4.13).

In barley, NSA for the unweathered seed was greater (P=0.08) than unweathered seed only in the Fortress treated area (Table 4.14). However, this pattern was not consistent in the other two seedbed conditions. The high number of spikes per unit area observed in the Fortress treated area may explain the yield increase in weathered barley in 1991.

4.4.2.2. Depth effects on NSA.

Seeding depth had no significant effect on NSA in wheat in 1991 (Table 4.15). However, shallow seeding resulted in an increase in NSA in 2 out of 3 seedbed conditions. Deep seeding significantly reduced the NSA in barley in 2 out of the 3 seedbed conditions (Table 4.16). In 1991, shallow seeding resulted in 8% and 15% (P<0.05) more heads in conventional tillage with Fortress herbicide, and zero tillage treatments, respectively, compared with deep seeding.

Differences in the NSA among the three depths can be attributed to differences in total emergence and tillering.

The number of spikes/m^2 increased with total emergence under all seedbed conditions. Tillering was also positively associated with NSA (Table 4.20). Deep seeding was shown to reduce the total plant stand compared with shallow seeding (Section 4.2.4). Tillering failed to compensate for this low stand in the 75 mm depth because tillering was higher in the shallow seeded plants compared to deep seeded plants (data not shown). The number of fertile tillers under deep seeding appeared to be reduced because at time of harvest, some tiller heads in the 75 mm depth were still green. Even if NSA in the 25 and 75 mm seeded plots were not significantly different in some cases, yield increase observed at shallow seeding was generally high and may be attributed to larger heads with heavier kernels. Although the number of spikelets/head was not determined, higher grain yield at shallow seeding may be due to more kernels/head.

4.4.3 Hectolitre Weight (HLW)

Hectolitre weight is commonly assayed by millers as a measure of potential flour yield. In the seed industry, HLW is also commonly assessed as a seed quality parameter. HLW was measured to determine if weathering influences HLW of the subsequent seed generation.

Table 4.15 Effect of seeding depth on yield components of wheat in 1991. Each value is an average of 6 observations.

Crop	Depth	NSA	HLW	TKW
			..kg/hl..	..mg..
WCT	1	677	81	35.7
	2	677	78	35.6
	3	671	78	35.4
C.V.(%)	14	10	3	
WFR	1	717	-	-
	2	754	-	-
	3	738	-	-
C.V.(%)	13			
WZT	1	684	77	35.2a†
	2	679	77	34.8ab
	3	668	77	34.3b
C.V.(%)	11	1	3	

‡Means followed by different letters within a column and seedbed condition are significantly different at P<0.05 LSD test. WCT*=Wheat under conv-till; WFR=Wheat in conv-till with Fortress herbicide; WZT=Wheat under zero-till.

Table 4.16. Effect of seeding depth on yield components of barley (1991). Each value is a mean of 5 observations.

Crop	Depth	NSA	HLW	TKW
			..kg/hl..	..mg..
BCT*	1	765	57	35.4a†
	2	766	57	35.0ab
	3	726	57	34.4b
C.V.(%)		9	2	3
BFR	1	618a	58.6	35.2
	2	604a	56.1	36.2
	3	572b	58.7	34.4
C.V.(%)		9	13	5
BZT	1	703a	-	-
	2	682a	-	-
	3	572b	-	-
C.V.(%)		13		

‡Means followed by different letters within a column and seedbed condition are significantly different at P<0.05 LSD test. *BCT=Barley under conv-till;BFR=Barley under Fortress herbicide; BZT=Barley under zero-till.

There was no significant seedlot by seeding depth interaction for HLW in either crop except for barley under conventional tillage in 1991 (Appendix A4.10). All seedlots had similar HLWs (Tables 13 and 14). No significant differences in HLW could be detected among seeding depths in either crop (Table 15-16). Generally, HLW showed a positive relationship with grain yield, although the relationship was negative in some experiments (Table 4.17).

Table 4.17 Correlation coefficients among growth parameters and grain yield for wheat and barley (1991).

Crop	Variable	Emerge	Tiller	TKW	NSA	HLW	Yield
	Emerge	-	-0.25	0.04	0.37**	0.02	0.34**
	Tiller	-0.25	-	0.11	0.39**	-0.02	0.24
WCT	TKW	0.04	0.11	-	0.08	-0.09	0.14
	NSA	0.37**	0.39**	0.08	-	-0.11	0.35**
	HLW	-0.02	-0.02	-0.09	-0.11	-	-0.14
	Yield	0.34**	0.24	0.14	0.35**	-0.14	-
	Emerge	-	-0.26*	0.17	0.34**	-0.04	0.26
	Tiller	-0.26*	-	0.39**	0.37**	0.09	0.20
	TKW	0.17	0.39**	-	0.31**	0.30*	0.62**
WZT	NSA	0.34	0.37**	0.31*	-	0.24	0.35**
	HLW	-0.04	0.09	0.30*	0.244	-	0.60**
	Yield	0.26	0.20	0.62**	0.35**	0.60**	-
	Emerge	-	-0.52**	0.23	0.43**	-0.17	-0.04
	Tiller	-0.52**	-	-0.02	0.21	0.04	-0.01
	TKW	0.23	-0.02	-	-0.00	0.31*	0.15
BCT	NSA	0.43**	0.21	-0.00	-	-0.06	-0.18
	HLW	-0.17	0.04	0.31*	-0.06	-	0.05
	Yield	-0.04	-0.01	0.15	-0.18	0.05	-
	Emerge	-	-0.63**	0.46**	0.67**	0.32*	0.44**
	Tillers	-0.63**	-	0.13	-0.19	0.16	0.01
	TKW	0.46**	0.13	-	0.28*	0.57**	0.68**
BZT	NSA	0.67**	-0.19	0.28*	-	0.15	0.68**
	HLW	0.32*	0.16	0.57**	0.15	-	0.41**
	Yield	0.44**	0.01	0.68**	0.20	0.41**	-

*=significant at P<0.05 LSD test
**=Significant at P<0.01 LSD test.

4.5 GRAIN YIELD.

4.5.1. Weathering effects on wheat grain yield.

There was no significant seedlot by seeding depth interaction for grain yield in wheat in both years (Appendix A4.14-15), indicating that all seedlots responded similarly at the 3 seeding depths. Even when all the seeding depths were averaged within each seedbed condition and seedlot, no significant yield differences could be seen in either year (Table 4.18).

Table 4.18 Grain yield (kg/ha) of spring wheat under three seedbed conditions. Each value is a mean of 15 and 18 observations in 1990 and 1991, respectively.

Crop	Seedlot (1990)				Seedlot (1991)			
	1	2	3	C.V.(%)	1	2	3	C.V.(%)
WCT*	5685	5584	5735	6.6	3927	3951	3953	3.9
WFR	5579	5607	5584	2.3	4077	4086	4096	3.6
WZT	4961	4978	4945	3.7	3905	3955	3852	3.7

†Means followed by different letters within each row and year are significantly different at $P \leq 0.05$ (LSD test).
WCT*=Wheat under conv-till; WFR=Wheat in conv-till with Fortress herbicide; WZT=Wheat under zero-till.

Despite the lack of any significant seedlot by seeding depth interaction for wheat grain yield (Table A4.14-15), data was further analyzed at each seeding depth to check for any patterns. Although not significant, unweathered wheat seed appeared to have a greater grain yield than weathered seed at deep seeding under all seedbed conditions in 1991 (Table 4.19).

Table 4.19 Wheat grain yield (kg/ha) as affected by weathering under different seedbed conditions and at three seeding depths. Each value is a mean of 5 and 6 observations in 1990 and 1991, respectively.

Crop	Seeding Depth	Seedlot (1990) 1	2	3	C.V.(%)	Seedlot (1991) 1	2	3	C.V.(%)
WCT	1	5639	5512	5928	10	4129	4055	4076	2
	2	5849	5694	5786	2	3806	4004	3965	4
	3	5565	5437	5567	4	3845	3797	3817	5
WFR	1	5839	5813	5813	2	4249	4276	4228	7
	2	5544	5598	5545	3	4051	4181	4238	3
	3	5355	5410	5392	3	3931	3823	3803	5
WZT	1	5103	5181	5202	3	4016	3982	3858	7
	2	5024	4952	4949	4	3883	4143	3883	6
	3	4755	4806	4684	4	3945	3738	3814	8

WCT*=Wheat under conv-till; WFR=Wheat in conv-till with Fortress herbicide; WZT=Wheat under zero-till.

There was no consistency in grain yield differences between weathered and unweathered seed at deep seeding in 1990. No yield differences between seedlots could be detected at shallow seeding in either year. This data is in agreement with other measurements taken earlier (Section 4.2-4.4) which showed only a very small response of wheat to weathering.

4.5.2 Weathering effects on barley grain yield.

There was no significant seedlot by seeding depth interaction for grain yield in barley (Appendix A4.14-15), indicating that all seedlots responded similarly at the 3 seeding depths. When all the seeding depths were averaged within each seedlot, significant yield differences among the seedlots were only detected in barley under Fortress herbicide in both years (Table 4.20).

Table 4.20 Grain yield (kg/ha) of barley under three seedbed conditions. Each value is a mean of 15 and 18 observations in 1990 and 1991, respectively.

Crop	Seedlot (1990)				Seedlot (1991)			
	1	2	3	C.V.(%)	1	2	3	C.V.(%)
BCT*	7497	7575	7525	3.2	4955	5318	5144	8.4
BFR	7893a†	7978a	7573b	3.9	5174b	5335a	5333a	3.6
BZT	6904	6919	6808	4.7	5335	5404	5618	3.2

†Means followed by different letters within each row and year are significantly different at $P \leq 0.05$ (LSD test).
*BCT=Barley under conv-till;BFR=Barley under Fortress herbicide; BZT=Barley under zero-till.

In 1990, in the Fortress treated area, the most weathered seed resulted in significantly lower grain yield than the unweathered seed (Table 4.20). There were no significant differences in grain yield among seedlots in the other two seedbed conditions. Grain yield for the unweathered seedlot under zero tillage was however, greater than yield from severely weathered seed.

In 1991, a reverse trend was observed, in which the severely weathered barley seed had significantly higher grain yield than the unweathered seed under the Fortress treated area (Table 4.20). Compared with unweathered seed in 1991, the severely weathered seed had 3% greater grain yield under Fortress treated area. Weathered seed also had 4 and 5 % higher grain yield (P=0.07) than unweathered seed in the conventional and zero tillage treatments, respectively.

Further analysis of data at each seeding depth was done, despite the absence of seedlot by depth interaction to check for yield patterns at the 3 depths (Table 21). The data showed that in 1990, unweathered seed had significantly higher grain yield (10 %) than the severely weathered seed at deep seeding in the Fortress treated area in 1991. Although not significant, grain yield of unweathered barley seed was also greater (7%) than weathered seed at 50mm depth in Fortress.

Table 4.21 Grain yield (kg/ha) of barley under 3 seedbed conditions and at 3 seeding depths. Each value is a mean of 5 and 6 observations in 1990 and 1991, respectively.

Crop	Seeding Depth	Seedlot (1990)				Seedlot (1991)			
		1	2	3	C.V.	1	2	3	C.V.
BCT*	25	7689	7723	7760	3	5186	5129	5161	7
	50	7551	7527	7468	4	4946	5306	5258	8
	75	7250	7474	7347	3	4902	5519	5014	9
BFR	25	8230	8460	8167	4	5243	5349	5455	3
	50	8039	7903	7528	5	5289b	5534a	5553a	2
	75	7571a	7410a	6850b	2	4991	5120	4991	4
BZT	25	7114	7277	7087	2	5552	5592	5923	4
	50	6726	6766	6499	7	5449	5521	5574	6
	75	6872	6714	6827	4	5004	5099	5356	9

†Means followed by different letters within a row and year are significantly different at P>0.05 (LSD test).
*BCT=Barley under conv-till;BFR=Barley under Fortress herbicide; BZT=Barley under zero-till.

There was no consistency in seedlot yield at any seeding depth in the other two seedbed conditions in 1990.

In 1991, severely weathered seed had 5 % more yield than unweathered seed under Fortress at the 50 mm depth. Although not significant in the other two conditions, grain yield for weathered seed was generally superior compared with yield from unweathered seed at all the 3 seeding depths.

Grain yield differences observed between the two years can be attributed to two sources of variation; (1) variation within seeds and (2) environmental variability during the growing seasons. Seedlots used in the two seasons were produced in different years, thus even if weathering was absent, seed vigour may still differ due to variation in environment of the mother plant. The seedlots used in 1990 appeared to be weathered to a greater extent compared with the 1991 seedlot. This is confirmed by the falling number tests (Table 3.1) which show greater alpha-amylase activity in the 1990 compared with the 1991 seedlots.

Handling of the seedlots was also different in the two years. Seedlots used in 1990 were harvested at nonuniform moisture contents in 1989. In 1991, seedlots were first fan-dried to about 12% moisture content before threshing. Moisture content at threshing has been shown to influence seed vigour (Entz et al., 1991). Although caution was taken to use seedlots harvested at similar moisture contents (M.C.), variation in M.C. at harvest among seedlots may have contributed to differences seen between the 2 years.

Temperature and rainfall distribution in the two years were also different. As previously outlined in the weather summary data, cold weather that prevailed in 1990 did not favour seed germination and emergence of weathered seed, particularly at deep seeding. There was a tendency to have better performance of unweathered seed compared to weathered seed at almost all seeding depths in 1990.

Weather conditions in 1991 were quite different, particularly temperature and rainfall distribution. Warm soils at planting time in 1991 improved germination and emergence of weathered seed as indicated by higher emergence index rates (Table 4.5-4.7). Although growth and development was similar for all seedlots, weathered seed had an advantage because of its relatively faster emergence compared with unweathered seed. Coupled with a degree of water stress in the latter growth stages of plants, weathered seed may have reached maturity faster as a result of its relatively faster emergence compared with unweathered seed, but no data is there to support this observation.

Gan et al. (1992) reported that grain yield contribution of the late emerging plants was marginal compared with yield from early emerged plants. Therefore, if there are no significant differences in emergence within the first three days between seedlots, yield differences may not be significantly different. Our data showed no significant differences in speed of emergence nor total plant stand between weathered and sound seed particularly at shallow seeding.

In summary, weathering appears not to be a critical factor under favourable germination environments. Weathered seed may actually be beneficial when conditions for seed germination and emergence are favourable. However, weathered seed may show reduced emergence under stressful conditions e.g. under deep seeding and cold soil conditions. The reduced plant stand may lead to lower grain yields if tillering fails to compensate for the low stand.

These results are consistent with those reported by Tekrony et al. (1989) where no yield differences could be seen between corn seedlots of high vigour and low vigour if stand establishment was not affected.

4.4.6 Effect of seeding depth on grain yield.

Seeding depth had a significant effect on grain yield for both wheat and barley in both years (Fig. 4.10 - 4.11). Shallow seeding resulted in consistently higher grain yield than when the crop was seeded at 50 or 75 mm.

In 1990, wheat under zero tillage had the highest yield increase (9 %) with shallow seeding compared with deep seeding. Wheat yields at shallow seeding were 10 % greater than yield at 75 mm depth under conventional tillage with Fortress in 1991. In all seedbed conditions deep seeding decreased wheat grain yields (Fig. 4.10a-b). Averaged between the two years, grain yield from shallow seeding was 7 % more than the yield from deep seeded plots.

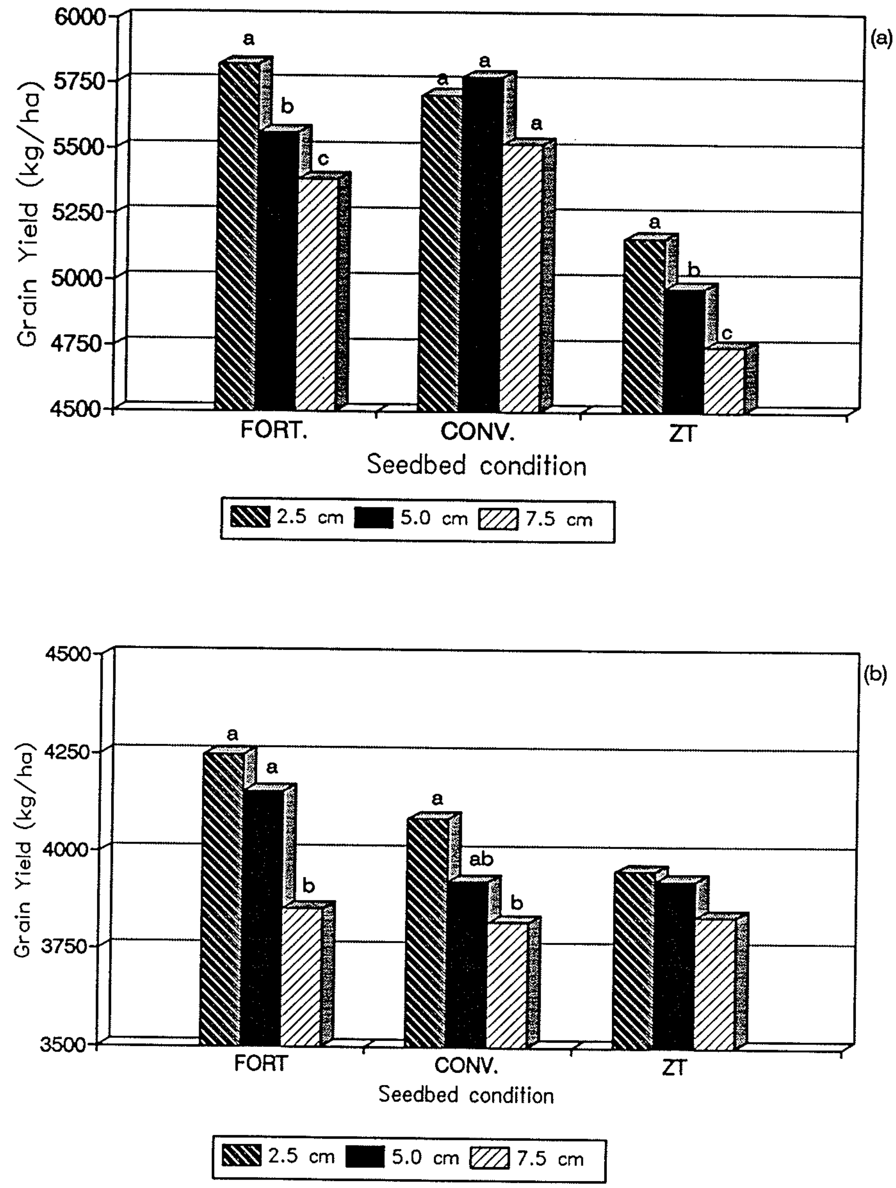


Fig. 4.10. Wheat grain yield as affected by seeding depth in (a) 1990 and (b) 1991. FORT=Conventional tillage with Fortress herbicide; CONV.=Conventional tillage; ZT=Zero tillage.

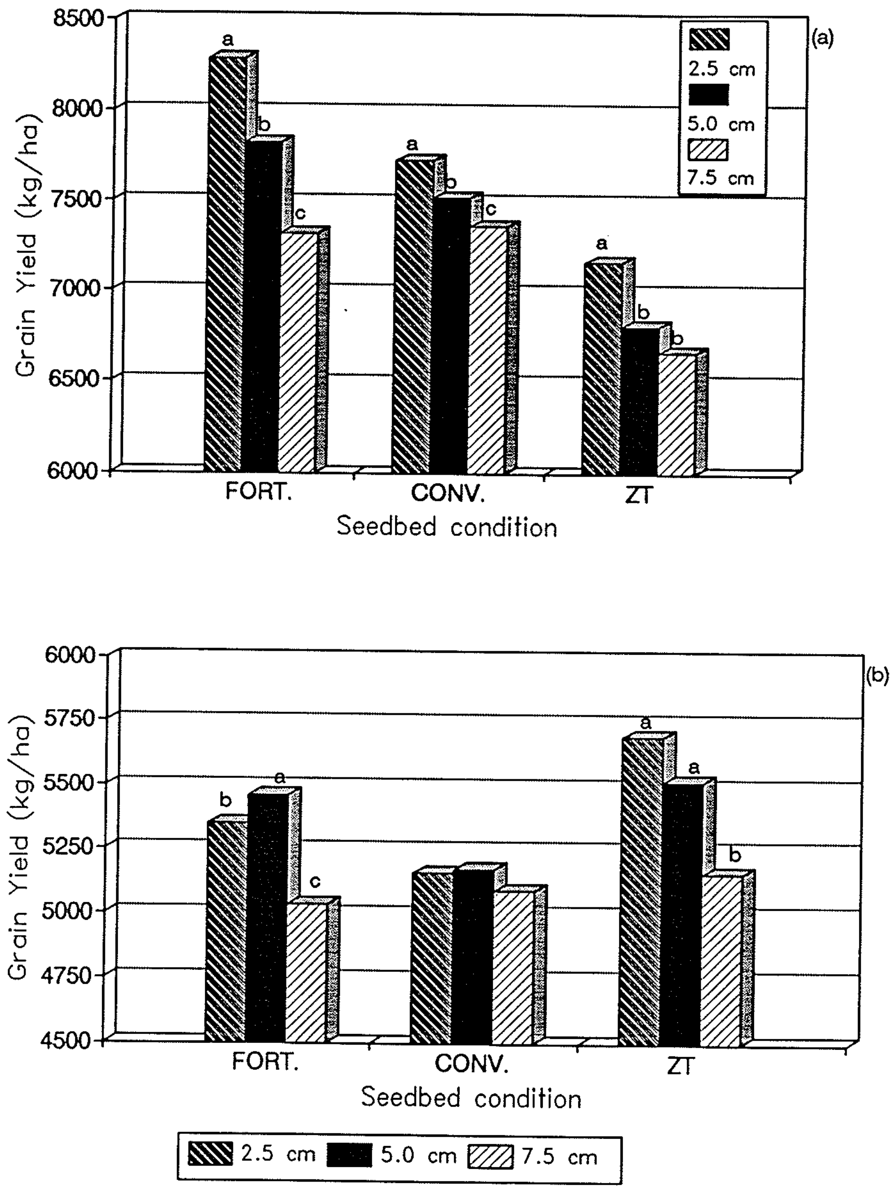


Fig. 4.11. Barley grain yield as affected by seeding depth in (a) 1990 and (b) 1991. FORT=Conventional tillage with Fortress herbicide; CONV.=Conventional tillage; ZT=Zero tillage.

Yield differences between seeding depths were more pronounced in barley than in wheat (Fig 4.11a-b). In 1990, shallow seeding resulted in a maximum of 14 % yield increase in barley under Fortress treatment compared to yield at 75 mm depth. On average, shallow seeding in 1990 resulted in 8 % more grain yield compared with yield from deep seeding. The maximum yield difference (10 %) between shallow and deep seeded barley in 1991 was from zero tillage plots. There were no significant yield differences between seeding depths in barley under conventional tillage in 1991. When yield from the three seedbed conditions was averaged by seeding depth, shallow seeding resulted in 5 % greater grain yield compared with deep seeding in 1991. When data was combined for the 2 years, deep seeding reduced barley grain yield by 7 %.

Yield reduction with deep seeding was relatively greater in the Fortress treated area in 1990 compared with other treatments. It appears that trifluralin injury to emerging seedlings was greatest in 1990 when the period of exposure to the herbicide was increased due to the cold soils. Since deep seeding generally reduced seedling vigour, the addition of herbicide injury may have caused further stress on seedlings. This resulted in reduced plant stand (Table 4.3-4.4) at deep seeding especially in barley. Even with compensatory growth, deep seeded plants were unable to recover from the loss in initial plant population and consequently lead to lower grain yields.

The highest grain yield among all seedbed conditions was from the Fortress treated area in both wheat and barley in 1990 (Fig 4.10-11). This superior grain yield from Fortress may have been due to a complete weed control, especially green foxtail, during the early period of plant growth. Trifluralin applied at rates below 1.0 kg active ingredient (ai) ha^{-1} has been reported to increase grain yield in wheat (O'Sullivan et al., 1985b) and had no significant effect on barley yield (O'Sullivan et al., 1985a). However, trifluralin applied at rates above 1.1 kg ai ha^{-1} cause severe reduction in seedling stand and consequent grain yield is also significantly reduced (O'Sullivan et al., 1985a and 1985b; Morrison et al., 1991).

Grain yield differences between different seeding depths were generally less in 1991 compared to 1990 because of different weather conditions between the two years. In 1991, drought at grain filling may have reduced yield in the shallow seeded plots. Barley grain yield at 25 mm was highest under zero tillage in 1991. This high yield under zero tillage compared to conventional tillage plots may have been due to moisture conservation in the former. However, the greatest yield increase (10 %) at shallow seeding in wheat was from conventional tillage with Fortress treatment. Wheat yields at the shallow seeding in the zero tillage plots was only 3 % higher than yield at 75 mm depth. This difference between wheat and barley may indicate that barley is more sensitive to water stress than wheat. Barley generally showed a greater sensitivity to seeding depth than wheat. At deep seeding, emergence in barley was reduced to greater extent than in wheat.

The other possible explanation for the small yield differences observed in 1991 between different depths may be due to the actual seeding depths used. From Appendix 3.1, it is obvious that the actual medium and deep seeding depths in 1991 were shallower than the same depth levels in 1990. Deep seeding in 1991 was particularly shallower compared with the 1990 depth. This would imply that plants seeded deep in 1991 were not as stressed as those seeded deep in 1990.

These findings support earlier reports that deep seeding reduces grain yield (Loeppky et al., 1989; Gan et al., 1992; Duczek and Piening, 1982). Decreased grain yield at deep seeding has been associated with poor emergence (Sunderman, 1964; Burleigh et al., 1965), reduced tillering (Loeppky et al., 1989) and increased root rot in barley (Duczeck and Piening, 1982).

In this study grain yield was positively correlated with emergence, tillering, and the grain yield components (Table 4.18). Yield differences between shallow and deep seeded plots can also be attributed to differences in speed of emergence index. Shallow seeding resulted in faster emergence (3 days earlier) than deep seeding. Earlier emergence can be expected to result in higher grain yield since grain yields of most annual crops have been shown to correlate with date of planting e.g. in winter barley (Knapp and Knapp, 1980).

Although no data was collected on root development, seedling samples that were examined showed greater root development in shallow seeded plants. Deep seeded plants showed fewer crown roots compared to shallow seeded plants. Previous studies (Black, 1970) have shown that tiller survival is most dependent on crown roots. Shallower placed crown roots could be better placed to capture moisture when light rains occur. The coefficient of correlation for tillering and yield was particularly larger at deep seeding, implying that at deep seeding, tillering had a greater contribution to yield than at shallow seeding.

In summary, deep seeding consistently decreased grain yields of both wheat and barley. Yield reductions with deep seeding were greater in barley than in wheat, indicating that barley is more sensitive to deep seeding. Yield reduction at deep seeding was associated with reduced initial plant population, reduced tillering, and lower NSA.

5. CONCLUSIONS

Although not consistent between the 2 years, weathered seed was more likely to reduce emergence compared with sound seed especially under stress conditions such as deep seeding and cold soil temperatures. Under favourable seedbed conditions, weathering of wheat and barley seed did not significantly affect seedling emergence. Our data showed that seedling emergence under "ideal" seedbed conditions may actually be enhanced by weathering of the seed. Plant growth and development as determined by dry matter, Haun growth stage, and leaf area index were not adversely affected by weathering.

Severely weathered seed appeared to have lower grain yields compared with unweathered seed in 1990. Reduced grain yield from weathered seed generally occurred at deep seeding (75 mm). No significant yield differences among seedlots could be detected at shallow seeding under any seedbed condition or year. Under favourable conditions, weathering does not appear to adversely affect grain yield. Data from 1991 showed that weathered seed can actually enhance grain yields.

Field emergence was consistently reduced with deep seeding in both crops and both years. Deep seeding delayed seedling emergence by average 3 days for both wheat and barley. Shallow seeding resulted in a more uniform emergence and crop maturity than deep seeding. Plant growth and development were also delayed with deep seeding. The growth parameters that were negatively affected by deep seeding were dry matter production, Haun growth stage, tillering, and leaf area index. The cumulative effects of deep seeding on plant growth and development parameters generally resulted in lower grain yield in both crops. Yield reductions associated with deep seeding were 7 % for wheat and 8 % for barley when averaged across all seedbed conditions and across the two years.

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APPENDIX

Table A3.1 Theoretical Vs Actual seeding depth.

Crop	Actual seeding depth (mm) 1990				1991			
	25mm	50mm	75mm	C.V.(%)	25mm	50mm	75mm	C.V.(%)
BFR	41b	57b	77a	23	41b†	51b	64a	17
BZT	37b	51b	73a	19	37c	48b	63a	16
WFR	39b	66a	69a	17	32c	44b	65a	14
WZT	35c	55b	68a	14	37b	49b	65a	24

†Means followed by different letters within each row and year are significantly different at P<0.05 (LSD test).

Table A3.2 1990 Mean square values for actual seeding depth

Source of Variation	DoF	WCT	WFR	WZT	BCT	BFR	BZT
Rep	4	-	206	50	-	21	64
Depth	2	-	1357**	1379**	-	1584**	1652**
Error	8	-	99	52	-	178	104
C.V.(%)		-	17	14	-	23	19

*=Significant at P<5%
**=Significant at P<1%

Table A3.3 1991 Mean square values for actual seeding depth

Source of Variation	DoF	WCT	WFR	WZT	BCT	BFR	BZT
Rep	4	-	0.3	0.6	-	0.4	0.4
Depth	2	-	54.2**	18.8**	-	13.3**	39.7**
Error	8	-	0.6	1.7	-	0.9	0.7
C.V.(%)		-	13.8	23.8	-	16.8	15.8

*=Significant at P<5%
**=Significant at P<1%

Table A4.1 1990 Sum of squares values for seedling emergence

Source of Variation	DoF	WCT	WFR	WZT	BCT	BFR	BZT
Rep	4	676	447	912	523	453	711
Depth	2	912	1021*	1282*	2951**	7920**	797*
Error	10	1446	945	1102	487	514	718
Lot	2	86	251	5	951**	45	153
Lot*Depth	4	168	237	225	220	729	358
Error b	30	6133	2237	1812	1037	1898	2218
C.V.		20	19	20	13	22	25

*=Significant at P<5%
**=Significant at P<1%

Table A4.2 1991 Mean square values for seedling emergence

Source of Var	DoF	WCT	WFR	WZT	BCT	BFR	BZT
Rep	5	73	41	22	156	78	119
Depth	2	547*	297	400*	1647**	2578**	1591**
Error	10	139	114	91	45	55	114
Lot	2	12	16	46	16	21	95
Lot*Depth	4	81	69	81	73	75	31
Error b	30	65	72	63	68	102	61
C.V.	13	14	13	14	19	14	14

*=Significant at P<5%
**=Significant at P<1%

Table A4.3 1990 Sum of squares values for speed of emergence

Source Var	DoF	WCT	WFR	WZT	BCT	BFR	BZT
Rep	4	249	63	167	606	68	153
Depth	2	2824**	2774**	2257**	10864**	8318**	1507**
Error	8	153	306	329	924	135	408
Lot	2	81**	33	39	71	184**	72
Lot*Dep	4	114**	28	10	57	462**	247*
Error b	24	6	29	20	60	12	473
C.V.		17	37	34	37	18	37

*=Significant at P<5%
**=Significant at P<1%

Table A4.4 1991 Mean square values for speed of emergence

Source Var	DoF	WCT	WFR	WZT	BCT	BFR	BZT
Rep	5	146	30	292	81	7	44
Depth	2	3025**	2164**	2118**	3192**	3530**	2866**
Error	10	88	89	11	62	17	19
Lot	2	5	38	43	15	11	76
Lot*Dep	4	16	47	37	26	15	119*
Error b	30	18	39	38	42	58	42
C.V.		15	26	26	25	34	27

*=Significant at P<5%
**=Significant at P<1%

Table A4.5 Mean square values for haun growth stage (1990)

Source Var	DoF	WCT	WFR	WZT	BCT	BFR	BZT
Rep	4	-	0.08	0.07	-	0.06	0.09
Depth	2	-	0.56	0.72	-	0.28**	0.50**
Error	8	-	0.07	0.03	-	0.03	0.06
C.V.(%)		-	5.30	3.60	-	3.20	4.30

*=Significant at P<5%
**=Significant at P<1%

Table A4.6 Mean square values for wheat and barley dry matter for three seedlots (1991).

Source Var	DoF	WCT	WFR	WZT	BCT	BFR	BZT
		...............g/0.25 m2...................					
Rep	5	29	10	6	38*	22	18
Lot	2	3	9	2	7	52	70*
Error	10	9	19	11	6	30	18
C.V.(%)		23	36	38	14	28	32
		................g/plant..................					
Rep	5	0.003	0.001	0.000	0.007	0.021	0.007
Lot	2	0.000	0.000	0.004	0.005	0.033	0.017
Error	10	0.002	0.000	0.002	0.002	0.015	0.009
C.V.(%)		20	17	23	13	26	29

*=Significant at P<5%
**=Significant at P<1%

Table A4.7 Mean square values for dry matter for wheat and barley at three seeding depths (1991)

Source Var	DoF	WCT	WFR	WZT	BCT	BFR	BZT
Rep	5	64	16	9	39	32	43
Depth	2	67	123**	101**	571**	794**	210*
Error	10	30	12	6	11	18	88
		...............g/plant.....................					
Rep	5	0.01	0.00	0.00	0.01	0.0	0.01*
Depth	2	0.01	0.01**	0.01**	0.12**	0.03	0.03*
Error b	10	0.02	0.00	0.00	0.01	0.02	0.00
C.V.(%)		54	12	14	15	29	

*=Significant at P<5%
**=Significant at P<1%

Table A4.8 Mean square values for leaf area index (LAI) (1990).

Source VaR	DoF	WCT	WFR	WZT	BCT	BFR	BZT
Rep	4	0.20	0.80**	3.25**	0.12	0.08	1.90*
Depth	2	0.44	0.12	0.13	0.09	0.04	0.13
Error	8	0.26	0.12	0.51	1.51	0.06	0.20
C.V.(%)		12	4	16	26	5	12

*=Significant at P<5%
**=Significant at P<1%

Table A4.9 Mean square values for TKW (1991).

Source Var	DoF	WCT	WFR	WZT	BCT	BFR	BZT
Rep	5	0.97	-	0.69	1.18	6.15	-
Depth	2	0.22	-	3.56*	4.57*	13.23	-
Error	10	0.46	-	0.65	1.06	4.21	-
Lot	2	0.00	-	0.09	1.41	2.20	-
Lot*Dep	4	0.85	-	0.75	0.77	9.46	-
Error b	30	0.96	-	1.28	1.14	3.74	-
C.V.(%)		3	-	3	3	6	-

*=Significant at P<5%
**=Significant at P<1%

Table A4.10 Mean square values for number of spikes per unit area (NSA) (1991).

Source Var	DoF	WCT	WFR	WZT	BCT	BFR	BZT
Rep	5	93	18932	9838	6494	2598	5388
Depth	2	5950	249	1097	9442	9833*	43256
Error	10	2637	10301	4816	4090	1236	9059
Lot	2	4840	4517	7307	12600	9945	6739
Lot*Dep	4	1512	6696	4030	5267	4390	3061
Error b	30	8717	9668	5221	4502	-	7022
C.V.(%)		13	15	11	9	9	13

*=Significant at P<5%
**=Significant at P<1%

Table A4.11 Mean Square values for HLW (1991)

Source Var	DoF	WCT	WFR	WZT	BCT	BFR	BZT
Rep	5	81	-	0.97	25	1339	-
Depth	2	84	-	0.26	22	693	-
Error	10	67	-	0.50	36	1294	-
Lot	2	92	-	0.58	46	934	-
Lot*Dep	4	79	-	1.58	25	1207	-
Error b	30	64	-	0.41	27	1413	-
C.V. (%)		10		0.83	2	13	-

*=Significant at P<5%
**=Significant at P<1%

Table A4.11 1990 Sum of Squares Values for Grain Yield of wheat and barley.

Source of Variation	DoF	WCT	WFR	WZT	BCT	BFR	BZT
Rep	5	1022642*	57911	43628	18705	148885	413057
Depth	2	241378	720735**	644482**	508059**	3827240**	980301**
Error (a)	10	243434	20981	80499	15599	205374	118370
Lot	2	258754	3290	4604	23285	911000**	58525
Lot*Depth	4	85479	3254	18391	27435	137344	65437
Error (b)	30	106993	22280	34316	58950	89838	104546
C.V.	20	6	3	4	3	4	5

*=Significant at P<5%
**=Significant at P<1%

Table A4.12 1991 Mean Square Values for Grain Yield of wheat and barley.

Source of Variation	DoF	WCT	WFR	WZT	BCT	BFR	BZT
Rep	5	187912*	47270	66904	59903	106716*	124940
Depth	2	3288007*	81522**	90157	1188	875342**	1228370**
Error (a)	10	65908	45510	34762	92474	161536	5611
Lot	2	3808	1701	55024	369364	152440**	337148
Lot*Depth	4	37531	42787	85183	214824	393913	4407
Error (b)	30	23933	22326	75708	170489	288131	27650
C.V.		4	3	7	8	3	7

*=Significant at P<5%
**=Significant at P<1%