ROTATIONAL BENEFITS OF SINGLE-YEAR FORAGE SEED CROPS

A thesis

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of

MASTER OF SCIENCE

by

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A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University

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Abstract

Rotational benefits of single-year forage seed crops.

Kerrie Chescu, Department of Plant Science, University of Manitoba. Major Professor, Dr. M.H. Entz.

Shorter-term forage seed crops have the potential to provide rotational benefits, however, little research on rotational benefits of forage seed crops has been conducted. Also, most existing research has focused on alfalfa or alfalfa-grass hay crop systems with less work focussed on rotational benefits of forage grasses. Field studies were conducted to investigate the effect of single-year forage grass seed crops on yield of subsequent bean (*Phaseolus vulgaris* L.) and sunflower (*Helianthus annuus* L.) crops and to determine how forage seed crops affect water use of the cropping system. In the forage year of the cropping system three forage seed crops were compared with barley (*Hordeum vulgare* L.): annual ryegrass (*Lolium multiflorum* L.); perennial ryegrass (*Lolium perenne* L.); and tall fescue (*Festuca arundinacea* Shreb.). Trials were conducted at two locations in Manitoba: Winnipeg, a silty clay soil with very wet conditions; and Carman a sandy loam soil with average moisture conditions. Few differences were observed at the Winnipeg site where excess water masked treatment differences. Tall fescue was found to use the most water ($p<0.05$) from the soil profile than other species, though differences were only observed at the Carman site. Annual ryegrass demonstrated the highest $WUE_{(Dry\ Matter)}$ of the all the crops grown.

Greater soil water use by tall fescue versus the other forages at Carman carried through until the next growing season. However, none of the previous forage crops prior to bean and sunflower crops affected yield compared to growing barley prior to bean and

sunflower crops. Additionally, growing forages prior to beans and sunflowers did not affect the ET or WUE of bean or sunflower production. Rotational efficient water use (REWU) was used to evaluate the water balance for the entire cropping system (forages plus beans/sunflowers). REWU of the forage/bean and forage/sunflower systems were higher ($p<0.05$) compared to the barley/bean and barley/sunflower system. The results of this experiment suggest that under average moisture conditions, forage seed grasses in rotation followed by beans (shallow-rooted) or sunflowers (deep-rooted) compliment root exploitation, resulting in greater rotational efficient water use over the entire cropping system compared to annual barley systems. Under excess moisture conditions even the combination of forages followed by a high water use annual crop (sunflower) did not provide sufficient water use intensity to deal with the extreme precipitation amounts.

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1.0 Introduction

In recent years, the rising cost of inputs (e.g. fuel, herbicides, fertilizers) coupled with the low prices received for many agricultural commodities has threatened the economic viability of many farms. Diversity of crops, livestock, farmer skills, and machinery is clearly essential for the development of a strongly integrated farm (Olson & Francis, 1995). In order to survive, farmers of today, must integrate some form of diversity into their farming systems. Farmers also need to recognize the importance of including diversity into their operation in order to protect the ecosystem.

Mixed farms are an excellent example of diversity with their broad range of activities that normally include some sort of livestock and crop production. Typically, mixed farms facilitate the inclusion of forage crops that are very important as a feed source for livestock, and also have the potential to increase diversity, even as seed crops. Manitoba has about 47,000 hectares devoted to forage seed production (Census of Agriculture, 2001) composing 30% of Canada's forage seed production (Manitoba Agriculture and Food, 2001). The forage seed industry in Manitoba is valued at over 25 million dollars/year at the farm gate level making it an economically important industry.

Another common method of introducing diversity into a farming system is through intensive crop rotation planning. Water is one of the most limiting factors in crop production, and therefore careful consideration should be given to efficient water use when planning a crop rotation. Crops should be managed in a rotation sequence so that complementary root systems fully exploit available water and nutrients (Karlen and Sharpley, 1994). Alternating between medium-rooted, shallow-rooted, and deep-rooted crops should theoretically exploit available water and nutrients and create a more water efficient cropping system.

There are other benefits to implementing this water efficient management system. For example, the dewatering characteristics of perennial forages play an important role in preventing soil salinization (Halverson and Black, 1974). Soil salinization is a threat to the long-term sustainability of crop production on approximately 25 % of Northern Great Plains cropland (Morrison and Kraft, 1994). Additionally, certain crops in rotation and certain cover crops can act as catch crops for residual nitrogen. Water use efficiency and efficient water use are potentially increased in rotation leading to greater and more efficient nitrogen uptake and reduced leaching losses (Pierce and Rice, 1988). Hence, by carefully planning crop rotations based on root exploitation, not only is a more water efficient cropping system created, but many potential environmental hazards (salinity, nitrate leaching) are reduced as well.

Unfortunately, previous research on rotational benefits (yield, water use, environmental impacts) of forages has concentrated on alfalfa and alfalfa-grass hay systems. Shorter-term forage seed crops have the potential to provide rotational benefits, however, little research on rotational benefits of forage seed crops has been conducted.

Based on this, the objectives of the is research project were:

1) To determine water use of three different species of forage seed crops when included in a crop rotation for one-year.

2) To determine how single year forage seed crops [annual ryegrass (*Lolium multiflorum* L.), perennial ryegrass (*Lolium perenne* L.), and tall fescue (*Festuca*

arundinacea Shreb.*)*] affect yield of subsequent sunflower (*Helianthus annuus* L.*)* and bean (*Phaseolus vulgaris* L.*)* crops.

3) To determine how single year forage seed crops (annual ryegrass, perennial ryegrass, and tall fescue) affect water use of subsequent sunflower (deep-rooted) and bean (shallow-rooted) crops.

2.0 Literature Review

2.1 Diversity

Diversity is one of the most overlooked facets of farming systems, yet it undoubtedly remains an integral component of sustainable farming practices. Therefore, it is important that there is a complete understanding of all aspects of diversity and how diversity completes the puzzle of a sustainable agriculture framework.

2.1.1 Temporal and Spatial Diversity

Diversity of farm fields can be temporal or spatial. Temporal diversity in fields is most often associated with changes in plant species or plant communities (Cruse and Dinnes, 1995). Temporal variation across years can be managed and enhanced with practices such as crop rotations (Karlen et al. 1994) and relay cropping (Thiessen-Martens and Entz, 2001). Spatial diversity is the variation found among different locations in a field (Cruse and Dinnes, 1995). Management practices affecting spatial diversity include intensive mixed intercropping (Waterer et al. 1994; Lyon, 1927), strip cropping (Cruse and Dinnes, 1995), the use of shelterbelts, and the inclusion of conservation structures such as grassed waterways and terraces (Sharp et al., 1995).

2.1.2 Implementing Diversity Through Crop Rotation

Crop rotation, by definition is the practice of growing a sequence of plant species on the same land (Yates, 1954). The practice of crop rotation has been in existence for thousands of years. No amount of chemical fertilizer or pesticide can fully compensate for crop rotation effects and analysis of individual factors generally does not explain the entire yield response associated with crop rotation (Foster, 1998; Wright 1990).

Crop rotation, the most common source of temporal diversity on an annual basis, is an effective management tool to maximize resource use (e.g. nutrients, soil water) and control pests (e.g. disease, weeds, insects). However, crop rotations are far less diverse structurally than the complexity of species and temporal diversity found in a natural setting. Differences in characteristics of the species within the rotation affect the biology of the farming system.

Not all crop rotations provide functional benefits to the farming system. For example, rotating wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) is by definition a crop rotation, however, both species are grasses with similar plant structure, plus they require similar planting methods, plant population density, and pest management. Wheat and barley also have similar life cycles, unless one is a winter crop and the other a spring-planted annual. The ecological niche and resource needs for crop growth within the field will be quite similar for these species, and hence the temporal diversity introduced by rotating these crops is minimal.

Greater temporal diversity results if grasses and broadleaf species are rotated within the cropping system. An example is the widely used corn *(Zea mays L.)* -soybean *(Glycine max L.)* rotation in the United States Mid-West (Karlen et al., 1994). Rotations of crops that require greatly different management practices will result in even greater levels of temporal diversity and greater rotational effects because different planting methods, plant population density, pest control and harvesting techniques are implemented.

2.1.3 Benefits from Crop Rotation Diversity

Crop rotation can affect soil biology (Kay, 1990), fertilizer needs (Kelner et al., 1997), soil physical conditions (Campbell et al., 1990), soil erosion (Pavlynchenko, 1942), allelopathy (Weston, 1996), crop yield (Bezdicek and Granastein, 1989), energy requirements of production (Hoeppner, 2001), and water quality (Karlen et al., 1994). Each crop in the rotation will be directly affected, to some extent, by the previous crop and will also affect the next crop grown in the sequence. Longer-term influences occur through the impact of each crop on soil properties.

Diversity created by crop rotation is also one of the most effective means of reducing disease and insect pests (Karlen et al., 1994). Following production of a crop, insect and microbial organisms for which that crop species is a host exhibit increased population sizes. If the same crop is grown the following year, insect pests or disease organisms specific to that crop will be more prevalent affecting potential development and yield of the crop (Bezdicek and Granatstein, 1989). Alternating crops with contrasting host-specific pest reduces potential yield loss. For example a crop of peas (*Pisium sativum L.*) and sundangrass (*Sorghum sudanese L.*) incorporated before potatoes (*Solanum tuberosum L.*) under irrigation in Washington state had an effect on yield similar to that of fumigation under continuous potatoes, indicating the potential for certain crops to reduce the level of soil borne pathogens (Cook, 1984).

Weed pressure can be reduced by sequential production of different crop species, especially by planting crops possessing different life cycles and growth characteristics. Alternating grasses and broadleaves changes the competitive environment for weeds and slows the population increase of particular species. Perennial crops such as alfalfa (*Medicago sativa L.*) (Ominski et al., 1999), allelopathic crops such as tall fescue (*Festuca arundinacea* Schreb.) and creeping foxtail (*Alopecurus arundinaceus* Poir) (Moyer and Boswall, 2002), and in drier regions, periods of fallow, all provide temporal diversity that can contribute to weed control (Cruse and Dinnes, 1995).

Well-designed rotations offer other diversity advantages compared to monocultures. For example, legumes in a rotation can fix substantial quantities of nitrogen (Entz et al., 2002; Kelner et al., 1997), reducing or eliminating nitrogen fertilizer requirements for subsequent crops. Rotations containing pasture or sod-forming crops can result in higher soil organic matter contents than continuous row crops (Robinson et al., 1996). The inclusion of perennial crops in a rotation will also reduce long-term rates of soil erosion. This is due to the sod-forming characteristics of perennial crop roots that are effective in anchoring the soil in place making it less vulnerable to erosion.

2.1.4 On-farm diversity

A low profit margin for most commodities threatens the economic viability of many farms. A farmer's response to low profit margins is often increased use of inputs, cultivation of land, postponement of conservation practices, and the acquisition of additional cropland with borrowed money (Olson and Francis, 1995). This strategy often increases the degradation of soil, water and other farm resources. Perhaps farmers need to turn to new approaches if they will be able to enhance conservation in the face of globalized and specialized agriculture.

Insight about the sustainability of production and income suggest that complementarity of livestock and crop enterprises will increase the stability of farming systems (Conway, 1987). The diversity of crops, livestock, farmer skills, and machinery is clearly essential for the development of a strongly integrated farm (Olson and Francis, 1995). The components that make up the farm must not only be diverse, but also complementary (Jackson, 1984). Mixed farms traditionally implement an abundance of diversity due to the various constituents that make up the system (livestock, manure, grain and forages). Additionally, mixed farms facilitate the inclusion of forages that are very important as a feed source for livestock, and also have the potential to increase diversity, even as seed crops.

A growing concern surrounding diversity is the fact that fewer farmers are cropping larger areas. The Canadian 2001 Census of Agriculture reported that there are 246, 923 farms in Canada, down 10.7% from 1996. However, the amount of land devoted to agriculture hasn't changed. This statistic is a clear indication that there are fewer farms that are getting bigger. So what does this mean for the fate of farm diversity? In Manitoba, mixed farms reporting receipts of $2,500 or more have decreased by 27.4% in the past five years (Census of Agriculture, 2001). This implies that farms are gearing towards specializing in either grains or livestock, and away from the traditional combination of "mixed" farming. This shift in farm type in itself could be a step away from diversity.

Under circumstances where the number of mixed farms is declining, fields must be managed to enhance production, increase income, and reduce farming impacts on the environment, in order for the farm to survive. Unfortunately, the use of diversified crop production and crop rotation has decreased in the past few decades (Karlen et al., 1994; Bezdicek and Granastein, 1989), while the land area devoted to monocropping has increased. This trend can be attributed to the substitution of chemical inputs and alternative management approaches for selected rotation effects. For example, with the introduction of herbicide resistant canola (*Brassica* spp.) in 1995, many farmers opted for the conveniences the system had to offer. As the popularity of herbicide resistant canola flourished, there came a point where the acres devoted to herbicide resistant canola out-numbered the conventional canola acres (Martens, 2000, personal comm.). The introduction of herbicide tolerant canola supports the reliance of herbicides to control weeds in-crop rather than the use of rotations to break weed cycles, which ultimately decreases the amount of temporal diversity being established in a given rotation.

It is a fact that the number of mixed farms, distinguished for their balance of diversity, is declining. However, there are still ways to implement on-farm diversity where farms are specialized in grain production. Manitoba has about 47,000 hectares devoted to forage seed production (Census of Agriculture, 2001) that is valued at over 25 million dollars/year at the farm gate level making up 30% of Canada's forage seed production (Manitoba Agriculture and Food, 2002). In the present study, growing tall fescue and ryegrass for seed production offers diversity to traditional crops that are grown in rotation because they are perennial grass seed crops with a different phenology compared to traditional cereal crops. Forage seed production represents an opportunity to have forages and the benefits they have to offer in grain farming. However, forage seed production also fits well into a mixed farming operation because of the forage re-growth potential. Perennial grass seed crops facilitate and 'complement' a grain – livestock system better than a grain crop, which has little or no late-season re-growth.

2.2 Forage Crop Descriptions

2.2.1 Tall Fescue (*Festuca arundinacea* Shreb.)

Tall fescue is native to central Europe. Traditionally, tall fescue has been cultivated for pasture and hay (Looman, 1983), however, tall fescue is now increasingly used for turf seed production.

Within North America, most tall fescue seed is currently grown in Oregon and Missouri in the United States (Young, 1997). With the continuing increase in demand for seed for amenity purposes, and the proliferation in the number of proprietary varieties of tall fescue, it is becoming increasingly difficult to provide adequate genetic isolation in the seed-growing zone of the Pacific North-West U.S.A. (Fairley and Lefkovitch, 1999). Hence, opportunity exists for diversifying the grass seed industry in Canada. Previous research has demonstrated the agronomic feasibility of growing tall fescue for seed in the Peace River region of Canada (Fairley and Lefkovitch, 1993) and in Manitoba (Manitoba Forage Seed Association, 2001).

Tall fescue has an open bunch growth habit. Plants extend basal area by tufts that grow from the edge of the crown making it a very competitive plant. Coarse, leafy stems in tall fescue support an open, nodding panicle (Looman, 1983).

Tall fescue can be challenging to establish. Seedlings are often regarded as having slow growth rates, which has been attributed to slow mobilization of seed reserves (Hayes, 1976), slow root growth (Hayes 1976; Brock et al., 1982) and slow tillering (Hill et al., 1985). In the Peace River region of Canada, low soil moisture in the fall combined with little subsequent snow cover, reduces spring vigour and subsequent seed production of tall fescue (Fairley and Lefkovitcvh, 1999). Therefore, surface soil water conservation practices are recommended to enhance plant establishment. Initial density and arrangement of tall fescue plants at establishment are important determinants of seed yield (Fairley and Lefkovitcvh, 1999). Early studies of crop competition and plant spatial arrangement show that moderate plant population densities maximize seed yield (Donald, 1963). Typical seed yields for tall fescue in Manitoba are reported to be 500 kg ha^{-1} (Manitoba Forage Grass Seed Production Guide, 1997).

Tall fescue is noted for its ability to perform well under moist conditions. Garwood and Sinclair (1979) found tall fescue, grown as a forage crop, to be outstanding both in the amount of water it utilized from the soil profile and the depth to which this water was used compared to other forage grass species [eg. timothy (*Phleum pratense L.*), perennial ryegrass (*Lolium multiflorum L)*]. Effective depths of utilization of water under 6-week defoliation intervals were: timothy, 70 cm; perennial ryegrass, 80 cm; tall fescue > 100 cm. It was concluded that the ability of tall fescue to draw water from such depths was related to its more extensive root system compared to the other species. Additionally, the ability of tall fescue to exploit water at depth helps to explain its tolerance to dry conditions (drought).

In the past, tall fescue use has been limited in some production areas due to poor plant persistence. However, tall fescue grasses infected with an endophyte fungus (*Acremonium coenophialum*) have better resistance to stressful conditions and are therefore more persistent than endophyte-free tall fescue (Bouten et al., 1993; Hill et al., 1991).

Tall fescue, when infected with the endophyte *Acremonium coenophialum*, is known to produce an ergopeptine-alkaloid (Hill et al., 1991). Animals that consume endophyte infected tall fescue experience a chronic health disorder known as fescue toxicosis (Hoveland et al., 1983) Toxicity can provide some challenges in feeding re-growth of tall fescue infected with the endophyte.

Interest in using grass seed production residues as part of livestock rations has increased recently in Manitoba. In other production areas, where turf-type perennial ryegrass and tall fescue residues have been fed, livestock disorders, as described previously, have been observed. These disorders, commonly called fescue foot or ryegrass staggers have been attributed to the endophytes that live within the grass plant. This potential problem can be remedied by diluting infected tall fescue feed sources with non-infected feed.

2.2.2 Perennial Ryegrass (*Lolium perenne* L.)

Perennial ryegrass is a commonly grown forage and turf-grass species in Europe, New Zealand and North America. Perennial and annual ryegrasses are among the most widely used of all forage grasses around the world. Ryegrasses are cool season grasses that have a tufted, bunchgrass perennial growth habit with a fibrous root system. Ryegrass has a blade up to 6 mm wide, 5 to 15 cm long with prominent ridges on the upper surface and is characteristically smooth and glossy on the lower surface (Best, 1971). In perennial ryegrass, a vernalization period is required for induction of flowering.

Typical yields for perennial ryegrass in Manitoba average between 600 to 800 kg ha $^{-1}$ (Manitoba Forage and Grass Seed Production Guide, 1997). Perennial ryegrass is well adapted to soils with good moisture holding capacity and is especially adapted to moist production areas (Manitoba Forage Seed Association, 2001). Previous research indicates that perennial ryegrass grown for forage production uses water to a depth of 80 cm (Garwood and Sinclair, 1979). Under Western Canadian conditions winter survival has limited seed production (Manitoba Forage Seed Association, 2001). In Western Canada, perennial ryegrass acts more as a biennual crop where seed is produced in the year after establishment and then the plants are lost to winterkill. It is often referred to as a "winter wheat alternative". Perennial ryegrass is either established in the spring under a cover crop or into stubble in the late summer. The objective is to have the perennial ryegrass over-winter as a juvenile plant in the 4 to 6 leaf stage as it appears to be more winter hardy in this stage than as a mature plant (Manitoba Forage Seed Association, 2001).

The opportunity exists for producers, who have mixed operations, to feed residues and re-growth of ryegrass production to livestock. However, two major syndromes that occur with feeding ryegrass are perennial ryegrass staggers and annual ryegrass toxicity. Affected animals exhibit various degrees of loss in coordination and other signs of neurological disorder (head shaking, stumbling and collapse, and severe muscle spasms), particularly when animals are disturbed or forced to run.

The main causal agent of ryegrass staggers are a group of potent tremorgens called lolitrems, the most important of which is lolitrem B (Gallagher et al., 1984). Lolitrem B is a potent inhibitor of neurotransmitters in the brain. An endophytic fungus, *Acremonium lolii*, produces the lolitrems that are often present in perennial ryegrass.

Turf cultivars of both tall fescue and perennial ryegrass are often deliberately infected with endophytes through breeding because the endophyte increases plant vigour, in part by producing ergot alkaloids (*A. coenophialum*) and termorgens (*A. lolii*). While the presence of the endophyte is advantageous when the grass is used for turf purposes it has negative effects on animal performance when the grass is consumed by livestock.

2.2.3 Annual Ryegrass (*Lolium multiflorum* L.)

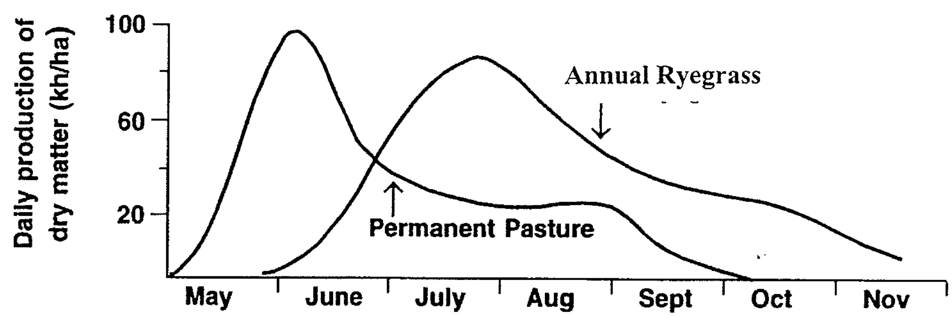
Annual ryegrass is used in many parts of the world as a forage grass because of its vigour and high yields. Annual ryegrass is often used for soil stabilization in establishing turf because seedlings of annual ryegrass are extremely vigorous and emerge rapidly (Blaser et al., 1956). Annual ryegrass is sometimes used as a companion crop, because of its soil stabilizing ability, in tall fescue seed establishment (Brede and Brede, 1988). In Western Canada, annual ryegrasses are adapted to the Black and Grey soil zones. Annual ryegrasses are noted for their ease of establishment, high forage quality, high yield and minimal management requirements (Foster et al., 1996).

Like perennial ryegrass, annual ryegrass also performs well on soils with good moisture holding capacity, and as such, annual ryegrass is well adapted to moist production areas. Although well suited to high moisture conditions, Ridley et al (1997) concluded that compared to other high water-use forages, annual ryegrass used relatively less water. Annual ryegrass must be seeded very early in the spring so that the seed crop can be harvested in late August. Typical seed yield for Manitoba ranges from 600 to 800 kg ha^{-1} (Manitoba Forage and Grass Seed Production Guide, 1997). Annual ryegrass is very flexible in terms of integrating grazing and seed production. In Oregon, grazing annual ryegrass in late winter and early spring up to the time when the apical meristems of all primary tillers are removed does not reduce seed yield (Young et al., 1996).

Vigorous plant growth is characteristic of this plant giving the crop excellent forage production potentials from straw and fall post-harvest re-growth (Manitoba Forage Seed Association, 2000). Experience across the prairies has shown that annual ryegrass has excellent forage production potential as a forage grass and as part of a seed production system. Straw yields of 7400 to 8650 kg ha^{-1} with a protein level of 10 to 12 % and fall re-growth of 2475 kg ha^{-1} with protein level of over 18 % make this a very value component of the production system (Manitoba Forage Seed Association, 2001).

Annual ryegrass is highly palatable and highly digestible. High fall production and quality makes ryegrass pastures well-suited to adding weight to weaned calves prior to marketing (Duane McCartney, personal comm., 2001, Lacombe, Alberta). Annual ryegrass also has the ability to extend the grazing season by providing additional forage in late September to November complimenting permanent pasture which is no longer producing forage at that time (Figure 1).

Figure 1



Annual ryegrasses reach peak production by mid-summer and continue growing until fall; they complement perennial pasture species by providing quality pasture in late summer and fall.

(Source: T. Kunelius. Annual Ryegrasses in Atlantic Canada. 1991. Ag.Can. Pub. 1859/E)

2.2.3.1 Tall Fescue and Ryegrass Forage Value

Both tall fescue and ryegrass are commonly used as forage for livestock producers across North America and around the world. These forages, under the right conditions, offer a good nutritive feed source for livestock. Tall fescue biomass accumulated for fall and winter use during later summer/early fall has more nutritive value but less yield than tall fescue biomass accumulated during the summer (Burns and Chamblee, 2000). These observations suggest that tall fescue is suitable for livestock producers who would like to extend their grazing season by stockpiling forage to be grazed by livestock in the later fall period (October to November). By keeping livestock on pasture longer, the time spent in confinement is shortened which reduces expensive feed costs, which are most often realized in confinement feeding (Sheldon, personal comm., 2001, Ste. Rose, Manitoba)

Evidence exists to suggest that ryegrasses have faster re-growth than tall fescue. When clipping treatments were used to stunt growth at an early stage, ryegrass was less responsive to clipping treatments than tall fescue which displayed stunting (Brede and Brede, 1988), perhaps indicating that ryegrass will re-grow faster and have more tillers than tall fescue. In simulated swards of ryegrass and tall fescue, dry matter production increased with less frequent defoliation but tiller numbers were highest under the $10^1/_2$-day defoliation interval (Bell, 1985). Many researchers (e.g. Chestnutt et al. 1977, Alexander and Thompson 1982) have reported increasing dry matter production of grasses with decreasing defoliation frequency. When both dry matter yield and digestibility are taken into account, there was little advantage in extending the frequency of defoliation past 42 days, especially for tall fescue (Bell, 1985). Periodic assessment of the proportion of green and dead tissue in the accumulated forage provides a useful estimate of its relative nutritive value and would help in determining the daily animal response expected from its use (Burns and Chamblee, 2000).

2.3 Benefits of Forages in Rotation

2.3.1 Yield Benefits

The influence of one crop on a subsequent crop in the rotation is chiefly dependent on use of soil moisture by the first crop, residual fertility effects, and effects on pest populations. Regardless of the cropping system, periodic rotation of crops is recommended for the control of certain weeds, diseases, and insects that can ultimately limit yield potential.

The inclusion of forages in rotations can lower the incidence of leaf and root diseases, and can improve soil nutrient availability (Dyke and Slope, 1978; Bullock, 1992; Stevenson and Van Kessel, 1996) which helps improve yields of crops following forages in rotation. A combination of crop rotation and residue management can increase the activity of soil microbes, decrease the build-up of harmful bacteria and pests (weeds, insects, disease), and provide the crop variety needed for top productivity by reducing limiting factors that affect yield. In a study by Eriksen (2001), barley and wheat yields were found to be generally higher with a grassland history than with a cereal history, especially in the first year after ploughing. According to Eriksen (2001), higher maximum yields following grassland than following cereal were probably caused by non-nitrogen effects of grassland such as improved soil structure and better resistance to fungal diseases. Stevenson et al. (1998) reported a spring barley yield benefit of 26 % in a rotation study that included a 2-yr forage mixture of timothy (*Phleum pratense L.*) and red clover (*Trifolium pratense L.*) compared to a monoculture, confirming the benefits of forages to subsequent crops in a rotation.

Producers perceive yield and weed control benefits from including forages in crop rotations with the greatest rotational benefits in Prairie Canada observed in wetter areas (Entz et al., 1995). Crop rotation is valuable for improving yield because weeds proliferate in crops with similar growth requirements. For example, grass weeds thrive in continuous corn, and broad-leaf weeds thrive in continuous soybean (Bullock, 1992). In a perennial cropping system, Ominski et al. (1999) found perennial alfalfa in Manitoba cropping systems shifted weed community composition away from wild oat *(Avena fatua* L.) and other summer weeds. Alternatively, on an annual basis, by including a grass crop prior to a broadleaf crop in a rotation, broadleaf specific herbicides can be used or allelopathic compounds could be released during the grass phase of the rotation that reduces the incidence of broadleaf weeds in the following broadleaf crop. Weeds provide competition for nutrients and water, which limits yield potential of the crop. By diminishing weeds and hence competition, higher potential crop yields can be realized.

The duration of a grass-based forage within a crop rotation sequence can increase both the yield of wheat and the infiltration of water in the soil (Bezdicek and Granastein, 1989). Research by Mazurak and Ramig (1963) indicated that after two years of bromegrass (*Bromus inermis* L.) and wheatgrass (*Agropyron spp.*) in rotation, wheat yield was increased by 0.5 Mg ha^{-1}, and after six years of the grass combination, wheat yield increased by 0.6 Mg ha^{-1} compared to yield of continuous wheat rotation. The soil water infiltration rate was also increased with an increase in the duration

2.3.2 Allelopathy

Allelopathy occurs when one plant species releases chemical compounds, either directly or indirectly through microbrial decomposition of residues that affect another plant species. Liebman and Dyck (1993) stated that including allelopathic plants in a crop rotation or as part of an intercropping system might provide a non-herbicide mechanism for weed control.

Allelopathic toxins from certain genotypes of tall fescue have been implicated in inhibiting growth of new birdsfoot trefoil (*Lotus corniculatus L.*) and red clover forage stands (Peters and Zam 1981). Such toxins may explain some of the difficulty in establishing birdsfoot trefoil in tall fescue sod (Peters 1968; Luu et al. 1982). This suggests that it may be desirable to grow one or more crops between a sod crop and no-till legume. However, the allelopathic nature of tall fescue may also be a useful tool in controlling certain weeds.

Moyer et al. (2000) found that under favourable weather conditions for plant growth, fall rye (*Secale cereale* L.) was as effective as post-harvest plus early spring tillage or herbicides in spring weed control in a subsequent wheat crop. The Moyer study underlines the importance of crops such as fall rye to organic cropping where non-herbicide weed control methods must be used.

2.3.3 Maintaining Soil Quality

Using different crop rotations may improve soil quality by more closely mimicking natural ecosystems than current farming systems (Karlen et al., 1995). Kay

(1990) stated that the characteristics of plant species being grown, the sequence of different species, and the frequency of harvest all affected soil structure by influencing the formation of biopores by plant roots and soil fauna. Crop rotations that include legumes and/or grasses are generally beneficial to aggregate stability and formation of favourable soil structure (Kay, 1990).

Soil aggregation is degraded by continuous use of tillage, which produces fine soil fractions that in dry periods are easily caught by wind and easily carried by runoff water. Erosion by wind and water results in a loss of valuable topsoil, the formation of gullies, and the deposition of silt. Pulverization usually goes hand in hand with the more detrimental process of depletion of root fibre. It is true that annual grain crops deposit large amounts of root material in the soil every year (Campbell et al., 1990). This fibre, however, is strong only as long as the plants live. Soon after harvest, the roots undergo rapid decomposition (Walster, 1933). Perennial grasses produce much stronger root fibre capable of binding the soil for a considerable length of time (Pavlynchenko, 1942).

Underground stems play a significant role in the production of new roots and stems, which take active part in competition for moisture, nutrients and light. They also serve as a coarse framework that holds the soil in place. Winter wheat and alfalfa, having no rhizomes and producing only 2 to 4 and 2 to 12 buds per crown, respectively, bind the soil less firmly than do perennial grasses with numerous culms and rhizomes (Pavlynchenko, 1942). Naeth et al. (1991) reported that high soil microbial populations associated with pasture grass rhizospheres produce polysaccharide mucigels that promote aggregation in the short term while in the long-term, promote the build-up of humic materials which stabilize aggregates.

Pavlynchenko (1942) documented the importance of nodal roots to “soil building”. He stated that nodal roots of grasses exert considerable binding effect upon the soil. Their significance, however, rests in their ability to produce multitudes of branches. These branches penetrate the soil in all directions and come into direct contact with the smallest soil particle. Unlike main roots, they are composed largely of young, actively absorbing tissue. Branches are also important for one plant species to compete with another (Pavlynchenko, 1942).

2.4 Soil Water

Water is one of the most important factors limiting crop productivity on the Canadian Prairies, where precipitation is unevenly distributed and is often lower than the potential evapotranspiration (ET) (De Jong and Cameron, 1980). Therefore, crops depend on existing soil moisture for their water requirements (Ash et al., 1992). Even in the driest regions of Western Canada, water from deeper soil layers is often left unused (Hurd, 1974). Management techniques that increase soil water storage and decrease water losses by evaporation (E) and by ET of non-crop plants increase the amount of water retained in the soil for subsequent use by crops. In this respect, careful development of crop rotations must be carried out to maximize water use within the soil profile, including subsoil water.

2.4.1 Evapotranspiration (ET)

Evaporation occurs when radiant energy from the sun heats water, causing the water molecules to become so active that some molecules rise into the atmosphere as vapor (Kramer and Boyer, 1995). A major portion of water absorbed by the root system of a plant (more than 95%) is lost to the atmosphere by transpiration (Kramer and Boyer, 1995). However, transpiration is essential for efficient supply of water and nutrients, $C0_2$ gas exchange, buffering leaf temperature and avoiding xylem cavitation (Woodward, 1998). Evapotranspiration is the combination of water evaporating from the soil and transpiration by plants.

Rainfall potentially available for crop ET is that which falls during the period from harvest of the most recent crop to harvest of the crop under consideration. Water loss from the system other than by crop ET lowers rainfall use efficiency. Low infiltration and high rainfall runoff, low soil water storage capacity, E of soil water before crop establishment, and ET by non-crop plants (weeds) all contribute to water losses. Also, crops with limited root systems, such as beans (Stegman and Olsen, 1976), may not use water from the soil profile effectively, thus contributing to low rainfall-use efficiencies (Unger et al., 1988).

The amount of water lost by E is influenced by climatic and soil conditions. Losses are greatest where the evaporative demand of the environment is highest (warm, dry, windy climate) and where soils retain a large amount of water at the surface or where the water readily moves to the surface by unsaturated flow or in the vapour phase (Unger et al., 1988; Brady, 1990).

Some soil water potentially available for ET may not be used because the crop plants have a limited root system or because a given crop may not extract water to the same soil matric potential as another crop (Fairbourn, 1982). In either case, the remaining water may be potentially available to a subsequent crop with a more extensive root system, such as sunflower (Conner and Hall, 1997), or one that extracts water to a lower matric potential (Unger et al., 1988).

2.4.2 Infiltration, Drainage and Runoff of Precipitation

Rainfall, soil and crop characteristics influence water infiltration, drainage and runoff. However, it is important that we first distinguish between these terms. Soil textbooks classify infiltration as the downward entry of water into the soil. Soil drainage, on the other hand, refers to the frequency and duration of periods when the soil is free from saturation with water. Runoff is defined as the portion of the precipitation on an area that is discharged from the area through stream channels. Water which is lost without entering the soil is called surface runoff and that which enters the soil before reaching the stream is called groundwater runoff or seepage flow from groundwater (Miller and Gardiner, 2001; Brady, 1990).

Runoff occurs when rainfall rates and amounts exceed the surface storage capacity and infiltration rate of a soil. This is often the case with intense rainstorms, or where rainfall occurs frequently, or with rapid snowmelt. Steep slopes, soil aggregate dispersion and surface sealing, and slowly permeable or impervious horizons in the soil profile also contribute to runoff. Infiltration may be especially low when the soil surface is smooth, bare, and devoid of crop residues prior to crop establishment or canopy development (Unger et al., 1988). Under such conditions, a soil may not be filled to field capacity because of low infiltration rates. Establishing or maintaining crop residue mulch on the soil surface usually will increase soil water through improved infiltration and/or decreased evaporation (Norwood, 1999).

Once the water penetrates the soil, some of it is subject to downward percolation and eventual loss from the root zone by drainage. In humid areas, up to 50% of the precipitation may be lost as drainage water (Brady, 1990).

2.4.2.1 Nitrate Leaching and Soil Salinity

Nearly all nitrogen fertilizers (except organic and slow-release fertilizers) are very soluble in water, and the final oxidized form, nitrate, moves readily in the soil. Soluble nitrogen also comes from soil humus, human and animal manures, fixation by soil bacteria and algae, and rainfall. With all of these sources of soluble nitrogen there are concerns about the destination of nitrogen and potential ground-water contamination from leaching. Campbell et al., (1994) demonstrated that in years with above-average precipitation, significant amounts of nitrate can leach beyond the rooting zone of cereals, even in the dry Ardic Haploboroll soils of southwestern Saskatchewan. Nitrate leaching in soils depends on soil texture, relative rates of plant uptake of nitrogen, several nitrogen transforming processes (eg. mineralization, immobilization, and denitrification), precipitation, fertilizer inputs, and drainage (Follett, 1989).

Certain rotation crops have the ability to use residual nitrate-nitrogen and excess water to reduce the severity or risk of nitrate leaching. For example, using simulation models, Delgado et al. (2001), determined that barley following a potato crop has the ability to use residual nitrogen and minimize nitrate nitrogen losses, which could potentially be lost to leaching. Cropping systems that include perennial plants are valuable in reducing subsoil nitrate-nitrogen accumulation. Olsen et al. (1970) observed that rotating corn with oats and bromegrass followed by alfalfa significantly reduced the concentration of nitrate-nitrogen in the soil profile compared to continuous corn. Water use efficiency and efficient water use are potentially increased in rotation leading to greater and more efficient nitrogen uptake and reduced leaching losses (Pierce and Rice, 1988). However, careful crop planning must be implemented. For example, deep-rooted forage crops such as alfalfa remove nitrate and water to a depth of 2.4 m, however, because alfalfa is a legume there is also an increase in the nitrogen supplying power of the soil, therefore, considerable nitrate leaching can still occur under these systems (Campbell et al., 1994). This suggests that forage grasses, which do not supply nitrogen, yet still have significant rooting depth, could be well suited to remove nitrate and water from the soil profile making them suitable to use in a rotation where nitrate leaching is a concern. Entz et al. (2001) looked at grass versus alfalfa systems, and found that greater nitrate-nitrogen extraction occurred with the grass treatment compared with continuous alfalfa in at soil depths from 0 – 120 cm.

Another potential problem that can arise due to surface hydrology is soil salinity. Soil salinity refers to a condition of the soil in which water soluble salts are present in sufficient amount to affect crop growth. Soil salinity generally occurs in water discharge areas where the water table is high, within 1 to 2 meters of the surface, especially in fine textured soils (Haluschuk, 2000).

Soil salinity is caused by many different circumstances, some of which occur naturally. Extremely wet spring conditions of excess soil moisture and periods of flooding can result in minimal annual crop production and therefore very little soil moisture use by crops. The drying out of these soils occurs by drainage and evaporation. High evaporative loss of soil water over an extended period results in the accumulation of soluble salts near the soil surface. Establishment of deep rooting crops and salt tolerant grasses, which consume large quantities of water over the growing season dry out soils and lower the water table reducing the incidence of salinity problems (Haluschuk, 2000). A lack of deep-rooted crops in cropping systems in many high moisture areas increases the occurrence of salinity problems.

In a study of long-term crop rotations, Beke et al. (1994) found that soil salinity increased under a fallow-wheat rotation and the least under a continuous wheat cropping rotation. This verifies the importance of careful crop rotation planning when dealing with salinity concerns. Halverson and Black (1974) stated that by using flexible crop rotations involving small grains, grasses, and deep-rooted crops, and a minimum amount of summer fallow, soil water loss by deep percolation could be prevented and development of saline seeps could be alleviated.

2.4.3 Strategies to Improve Water Use

Plant growth in semi-arid regions is limited more by water than by any other factor. Crop rotations can be used to help with both soil water storage and water use. Soil water storage capacity can be increased by imposing changes on the soil profile and increasing organic matter content of the soil (Unger et al., 1988). Crop rotations can do this by increasing soil organic matter. For example, rotations containing pasture or sod-forming crops can result in higher organic matter contents than continuous row crops (Robinson et al., 1996). Including deeper rooted crops such as sunflower or alfalfa is a practical method of utilizing soil water and nutrients stored below the normal rooting zone of most annual crops (Unger et al., 1988). The success of deeper roots is based on the assumption that there is water in the soil profile, and that the present root system is able to extract that water (Ludlow and Muchow, 1990). Soils with higher water potential characteristics such as those with high clay content may make water extraction more difficult. Soil structure also affects plant growth. The most obvious effects are on root growth, which is strongly inhibited by hard soil, and which in turn influences the ability of the root system to extract adequate water and nutrients from the soil (Passioura, 1991). Wright and Smith (1983) proposed that root systems that extract water more efficiently from the soil through deeper rooting can expand the soil water supply.

Additionally, to minimize evaporation, the soil should be covered with a crop at all times. Longer season crops such as sunflowers (Angadi and Entz, 2002b) or perennial crops such as forage grasses and legumes (Chanasyk and Naeth, 1999; Fairbourn, 1982) are primary examples of crops that achieve season long crop cover and minimize loss to evaporation.

2.4.3.1 Forages Used in Rotation to Improve Water Use

When included in rotation, forages have the ability to affect the water use of the cropping system. Forages improve the soil aggregate size distribution (Anonymous, 1949), but in drier regions cereal yield is decreased following alfalfa or forages (Austenson et al., 1970), probably because of greater soil water extraction by forages. Extraction of subsoil water essentially increases the recovery efficiency (Pierce and Rice, 1988), which is the ratio of water used to the amount of water available. However, by drying the soil profile, alfalfa can also reduce water available to the following crop. Therefore, depending on the following crop's water needs and the moisture conditions of the growing season the drying action by the proceeding alfalfa can either be an advantage or disadvantage.

In wetter areas, especially in the Gray soil zone, the inclusion of forages and legumes in rotations are valuable in improving soil water use (Bowren, 1974; Bentley et al., 1971). For example, a crop such as dry bean, is sensitive to excess water (Stegman and Olsen, 1976). In a high moisture area a forage crop could be is grown in the previous year, with the goal of creating a better moisture situation for bean crop production.

Biological tillage is the improvement of soil structure by biological means such as the action of plant roots, earthworms and other soil organisms. Plant roots may naturally improve the soil by physically binding and stabilizing aggregates, releasing exudates compounds that bind aggregates, and creating channels in the soil (Dexter, 1991; Bathke et al., 1992). Perennial forage crops, because of their widespread root biomass and continuity of their root systems over several years, have great potential to create a network of biopores and perform biological tillage. The channels created by biological tillage in forage crops could permit following crops to access more water by better rooting.

2.4.3.2 The Role of Tillage in Improving Water Use

Efficiencies of soil-water extraction and use are important factors determining crop productivity in dryland regions and are commonly influenced by tillage practices. No-till systems are characterized by higher rates of soil water infiltration (Edwards et al., 1988; Dao, 1993) and lower levels of soil evaporation (Bond and Willis, 1969), resulting in higher levels of available soil water and spring seeding than tilled systems (Lafond et al., 1992). Higher levels of available water should create ideal situations for plants to obtain greater physiological efficiency.

There is usually more water in the soil under minimum tillage than under conventional cultivation (Pearson et al., 1991). Snow, which accounts for an average 30% of annual precipitation in the northern Plains region, contributes an average of 45 mm (Willis and Carlson, 1962) of additional water to no-till systems, while deJong and Steppuhn (1983) concluded that an average of 30 mm was conserved under no-till. The greatest moisture advantage under zero tillage occurs early in the growing season, when E is the dominant means of soil moisture loss (Gauer et al., 1982).

No-till cropping systems will preserve the macropore flow system from one crop to the next (Edwards et al., 1988). Macropores appear to be effective in conducting water through the soil below the surface layer, even when the surface layer has been roto-tilled and a row crop planted (Meek et al., 1990). Hence, the benefits of no-till remain in the subsurface even if tillage is re-introduced to the surface layer of the system.

During early and mid-season crop growth, the soil moisture content in the seedbed of zero-tilled plot is higher than that of conventional (Gauer et al., 1982; Shanholtz and Lillard, 1969). The soil water and tillage relationship is an important aspect to consider for successful establishment of forage crops, especially in forage grass crops. Grass seedling crops are sensitive to moisture deficits and therefore require a firm moist seedbed, which can be created in zero-till situations. For example, Allen and Entz (1994) found higher plant populations of grasses and alfalfa under no-till establishment due to higher soil surface water content.

2.4.4 Rotational Water Use

There have been numerous efforts to describe and quantify water use within a crop. The most popular term in use today is water use efficiency (WUE), which is expressed in kilograms of dry weight produced per hectare per millimetre of ET (Viets, 1967). This water-plant relationship is controlled by a number of complex climatic factors such as temperature, humidity, radiation intensity, and wind (Fairbourn, 1982). WUE can be influenced by soil management factors such as surface residue management, which decreases the moisture evaporation component allowing a greater percentage of moisture to be utilized by the crop (Viets, 1967). Water-use efficiency based on field data deals with the relationship of yield to ET because making independent measurement of E and T under field conditions over a growing season is virtually impossible.

Unfortunately, WUE just considers ET efficiency within a single crop, and it does not consider a whole cropping system (i.e., a number of crops growing in rotation or the periods between crop growth). There is a need to expand the definition of WUE to consider more than just the current crop. Pierce and Rice (1988) proposed an equation that combines seasonal WUE with recovery of precipitation falling in the intervening period. Pierce and Rice refer to WUE as physiological efficiency (biomass to water used). Physiological efficiency represents the ratio between plant productivity and water resources used in the growing season. Recovery efficiency is defined by Pierce and Rice as the ratio of water used (Wu) to water available (Wa). Recovery efficiency represents water used by the plant from all available water resources, which could include both over-winter precipitation and growing season precipitation. Recovery efficiency allows us to expand and include over-winter period or multiple growing seasons.

Water available (Wa) represents all water available to the plant during a defined period and could be calculated using mass balance principles. If water used is defined in terms of ET (or transpiration) then:

$$EWU = \frac{ET}{Wa} \times WUE \qquad (1)$$

The uniqueness of Pierce and Rice's work is in the EWU equation. The recovery efficiency portion of EWU can represent different periods of time, from months to years. This therefore, provides a method of quantifying the efficiency on an entire cropping system basis, including stored over-winter precipitation, rather than just considering one crop within a single growing season.

2.5 Bean and Sunflower Production

2.5.1 Bean (*Phaseolus vulgaris* L.)

The common bean is an annual legume cultured for its green pod and dry seed. Although it originated in the semi-tropical regions of Central America, frosts do occur in the higher elevations of its habitat and so it is adapted to a wide climatic zone (Halterlein, 1983). Commercial production of dry beans in Manitoba began in the mid-1960's with 40 hectares seeded and harvested in 1963. By 1981, the seeded area had increased to 7,800 hectares with further significant increases occurring in the mid-1990s. There are agronomic benefits to dry bean production as well as net returns, which are at least as good as wheat production (Manitoba Agriculture and Food, 2002). A record 93,120 hectares of dry beans were seeded and harvested in 2000, an increase of 25 percent from the previous record in 1999, when the seeded area was 68,825 hectares. Manitoba, the largest producer of dry beans in the country, produced 53 percent of the Canadian dry bean crop in 2000, up from 29.7 percent in 1999 (Manitoba Agriculture and Food, 2002). In the past five years an average of 20,240 hectares of field beans have been planted annually in Manitoba, with a trend to increasing acres in recent years (Manitoba Field Bean Production Guide, 1998).

Bean plants are very sensitive to soil water conditions; therefore, quality and yield can suffer greatly from even brief periods of water shortage (Halterlein, 1983). Because beans have a shallow root system they are sensitive to both excess soil water and standing water. Beans were found to be most sensitive to excess soil water during flower bud formation and at flowering (Peer and Kolvec, 1964). For example, heavy rains in southern Manitoba in 2001 and 2002 took a heavy toll on bean production.

Stegman and Olsen (1976) have observed that the root zone depth of bean advances to near 91.4 – 106.7 cm by the time of full ground cover (pre-flowering). Maximum root depth for adequately watered plants was found to be 81-102 cm. At all growth stages at least 50% of root were found to be in a zone bounded by a depth of 30 cm and lateral extension of 20 cm. Less than 10% of roots ever extended to a depth exceeding 46 cm (Stegman and Olsen, 1976).

Deep percolation of salts and nutrients from soil water drainage have been implicated as a leading cause of soil salinity and groundwater contamination (Beke et al., 1994). Due to dry bean's characteristic shallow rooting depth, its highly likely that deep percolation of water results in potential salinity problems when beans are grown in a high moisture environment, especially in poorly drained soils. A method of addressing this problem is by including a heavy-water use perennial forage crop such as tall fescue (Garwood and Sinclair, 1979) or alfalfa (Entz et al., 2001) to "de-water" the soil prior to bean production.

2.5.2 Sunflowers (*Helianthus annuus* L.)

Sunflower is one of the four major annual crops in the world grown for edible oil. In addition to the high quality of oil, sunflower is an important crop because of its adaptation to marginal land in many areas of the temperate zones of the world (Robinson and Everett, 1990).

Manitoba is the largest producer of sunflowers in Canada. In 2000, 62,750 hectares of sunflowers were planted and 58,700 hectares harvested to produce 102 million kilograms of seed, 22.8 percent above the 1999 crop. Manitoba produced 85.4 percent of the Canadian sunflower seed crop in 2000, down from a high of 96 percent in 1981 (Manitoba Agriculture and Food, 2002).

The ability of plant root systems to absorb soil water depends upon depth and intensity of root exploration. These two parameters vary with crop development and conditions of soil moisture. Root depth and soil texture, together establish the maximum soil water-holding capacity for a crop (Connor and Hall, 1997). Sunflower roots continue to grow up to physiological maturity (Jaafer et al., 1993), extracting water from deeper soil layers during seed filling. Deeper roots are considered more efficient in water extraction than shallow roots because they are younger, less crowded and are in a wetter soil profile (Taylor and Klepper, 1978). Sunflower's root system is "explorative" of large soil volumes with a combination of thick and thin roots, small average specific root length, and small root length density (Angadi and Entz, 2002b, Connor and Sadras, 1992). This combination of characteristics enables sunflower to extract more water than most other crops, especially from deep soil layers (Connor and Hall, 1997). Sunflower is exceptional in this regard because its roots explore soil to greater depths, commonly extending below 2 meters (Bremner et al., 1986; Sadras et al., 1989; Stone et al., 2001), more than most other annual crop species. Other studies (Lindstrom et al., 1982; Hattendorf et al., 1988; Stone et al., 2001) have shown water use by sunflower exceed that of other row crops by about 20 % when grown under relatively favourable soil water conditions. In a study by Stone et al. (2001) sunflower roots advanced downward from 0 to 60 days after emergence at a rate and depth 46 and 35 % greater, respectively, than that of sorghum (*Sorghum bicolor* L.). The faster advance rate and deeper depth of rooting aid sunflower in drought avoidance and use of water from deeper soil depths.

Due to the vast adaptability of sunflowers, benefits of root traits therefore depend on the local pattern of water availability. In southwestern Manitoba, sunflower is often included at the "end" of a rotation to scavenge water deep in the soil profile.

3.0 Materials and Methods

3.1 General

Field experiments were conducted to investigate the effect of single-year forage seed crops in a cropping system. A three-year crop rotation experiment was conducted at two locations in Manitoba, representing different agroclimatic conditions and soil types. The Winnipeg experiment was conducted at the Department of Plant Science Field Research Facility (49.8 °N, 97.2 °W). The soil at Winnipeg was a clay (Riverdale series, Entisol, cumulic Regosol) with gradual release of water and slow development of stress. The Carman trial was conducted at the University of Manitoba Carman Research Station (49.5 °N, 98.0 °W). The soil at Carman was a sandy clay loam (Denham and Eigenhof series, Ucid Boroll, Orthic Black Chernozem) with characteristic quick release of water and rapid development of stress.

The three-year crop rotation consisted of spring wheat in year 1, forage seed crops in year 2, with dry beans and sunflowers grown in year 3 (Table. 1). The trial was arranged as a randomized complete block design with four replications. The plot sizes were 24 m by 8 m in Winnipeg and 24 m by 10 m in Carman in year 1 and 2. In year 3, test crops (dry beans and sunflowers) were grown on plots 6 m by 8 m in Winnipeg and 6 m by 10 m in Carman. For a summary of field operations, at the Carman and Winnipeg sites, see appendix Tables A1 and A2, respectively.

Measurements included water use patterns, yield and dry matter production and visual effects of forages on the growth of beans and sunflowers.

Table 1. Three-year crop rotation (spring wheat - forage grass – beans/sunflowers) sequence at Carman and Winnipeg.

Year 1 –1999	Year 2 – 2000	Year 3 – 2001
Wheat (Tall fescue under-seeded in spring at Carman) (Tall fescue seeded in the fall at Winnipeg)	Tall Fescue	Dry Beans Sunflowers
Wheat (P. ryegrass seeded in fall)	Perennial Ryegrass	Beans Sunflowers
Wheat	Annual Ryegrass	Beans Sunflowers
Wheat	Barley (control)	Beans Sunflowers

3.2. Experimental Treatments and Field Management

3.2.1 Year 1

The four treatments for 1999 (Year 1) were: spring wheat alone; spring wheat under-seeded to tall fescue; and spring wheat with perennial ryegrass sown after harvest of the wheat. Initially both tall fescue and perennial ryegrass were under-seeded in the spring with the wheat. However, an in-crop application of Hoe Grass (diclofop-methyl), to which forages were thought to be tolerant, damaged both the tall fescue and perennial ryegrass at Winnipeg and the perennial ryegrass at Carman. Hence, tall fescue and perennial ryegrass at Winnipeg and perennial ryegrass at Carman had to be re-seeded in the fall after wheat harvest. The tall fescue under-seeded at Carman was able to survive and reseeding was not necessary.

All seeding was conducted using a Fabro small plot double disc drill (Swift Manufacturing Co., Swift Current, SK.). Wheat was sown on June 3, 1999 at Winnipeg and May 27, 1999 at Carman at a depth of 5 cm. In plots where no forages were underseeded, spring wheat was sown at 135 kg ha^{-1}. Wheat plots that were under-seeded to grasses were sown at a rate of 80 kg ha^{-1}. Tall fescue (common forage seed) was under-seeded at a rate of 15 kg/ha immediately after wheat seeding at both sites using the same plot drill equipped with depth bands. Tall fescue at Winnipeg was reseeded on August 11, 1999 once wheat was removed for greenfeed. Perennial ryegrass (cv. Bastion) was reseeded on August 11 at Winnipeg and August 10 at Carman, at a rate of 15 kg/ha after the spring wheat crop was harvested for greenfeed. Row spacing and seeding depth for all grass treatments was 15 cm and 2.5 cm, respectively.

The remaining wheat plots were combine harvested on September 22, 1999 at Winnipeg and August 27, 1999 at Carman. Remaining straw was harrowed off of the plots.

3.2.2 Year 2

The four treatments for 2000 (Year 2) were: annual ryegrass, perennial ryegrass, tall fescue and barley. Annual ryegrass and barley were seeded using a Fabro small plot double disc drill (Swift Manufacturing Co., Swift Current, SK.). Annual ryegrass (cv. Barspectra) was sown at a rate of 15 kg ha^{-1} at a depth of 2.5 cm on April 27, 2000 in Carman, and April 28, 2000 in Winnipeg. Barley (cv. CDC Thompson) was sown at a rate of 120 kg ha^{-1} on May 16, 2000 in Carman and May 22, 2000 in Winnipeg. Row spacing for all treatments was 15 cm. Fertilizer was spread using a Valmar spreader at a rate of 91 kg ha^{-1} of ammonium nitrate (34-0-0) at Carman and 93 kg ha^{-1} of ammonium nitrate (34-0-0) at Winnipeg. Phosphorous (11-52-0) was placed with the seed at a rate of 20 kg ha^{-1} $P_2 0_5$.

All forage grasses and barley were successfully established at both Winnipeg and Carman. The annual ryegrass at both locations started off weak but began growing rapidly as time. The perennial ryegrass and tall fescue on the June 2 measurement displayed abundant growth in the spring indicating good stand establishment at both Winnipeg and Carman.

Tall fescue was harvested for seed by hand on July 24, 2000. Biomass remaining was removed by swathing and baling remains at Carman, and by using the Haldrop model 6800 forage harvester at Winnipeg. Forage was cut to a stubble height of 5 cm. Perennial ryegrass, annual ryegrass and barley was harvested for seed on August 14 and 15, 2000, in Carman and Winnipeg, respectively. Remaining biomass was removed in Carman on August 14, 2000 using the swathing and baling method. Remaining biomass was removed from Winnipeg on August 16, 2000 using the Haldrop forage harvester.

Biomass was removed from each forage crop after seed harvest had taken place in order to monitor post-harvest forage plant re-growth.

The experimental area in Carman was sprayed with glyphosate at a rate of 5 L ha^{-1} on October 1, 2000 in order to terminate forages and to control weeds in barley stubble. Forage was given a chance to dry down and it was then swathed, baled and bales were removed on October 10, 2000. On October 11, 2000, the entire experimental area was disced 3 times with a tandem disc in a manner that would prevent mixing of soil from the various treatments.

The experimental area in Winnipeg was sprayed with glyphosate at a rate of 5 L ha^{-1} on September 30, 2000 in order to terminate forages and control weeds in barley stubble. Forage was given a chance to dry down and was then removed using the Haldrop 6800 forage harvester on October 4, 2000. After removing the forage, the entire experimental area was disced 3 times with a disc in a manner that would prevent mixing of soil from the various treatments.

3.2.3. Year 3

In 2001 (Year 3), the four forage treatments (annual ryegrass, perennial ryegrass, tall fescue, and barley) were subdivided and two different test crops were grown: dry beans, and sunflowers, creating a split-plot randomized complete block design with four replications. Each forage treatment at both locations was soil tested separately to determine nutrient levels. Refer to Appendix Table A4 and A5 for the initial spring nutrient status. All plots at Winnipeg were fertilized with a Valmar broadcaster at a rate of 60 kg N ha^{-1} in the form of ammonium nitrate (34-0-0) on July 5, 2002. An additional 19 kg N ha^{-1} and 23 kg S ha^{-1} was applied in the form of ammonium sulphate (20-0-0-24) on the same day. At Carman all plots were fertilized with a Valmar broadcaster at a rate of 30 kg of actual N ha^{-1}, 47 kg of P_20_5 ha^{-1}, 28 kg of K_20 ha^{-1} and 24 lbs of actual S ha^{-1}, which was incorporated with spring tillage on May 25, 2001. On June 19 an additional 26 kg of actual N ha^{-1} was broadcast on all plots at Carman in the form of ammonium nitrate (34-0-0).

An application of Edge (ethalfuralin) herbicide was applied with a Valmar broadcaster at a rate of 17.1 kg ha^{-1}. The granular herbicide was incorporated with a tandem disc on May 30, 2001 at Winnipeg and with a cultivator on May 25 at Carman. The dry beans and sunflowers were seeded using a Fabro small plot double disc drill. Dry beans (cv. AC Thunder) were seeded at a rate of 80.7 kg ha^{-1} to a depth of 4 cm on May 30, 2001 and June 4, 2001 in Carman and Winnipeg, respectively. Sunflowers (cv. IS-6111) were seeded at a rate of 12.7 kg ha^{-1} to a depth of 4 cm on May 30, 2001 and June 4, 2001 in Carman and Winnipeg, respectively. Sunflowers were seeded at a higher rate than recommended due to difficulty in obtaining such a low seeding rate using a commercial seed distribution box on the seeder. Sunflower plants were thinned, after emergence and plant stand counts, to a population of 59,303 plants ha^{-1}. Sunflowers were sprayed with Cymbush (cypermethrin) at the recommended rate for sunflower beetles at Winnipeg on July 22. Sunflowers at Carman were sprayed on June 21 with Decis (deltamethrin) at the recommended rate for sunflower beetle control.

Both beans and sunflowers were harvested on September 24, 2001 at both Carman and Winnipeg. Sunflowers were harvested by hand. Beans were harvested on September 26, 2001 with a Kincaid Massey Ferguson straight-cut plot combine.

3.3 Environmental Monitoring

Weather conditions at both Winnipeg and Carman were monitored for the three-year duration of the crop rotation study. Meterological stations located less than 500 m away from the research plots were the source of data collection. Average monthly rainfall and temperature were recorded for the 2000 and 2001 growing seasons (May to September). Monthly precipitation was recorded starting at the beginning of the 2000 growing season to the end of the 2001 growing season for Winnipeg and Carman and it included over-winter precipitation.

3.4 Agronomic Measurements

3.3.1 Year 1

Yield was the only agronomic measurement taken in Year 1, and crop was harvested using a small plot combine.

3.3.2 Year 2

Volumetric soil water content between 10 and 170 cm (150 cm at Carman) was determined in 20-cm increments using a field calibrated neutron moisture gauge (Troxler Model 4330, Research Triangle Park, NC). One aluminum neutron access tube was positioned in each plot. Soil water between 0 and 10 cm was determined gravimetrically by extracting two known diameter soil cores from each plot. Volumetric water content was determined by taking the bulk density at each site and using it to convert from a gravimetric basis to a volumetric basis. After all the plots are cut and forages were removed (post harvest) soil water in the top 10 cm was determined by using a neutron moisture gauge with a surface shield as illustrated by Chanasyk and Naeth (1988). Water measurements were taken every two to three weeks throughout the entire growing season (refer to Table A1 and A2 in the Appendix for dates samples were taken).

Field capacity at Winnipeg was assumed to be the highest volumetric water content measured in the field trials as outlined by Entz (1988). It was felt that Carman never had saturated soil to determine field capacity as there was not as much precipitation in Carman as there was in Winnipeg.

Dry matter samples were taken approximately at the same time as soil water measurements (in two to three week intervals). This was accomplished by taking two 1-m lengths of row randomly within the plot. Samples were oven dried at a temperature of 65° for a period of 72 hours. Samples were weighed using an electronic scale. Dry matter samples were taken to determine re-growth of the crops until such a time that they were terminated.

Seed yield of the plots was established by manually cutting four 0.5 m^2 of seed heads from each plot at time of ripeness. Seed heads were then put in cloth bags and kept in an aerated room until they were threshed using a stationary threshing machine.

Evapotranspiration was also calculated by determining water in the 0 – 150 cm soil profile at the beginning of the growing season (spring) based on neutron probe measurements. The initial water content (spring) was subtracted from the amount of water measured in the soil profile at the end of the growing season (fall). This value represented the water used from the soil profile by the plants from seeding to harvest. Accumulated precipitation during the growing season was added to the water used from the soil profile during the growing season to determine the ET for each forage crop. The formula for ET is:

$$\text{ET} = [\text{Initial water (mm)} - \text{End water (mm)}] + \text{Rainfall (mm)} \qquad (1)$$

Water Use Efficiency (WUE) was determined for seed production and dry matter (at harvest) production for all four treatments. Water use efficiency was determined by dividing the kg ha^{-1} of harvested material (seed or dry matter) by the amount of ET (mm). The formula for WUE is:

$$\text{WUE} = \frac{\text{Yield (kg ha}^{-1}\text{)}}{\text{ET (mm)}} \qquad (2)$$

It is important to note that ET and WUE measurements were calculated under the assumption that there were no losses to water-run off or leaching. At Carman these assumptions held. Due to excessive rainfall and probable water run-off and leaching, data from the Winnipeg site was not used for the ET and WUE calculations.

3.3.3 Year 3

Soil tests were conducted in the spring of year three prior to seeding at both Winnipeg and Carman. Separate samples were taken from each forage plot with reps being grouped. Bulked samples for each forage treatment were sent to Norwest Labs for analysis. Results gave an indication of residual nutrient levels after forage grass production (Tables A4 and A5).

Volumetric soil water content was determined at both sites using the neutron moisture gauge measures were made at increments of 20-cm depths from depths of 10 to 150 cm at both sites. An aluminium access tube was newly installed in each subplot of beans and sunflower that were grown after the three forages and the barley grain treatments. Tubes were positioned within the row of the bean and sunflower crops to have a better representation of plant root activity. Volumetric soil water at 0-10 cm was measured using a neutron moisture gauge with a surface shield, as illustrated by Chanasyk and Naeth (1988). Measurements were taken four times during the growing season; emergence, flowering, grain filling and harvest.

Plant density counts were taken after emergence of the two crops. Two 1-meter lengths of row were counted in each sunflower and bean plot and were then adjusted to plants m^{-2}. Plant stand counts were done on June 22, 2001 and July 13, 2001 in Carman and Winnipeg, respectively. After plant stand counts were completed, sunflowers were hand-thinned to a population of 59,303 plants ha^{-1} (24,000 plants $acre^{-1}$).

Plant development staging for sunflowers was done using methods described by Schneiter and Miller (1981) on July 12, 2001 and July 13, 2001 at Winnipeg and Carman, respectively. Bean plant development was rated according to the Compendium of Bean Diseases (Hall, 1991) and was measured on July 12, 2001 and July 13, 2001 at Winnipeg and Carman, respectively.

Dry matter samples were taken at grain filling and at harvest. Dry matter samples of both sunflower and beans were taken on August 15 and September 24 at both locations. Sampling involved taking two 1-meter lengths of row. Samples were then dried for 72 hours at 65 °C in drying ovens. Samples were subsequently weighed on an electronic scale to determine dry matter weight per area.

Both beans and sunflowers were harvested on September 24, 2001 at both Carman and Winnipeg. Sunflowers were harvested by taking random 10, 1-meter lengths of row in each plot. Heads were dried down in a drying room and run through a combine to thresh seeds from the head at a later date. Beans were harvested with a straight-cut plot combine. The area harvested (26 m^2) with the combine was measured so yield could be determined.

ET was determined for seed production and dry matter production for the sunflower and dry bean test crops following the four forage treatments. ET was determined separately for sunflowers and dry beans.

Rotational Efficient Water Use was also determined for the forage and bean/sunflower years combined. The forage-sunflower and forage-bean systems were calculated and analyzed separately. Calculations were based on the total dry matter (at harvest) production of the forage and sunflower (or bean) crops and water use (ET) of the forage and sunflower (or bean) crops over the two growing seasons including overwinter precipitation. Yield data was obtained from dry matter production rather than seed production because of below average seed yields in the year of the forage crops. The formula used for Rotation Efficient Water Use (Pierce and Rice, 1988) was:

$$\text{EWU}\ \frac{(\text{Kg ha}^{-1})}{(\text{mm})} = \frac{\text{Wu (mm)}}{\text{Wa (mm)}} \times \frac{\text{Y (Kg ha}^{-1})}{\text{Wu (mm)}} \qquad (3)$$

Efficient water use is the product of the recovery efficiency [ratio of water used (Wu) to water available (Wa)] and physiological efficiency [ratio of yield (Y) to water used (Wu)].

3.4 Statistical Analysis

Water data and dry matter production for year two (2000) from both Carman and Winnipeg were analyzed as randomized complete block design (RCBD) experiments, using analysis of variance (ANOVA) procedures on the Statistical Analysis Systems

(SAS) software package (SAS Institute Inc., Cary, NC, USA) version 8.2 for Windows. Means were compared using the Fisher's Least Significant Difference (LSD) test at the $p < 0.05$ level. Homogeneity of variances were tested on the dry matter data using Bartlett's test and log transformation of data was performed in accordance with the results of the Bartlett's test. Data is presented as actual values in the results and discussion section. It has been indicated where log transformation of data was performed. Log transformed data including least significant difference (LSD) values are presented in Table A3.

Water use data, dry matter production, and yield data collected from 2001 (year 3) were analyzed separately for sunflowers and dry beans. Therefore, the sunflowers were analyzed as a randomized complete block design RCBD experiment and the beans as a separate RCBD experiment. Both experiments were analyzed using ANOVA procedures on the SAS software package (SAS Institute, 1986). Means were compared using Fisher's Least Significant Difference (LSD) test at the $p < 0.05$ level. Yield and dry matter production data were tested for homogeneity of variances using a Bartlett's test. All data tested positive for homogeneity of variances and therefore, log transformation was not necessary.

Due to limited data collected in 1999, there was no statistical analysis procedures performed.

4.0 Results and Discussion

4.1 Environmental Conditions

Winnipeg

In 1999 and 2000, the mean air temperature was within 1° C of the long-term average at Winnipeg, while the 2001 mean air temperature was almost 2 ° C above the long-term average (Table 2). Precipitation in 1999 was close to the long-term average, however, precipitation in 2000 and 2001 was well above the long-term average for the months of May to September. Precipitation in 2000 was the highest; almost double the long-term average, while precipitation in 2001 was over 100 mm more than the long-term average.

Carman

From 1999 to 2001, mean air temperature at Carman was within 1° C of the long-term average (Table 3). Total precipitation in 1999 was just over 30 mm higher than the long-term average, while total precipitation in 2000 and 2001 was slightly lower than the long-term average.

4.2 Year 1 – 1999

4.2.1 Wheat Yield

The remaining wheat that was not underseeded or reseeded to forage grasses was harvested in the fall of 1999. Although the wheat yield was not measured, it was estimated to be an average crop of 3000 kg ha^{-1}.

Table 2. Monthly air temperatures and precipitation at Winnipeg, Manitoba in 1999, 2000, and 2001, and the 30-year average (1961-1990)*.

	Temperature (°C)					Precipitation (mm)			
	1999	2000	2001	30-yr Avg.		1999	2000	2001	30-yr Avg.
May	13.0	12.9	13.6	11.6		107.7	72.1	115.3	59.8
June	17.3	15.6	17.5	16.9		98.8	259.6	97.6	83.8
July	20.7	20.9	20.8	19.8		77.0	101.6	184.9	72.0
August	19.3	19.8	20.9	18.3		37.6	109.7	35.6	75.3
September	12.3	12.5	14.6	12.4		62.2	62.0	13.2	51.3
Average	16.5	16.3	17.5	15.8	Total	383.3	605.0	446.6	342.2

* (Weather Station at the Winnipeg International Airport) Environment Canada Atmospheric Environment Service, Winnipeg, Manitoba. R3C 3V4.

Table 3. Monthly air temperatures and precipitation at Carman, Manitoba in 1999, 2000, and 2001, and the 30-year average (1961-1990)*.

	Temperature (°C)					Precipitation (mm)			
	1999	2000	2001	30-yr Avg.		1999	2000	2001	30-yr Avg.
May	11.8	11.5	12.8	11.6		142.0	55.0	52.6	54.0
June	16.0	14.6	16.2	17.1		74.0	93.6	41.2	75.0
July	18.8	18.9	19.8	19.8		83.2	46.8	192.5	77.0
August	18.1	18.7	19.5	18.4		31.0	86.0	22.2	66.0
September	11.3	11.8	13.4	12.5		36.6	40.0	13.6	49.0
Average	15.2	15.1	16.3	15.9	Total	366.8	321.4	322.1	334.0

*Environment Canada Atmospheric Environment Service, Winnipeg, Manitoba. R3C 3V4

4.3 Year 2 – 2000

4.3.1 Dry Matter Production

4.3.1.1 Dry Matter Accumulation

Dry matter production was monitored at regular intervals during the forage production year to determine growth characteristics of the three forage species. Results from dry matter accumulation monitoring during the 2000 growing season indicated unique patterns between the forage grasses (Table 4). Perennial ryegrass and tall fescue had significantly more dry matter accumulation at the beginning of the growing season than annual ryegrass at both Winnipeg and Carman, because they are both perennial crops that start growing early in the season.

Winnipeg

Perennial grasses (tall fescue and perennial ryegrass) produced significantly more dry matter than annual ryegrass and barley up until the July 10, 2000 sampling date. On the July 24, 2000, sampling date, the DM production of annual ryegrass was no longer significantly less than that of tall fescue. However, the perennial ryegrass DM production still remained significantly higher than that of annual ryegrass and barley. The fact that annual ryegrass had the ability to "catch up" to some of the perennial forages (tall fescue) by the middle of the growing season, re-affirms that annual ryegrass has the capability to fit into an annual grazing system where large amounts of forage are needed in a short period of time (McCartney, 2000).

Carman

Forage grasses at Carman had similar growth patterns to Winnipeg with perennial forages (perennial ryegrass and tall fescue) having significantly more dry matter accumulation than the annual crops (annual ryegrass and barely) for the first three sampling dates (Table 4). One difference was on the July 10 sampling date, barley was no longer significantly different from tall fescue leaving only annual ryegrass produces significantly less dry matter than the perennial forages. The opposite trend occurred in Winnipeg, where barley and annual ryegrass had similar growth patterns. This observation may indicate that there was a better barley crop establishment at Carman than at Winnipeg. By the July 24, 2000, sampling date all forage seed crops and barley had similar dry matter yield.

4.3.1.2 Late-season/post-harvest dry matter production

Samples taken on September 26 represent the dry matter re-growth post-harvest for both Winnipeg and Carman. Annual ryegrass proved to have significantly more dry matter production than perennial ryegrass and barley at the Winnipeg site (Table 4). Although annual ryegrass had more dry matter than tall fescue it was only significantly different from the perennial ryegrass and barley. The ability of annual ryegrass to accumulate over 3000 kg ha^{-1} of dry matter forage after seed harvest makes it an excellent candidate for late-season grazing for livestock. This supports previous findings by McCartney (2000) who explored the potential of grazing annual ryegrass for backgrounding beef calves at the Agriculture and Agri-Food Canada Research Station in Lacombe, Alberta.

Table 4. Dry matter production of forage crops (kg ha^{-1}) at Carman and Winnipeg, 2000. Statistical analysis on Carman June 8, Winnipeg June 2, and Winnipeg June 8 was performed on log-transformed data. Within sampling date means with the same letter are not significantly different LSD ($p<0.05$)

	June 2	June 8	June 28	July 10	July 24	Aug 9	Sept 7	Sept 26
				Carman				
				Kg ha^{-1}				
Annual Ryegrass	103.4 c	404.9 c	2082.6 b	4410.0 c	7490.0 a	7910.8 a	2302.2 a	3755.4 a
Perennial Ryegrass	1260.5 b	1701.3 b	5245.4 a	9012.0 a	7319.0 a	7200.3 a	1511.1 a	3172.4 a
Tall Fescue	2832.2 a	3566.0 a	5160.1 a	8120.0 ab	8716.0 a	1557.0 b	1705.4 a	2955.1 a
Barley	248.4 c	470.5 c	2909.2 b	5648.0 bc	9724.0 a	7920.2 a	0 b	0 b
LSD	*695.9*	*1002.7*	*899.9*	*2906.2*	*2292.8*	*1281.0*	*1321.5*	*948.0*
p - value	*<0.0001*	*<0.0001*	*<0.0001*	*0.0199*	*0.1276*	*<0.0001*	*0.0193*	*<0.0001*
				Winnipeg				
				Kg ha^{-1}				
Annual Ryegrass	190.7 b	858.4 b	3147.0 b	5976.8 b	9740.0 b	7901.4 a	2289.3 a	3218.3 a
Perennial Ryegrass	2295.3 a	4860.8 a	7369.2 a	9535.6 a	14111.0 a	4431.9 b	944.5 bc	2035.1 b
Tall Fescue	2941.9 a	5499.6 a	7421.7 a	10845.2 a	12110.0 ab	1300.4 c	1744.0 ab	2544.3 ab
Barley	29.8 c	299.1 c	1671.8 c	4286.8 b	5628.0 c	7920.2 a	0 c	0 c
LSD	*835.88*	*1049.5*	*1391.9*	*1890.2*	*3321.3*	*2129.0*	*1229.1*	*1161.4*
p - value	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*0.0015*	*0.0002*	*0.0112*	*0.0008*

At Carman, no significant differences between the three forage seed crops for post-harvest forage accumulation were observed. The barley as expected produced no dry matter after harvest. The components that make up the farm must not only be diverse, but also complimentary (Jackson, 1984). Dry matter produced by tall fescue, perennial ryegrass and annual ryegrass are complimentary to a mixed livestock farm operation because they provide grazing in the fall.

Grazing forage aftermath may have different rotational effects than if the forage were cut and baled. Some positive implications of grazing the forage seed residue include nutrient cycling and value-adding to the forage system. However, there are some negative implications that can result from grazing. For example one study indicated bulk density increased more rapidly with increasing cumulative cow-days for annual forages compared to perennial forages (Twerdoff et al., 1991a). In this study, the perennial forages in this system are treated like an annual crop and as a result grazing could have a negative effect on the bulk density of the soil.

4.3.2 Forage Seed Yield

Winnipeg

Forage seed yield varied between species. As expected, barley had the highest yield followed by annual ryegrass, perennial ryegrass and finally tall fescue (Table 5). Yields obtained from the forage grass species in this experiment were below the averages traditionally seen for these crops. For example, according to the Manitoba Forage and Grass Seed Production Guide (1997), perennial ryegrass and annual ryegrass average seed yields are between 600 to 800 kg ha^{-1}, and tall fescue around 500 kg ha^{-1}. Yield results from Winnipeg were about 200 kg ha^{-1}, 475 kg ha^{-1} and 385 kg ha^{-1} less than the provincial average for annual ryegrass, perennial ryegrass and tall fescue, respectively. The lower yields could be attributed to harvesting techniques and severe shattering losses. However, it is interesting to note that annual ryegrass, an annual crop, had much higher yields that came closer to the provincial average compared to the perennial crops; perennial ryegrass and tall fescue. Ease of establishment, high yield and minimal management requirements are noted characteristics of annual ryegrass (Foster et al., 1996), which could explain its higher yield.

Carman

The soil at Carman is a sandy-clay loam with higher hydraulic conductivity and quick release of water, while Winnipeg is a clay with lower hydraulic conductivity and slow release of water, which may explain why there were clearer water extraction at Carman versus Winnipeg.

Results for seed yield at Carman were similar to trends at Winnipeg, with barley having the highest yield followed by annual ryegrass, perennial ryegrass and tall fescue the lowest (Table 5). Yield results from Carman were about 250 kg ha^{-1}, 445 kg ha^{-1} and 400 kg ha^{-1} less than the provincial average for annual ryegrass, perennial ryegrass and tall fescue, respectively. Once again, annual ryegrass had yield values much closer to the industry average compared to perennial ryegrass and tall fescue.

Table 5. Seed yield of forage grass seed crops and barley (kg ha^{-1}) at Carman and Winnipeg, 2000.

	Carman	***Winnipeg***
	Yield (kg ha^{-1})	
Annual Ryegrass	400.4	451.9
Perennial Ryegrass	209.6	174.9
Tall Fescue	95.6	116.4
Barley	2141.1	1871.0

4.3.3 Crop Water Use

Water use activity was measured by taking neutron probe measurements in 20-cm soil depth increments. Results for volumetric water content at Carman and Winnipeg are given in Figures 2 and 3, respectively. For the purpose of comparison, calculations of mm of water in the soil profile were grouped into four soil depth increments: 0 – 30 cm; 30 – 90 cm; 90 – 170 cm; and 0- 170 cm at Winnipeg. Carman soil profiles were grouped into: 0 – 30 cm; 30 – 90 cm; 90 – 150 cm; and 0 – 150 cm. Results for the grouped profiles for Carman and Winnipeg are given in Tables 6 and 7, respectively.

4.3.3.1 Soil Water Content

Winnipeg

Precipitation for the 2000 growing season at Winnipeg was nearly double that of the long-term average indicating excessively wet conditions (Table 2). The abnormally high amount of rainfall may have eliminated possible differences in volumetric water content between different grass treatments. However, differences were observed in the 0 – 30 cm soil depth for the first three sampling dates, May 26, June 9 and June 28 (Table 6). Tall fescue plots had considerable less water than both annual ryegrass and barley plots, while perennial ryegrass plots has significantly less water than the annual ryegrass plots. Perennials begin to dewater soil as soon as growth begins in the spring (April), whereas annuals only begin to reduce soil-available water when ground cover has been achieved (mid-June) (Twerdorff et al., 1999a). As expected the perennial grasses

Table 6. Soil moisture content (mm) of the soil profile at 0-30 cm, 30-90 cm, 90-170 cm and 0-170 cm depth intervals of annual ryegrass, perennial ryegrass, tall fescue and barley crops at Winnipeg, 2000. Means with the same letter are not significantly different LSD (p<0.05).

	0 – 30 cm	30-90 cm	90-170 cm	0-170 cm
May 26				
Annual Ryegrass	120 a	264 a	359 a	743 a
Perennial Ryegrass	104 bc	265 a	366 a	737 a
Tall Fescue	102 c	260 a	358 a	721 a
Barley	113 ab	257 a	356 a	729 a
LSD	*10.74*	*6.67*	*12.89*	*18.13*
June 9				
Annual Ryegrass	118 a	263 a	358 a	739 a
Perennial Ryegrass	95 b	256 a	353 a	704 b
Tall Fescue	87 b	245 b	356 a	690 b
Barley	116 a	259 a	359 a	735 a
LSD	*11.53*	*10.29*	*12.08*	*22.87*
June 28				
Annual Ryegrass	140 b	270 a	362 a	772 a
Perennial Ryegrass	143 a	273 a	365 a	782 a
Tall Fescue	137 c	274 a	364 a	776 a
Barley	144 a	273 a	366 a	784 a
LSD	*3.16*	*7.50*	*7.13*	*11.53*
July 14				
Annual Ryegrass	135 a	271 a	362 a	769 a
Perennial Ryegrass	139 a	271 a	362 a	773 a
Tall Fescue	137 a	269 a	366 a	773 a
Barley	139 a	271 a	363 a	774 a
LSD	*4.06*	*5.93*	*6.66*	*12.93*
July 31				
Annual Ryegrass	107 a	265 a	366 a	738 a
Perennial Ryegrass	105 a	264 a	369 a	739 a
Tall Fescue	105 a	267 a	371 a	744 a
Barley	107 a	267 a	368 a	743 a
LSD	*12.94*	*10.37*	*5.07*	*22.16*
August 14				
Annual Ryegrass	105 a	254 a	361 a	721 a
Perennial Ryegrass	106 a	254 a	360 a	721 a
Tall Fescue	110 a	259 a	364 a	734 a
Barley	117 a	262 a	362 a	742 a
LSD	*14.21*	*16.41*	*8.19*	*26.90*
September 8				
Annual Ryegrass	136 a	274 a	370 a	782 a
Perennial Ryegrass	135 a	274 a	372 a	782 a
Tall Fescue	135 a	274 a	369 a	778 a
Barley	132 a	274 a	369 a	777 a
LSD	*9.12*	*7.70*	*9.04*	*20.24*
September 25				
Annual Ryegrass	114 a	267 a	367 a	749 a
Perennial Ryegrass	112 a	269 a	367 a	749 a
Tall Fescue	112 a	268 a	367 a	748 a
Barley	115 a	269 a	365 a	751 a
LSD	*7.81*	*6.10*	*8.00*	*16.42*

(perennial ryegrass and tall fescue), used significantly more water from the soil profile than the annual ryegrass and barley, which were the annual spring planted crops. This trend continued on to the June 9th sampling date with perennial ryegrass and tall fescue plots having drier profiles that the annual plots. On the June 28 sampling date, tall fescue plots had less water in the 0 – 30 cm soil depth than all other grass plots indicating more water use by the tall fescue. Greater water use may be due to greater early season dry matter accumulation for tall fescue compared with other forage crops at Winnipeg (Table 4).

No other differences in soil moisture were observed between forages at any point during the growing season. This lack of difference was attributed to high rainfall amounts that kept the soil saturated throughout the entire growing season. Soil water content patterns in Figure 2 clearly demonstrate the effect of the high rainfall on water use between the annual ryegrass, perennial ryegrass, tall fescue and barley treatments. A line, which is assumed to be field capacity, is shown in the June volumetric water content diagram for Winnipeg (Figure 2). There was little deviation from the field capacity line drawn in June and the other months indicating the soil was close to field capacity throughout most of the growing season regardless of treatment.

Carman

Unlike Winnipeg, precipitation at the Carman site was close to the long-term average for the growing-season (Table 3). As a result more soil water content differences were observed between treatments (Table 7). Results for the first sampling date (May 25) showed no difference in the amount of water between any of the four grass soil profiles.

This could indicate a slower start by the perennial grasses at Carman compared to the Winnipeg location, which already had significant differences in DM accumulation between the perennial grasses (tall fescue and perennial ryegrass) and the annual grasses (annual ryegrass and barley) at that point in time (Table 4). This indicates that ET is very much a function of transpirational leaf area.

By the June 9th sampling date, tall fescue had already used much more water than perennial ryegrass, annual ryegrass and barley, as indicated by the significantly lower amount of water present (Table 7). Again, this supports findings by Twerdoff et al., (1999a) that perennials begin to dewater soil as soon as growth begins in the spring. As in Winnipeg, tall fescue had accumulated more dry matter than perennial ryegrass, annual ryegrass and barely, which would explain why more water is being used from the tall fescue soil profile compared to the other three grasses (Figure 3). No differences in soil water between forages were observed in the 0 – 30 cm zone for the June 28th sampling date likely attributed to rainfall two days before the sampling date (Figure 7). However, on that same sampling date, tall fescue plots had significantly less water in the 90 – 150 cm depth than the other forage plots; this trend carried into the July 10th measurement date. This observation suggests that tall fescue roots were active in the 90 – 150 cm zone at that point in time. This supports findings by Garwood and Sinclair (1979) that proved tall fescue had an effective rooting depth of > 100 cm. There were also differences in the 0 – 30 cm zone for the July 10 measurement indicating that annual ryegrass used the most water, followed by tall fescue. Annual ryegrass likely had the driest profile in the 0 – 30 increment as a reflection of the rapid growth that had occurred in annual ryegrass that allowed for the "catch-up" effect to occur by the end of July (Table 4).

The rest of July and August showed no significant differences in the amount of water present in the various profiles. This may be partly explained by the fact that tall fescue was harvested at the end of July while the remaining forages were not harvested until the middle of August. Forage harvest removed all biomass, which would limit the plant's water use capacity. As re-growth occurred into September, there were once again detectable differences in volumetric water content. The readings on both September dates show that all three forage grass crops dried out the upper half of the soil profile compared to the barley, which had no re-growth. The September 26 water data (Table 7) illustrates that the grasses were still actively growing and transpiring late into the growing season indicated by the drier soil profile compared to the barley plot.

Although it was not always significant, there was a trend to lower volumetric water contents between 0 and 150 cm for tall fescue treatments compared to the other forage treatments (Figure 3). Previous finding indicate that tall fescue has outstanding water and rooting depth capacity compared to other forage grasses (Garwood and Sinclair, 1979). The water use patterns in the present study re-affirm tall fescue's ability to use more water and reach deeper rooting depths than other forage grasses.

Table 7. Soil moisture content (mm) of the soil profile at 0-30 cm, 30-90 cm, 90-150 cm and 0-150 cm depth intervals of annual ryegrass, perennial ryegrass, tall fescue and barley crops at Carman, 2000. Within soil depth increments means with the same letter are not significantly different LSD ($p<0.05$).

	0 – 30 cm	30-90 cm	90-150 cm	0-150 cm
May 25				
Annual Ryegrass	68 a	148 a	232 a	449 a
Perennial Ryegrass	70 a	160 a	245 a	476 a
Tall Fescue	64 a	122 a	213 a	400 a
Barley	70 a	146 a	225 a	443 a
LSD	*8.42*	*40.81*	*46.07*	*71.20*
June 9				
Annual Ryegrass	56 a	143 a	220 a	420 a
Perennial Ryegrass	49 a	143 a	233 a	426 a
Tall Fescue	36 b	106 a	182 a	325 b
Barley	52 a	138 a	215 a	406 a
LSD	*10.78*	*34.23*	*46.85*	*75.1*
June 28				
Annual Ryegrass	65 a	162 a	241 a	469 a
Perennial Ryegrass	79 a	170 a	260 a	510 a
Tall Fescue	67 a	122 a	190 b	380 b
Barley	72 a	163 a	240 a	476 a
LSD	*15.34*	*41.41*	*43.59*	*65.67*
July 10				
Annual Ryegrass	59 c	146 a	233 a	440 a
Perennial Ryegrass	70 a	151 a	244 a	466 a
Tall Fescue	60 bc	113 a	187 b	361 b
Barley	69 ab	138 a	227 a	435.a
LSD	*9.22*	*34.17*	*32.85*	*65.00*
July 24				
Annual Ryegrass	50 a	127 a	230 a	408 a
Perennial Ryegrass	52 a	134 a	232 a	419 a
Tall Fescue	45 a	98 a	182 a	326 a
Barley	54 a	125 a	214 a	394 a
LSD	*10.92*	*38.60*	*44.66*	*80.55*
August 12				
Annual Ryegrass	74 a	120 a	224 a	420 a
Perennial Ryegrass	84 a	129 a	223 a	437 a
Tall Fescue	81 a	104 a	173 a	359 a
Barley	85 a	150 a	211 a	447 a
LSD	*11.56*	*33.57*	*55.57*	*83.68*
September 7				
Annual Ryegrass	82 a	108 b	219 a	411 a
Perennial Ryegrass	88 a	121 b	211 a	421 a
Tall Fescue	89 a	92 b	165 a	347 a
Barley	87 a	154 a	210 a	453 a
LSD	*11.28*	*29.68*	*63.00*	*83.36*
September 26				
Annual Ryegrass	49 b	108 a	223 a	381 a
Perennial Ryegrass	54 b	114 a	213 a	382 a
Tall Fescue	47 b	86 a	169 a	303 a
Barley	71 a	141 a	216 a	428 a
LSD	*13.80*	*37.45*	*57.83*	*90.59*

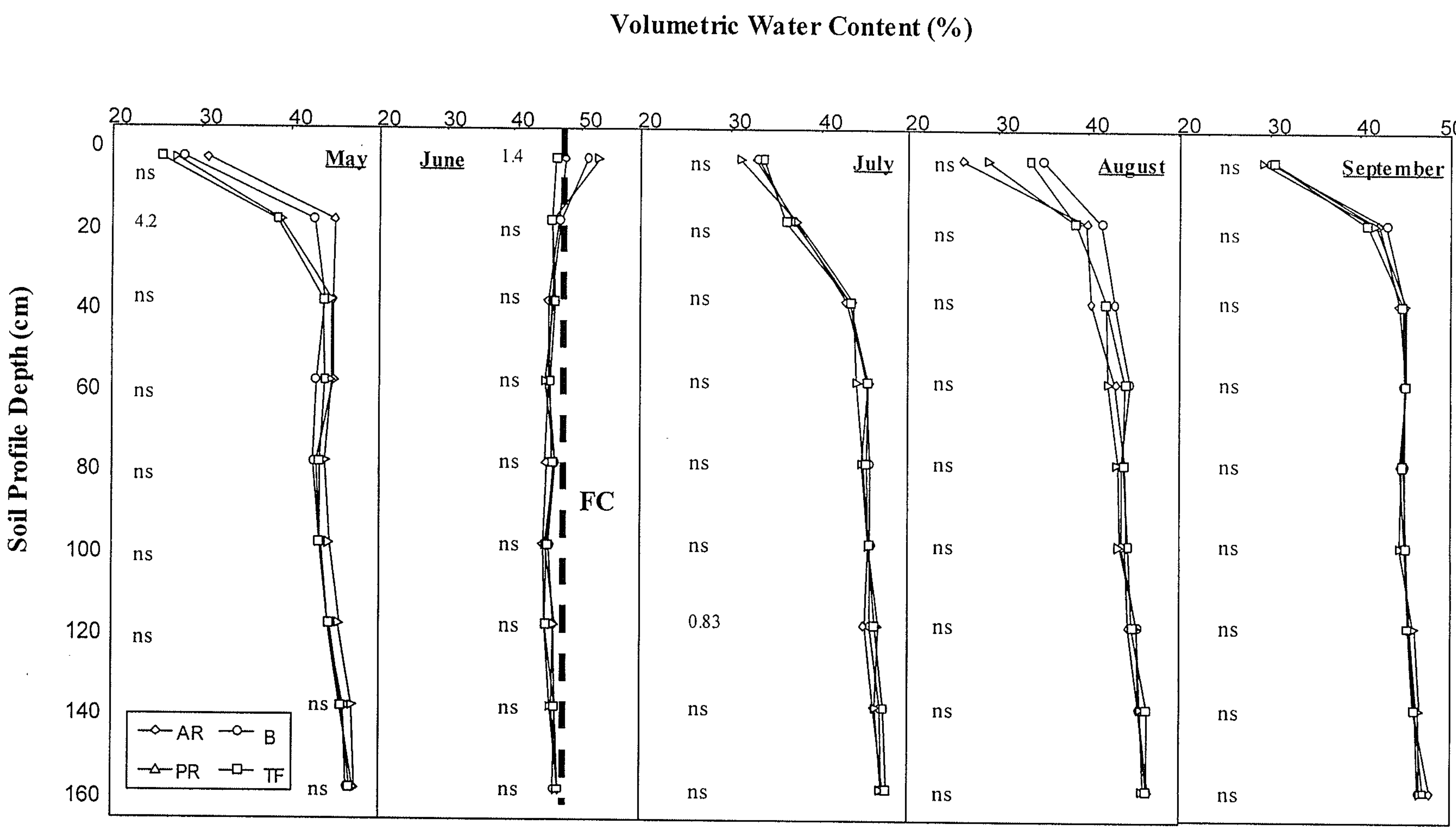


Fig. 2. Soil profile water content percent (cm^3 cm^{-3}) during 2000 growing season at Winnipeg, MB, representing a comparison of four different forage seed crops (AR, annual ryegrass; B, barley (control); PR, perennial ryegrass; TF, tall fescue). Dates water measurements were done are May 26, June 28, July 31, August 14, and September 25. Data points with numerical values represent LSD's that are significant at the 0.05 probability level (ns, non significant). ▬ ▬FC (estimated field capacity)

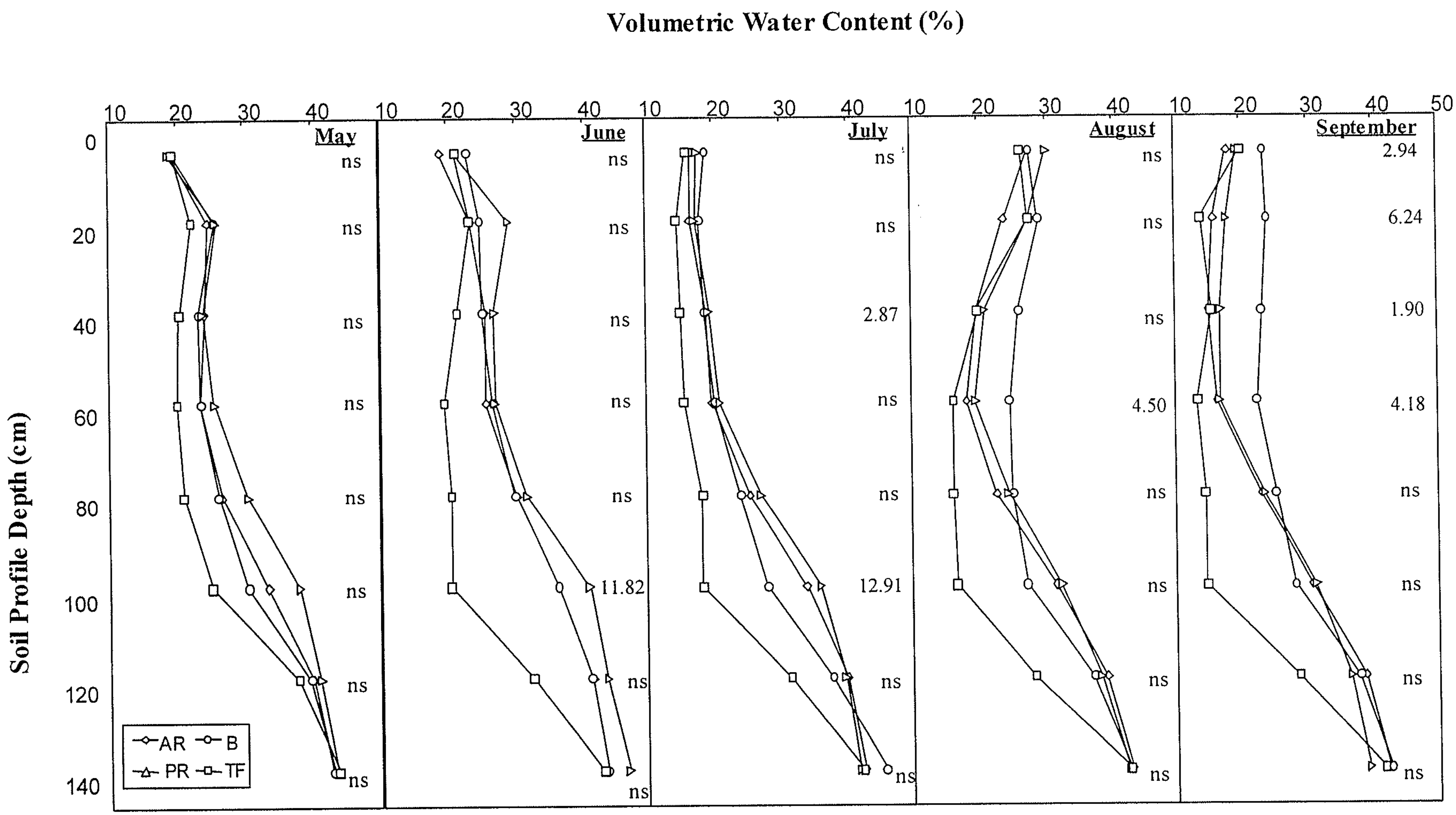


Fig. 3. Soil profile water content percent (cm^3 cm^{-3}) during 2000 growing season at Carman, MB, representing a comparison of four different forage seed crops (AR, annual ryegrass; B, barley (control); PR, perennial ryegrass; TF, tall fescue). Dates water measurements were done are May 25, June 28, July 24, August 12, and September 26. Data points with numerical values represent LSD's that are significant at the 0.05 probability level (ns, non significant).

4.3.3.2 Evapotranspiration (ET)

ET was only determined for Carman during the May to September growing season as it had close to normal precipitation patterns when compared to the long-term average (Table 3) and therefore, moisture loss to deep drainage and surface runoff were assumed to be zero. Winnipeg data was not used to determine consumptive water use due to excessive rainfall (Table 2) that would likely have resulted in deep drainage and run-off.

ET was very similar for the two perennial forages, tall fescue and perennial ryegrass (Table 8). Tall fescue, perennial ryegrass and barley all had significantly higher ET than annual ryegrass for the entire season. This was a somewhat unexpected result as the annual ryegrass had an additional 45 days of growth (post harvest) compared to the barley, which in theory would require more water. This suggests that annual ryegrass was more efficient in its use of water and that we would expect to see higher dry matter water use efficiencies. This is supported by Ridely et al. (1997) who found annual ryegrass to use the least amount of water compared to the other pasture species tested. Although annual ryegrass uses less water it is still considered well adapted for moist production areas (Manitoba Forage Seed Council, 2000).

4.3.3.3 Water Use Efficiency (Dry Matter)

Water data from Winnipeg was not used in these calculations due to excessive precipitation (Table 2). The calculations for Carman are under the assumption that there were no losses to deep drainage or run-off.

Significant differences were observed in WUE $_{(DM)}$ values between forage species. Annual ryegrass had significantly higher WUE $_{(DM)}$ than all other species, once again demonstrating that it is a well-suited crop for livestock production where large amounts of accumulated biomass are necessary, especially important in dry years (Table 8). Tall fescue and perennial ryegrass had lower WUE $_{(DM)}$ values compared to the annual ryegrass. Barley had the lowest WUE $_{(DM)}$ value making it the least suitable for a mixed (livestock-grain) operation it terms of maximizing production per unit of moisture.

Table 8. Evapotranspiration (mm) and water use efficiency of seed yield (kg ha^{-1} grain mm^{-1}), and water use efficiency of dry matter production (kg ha^{-1} DM mm^{-1}) of annual ryegrass, perennial ryegrass, tall fescue, and barley at Carman, 2000. Means with the same letter are not significantly different LSD ($p<0.05$).

	Evapo-transpiration (mm)	WUE_{yield} *(kg ha^{-1} seed ET mm^{-1})*	WUE_{DM} *(kg ha^{-1} DM ET mm^{-1})*
Annual Ryegrass	355 b	2.01 b	32 a
Perennial Ryegrass	435 a	0.88 c	23 b
Tall Fescue	438 a	0.45 c	26 b
Barley	409 a	9.20 a	19 c
LSD	*36.04*	*0.99*	*4.27*

4.3.3.4 Water Use Efficiency (Seed Yield)

Water Use Efficiency for seed yield was very much a function of seed yield (Table 5). As expected, barley had the highest $WUE_{(seed\ yield)}$ (Table 8). Annual ryegrass had the second highest $WUE_{(seed\ yield)}$ and highest of the three forage seed grasses. This infers that when selecting forage seed crops, if the goal is to conserve water and increase water use efficiency, annual ryegrass has an advantage over perennial ryegrass and tall fescue.

4.4 Year 3 – 2001

4.4.1 Test Crop Establishment

In Year 3, there were two different test crops grown, dry beans and sunflower. Beans are a shallow-rooted crop. Peer and Kovec (1964) found that less than 10% of the root ever extends past the 46 cm depth. A rotation that includes a high frequency of dry beans may become more susceptible to waterlogging and even surface salt build-up. Sunflower, being the deepest rooting annual crop in Manitoba (Angadi and Entz, 2002b), might be able to exploit water deep in the soil profile unused by the previous forage crop.

4.4.1.1. Plant Stand Counts

There was no significant difference in plant stand counts between the different forage treatments (annual ryegrass, perennial ryegrass, tall fescue and barley) for either the beans or the sunflowers at either site (Table 9). This observation indicates that forages had no effect on crop establishment of bean and sunflower crops in the following year. However, tillage operations in the previous fall and spring (Table A1 and A2) could have masked some of the differences between forage treatments.

Table 9. Plant stand counts taken in sunflower and bean test crops following annual ryegrass, perennial ryegrass, tall fescue, and barley seed crops (plants m^{-2}) at Winnipeg and Carman, on July 13, 2001 and June 22, 2001, respectively. Means with the same letter are not significantly different LSD ($p<0.05$).

	Sunflowers		Beans	
	Winnipeg	Carman	Winnipeg	Carman
Annual ryegrass	17 a	11 a	20 a	22 a
Perennial ryegrass	18 a	8 a	20 a	20 a
Tall Fescue	17 a	8 a	25 a	19 a
Barley	15 a	10 a	23 a	24 a
LSD	*3.92*	*6.74*	*6.47*	*6.13*

4.4.1.2 Plant Development

Winnipeg

Plant development stage for sunflowers was measured using the method described by Schneiter and Miller (1981) (Appendix Table A7). No statistical analysis was conducted on the data, therefore results are only observational. By July 12, sunflowers following barley appeared to be further developed than sunflowers grown after the annual ryegrass, perennial ryegrass or tall fescue crops (Table 10). There could be several possible explanations for this observation. First, there was less crop residue left on barley plots compared with forage crops resulting in a greater percentage of soil to be exposed to radiation and therefore greater early season soil heat accumulation (Gauer et al., 1982). Higher soil temperatures could have initiated more rapid germination and emergence, which would explain the advanced development of the sunflower plants grown after barley. Second, higher residual nutrients remained in the soil after barley compared to the three forage grasses (Tables A4 and A5). Soil tests taken at Winnipeg (Table A4) indicated higher nitrogen and sulphur levels in the barley plot (ranging from 20 to 30 kg ha^{-1} and 30 to 50 kg ha^{-1}, respectively) compared to that of annual ryegrass, perennial ryegrass or tall fescue. These supplemental nutrients could have advanced sunflower physiological development. Plots at Winnipeg were not fertilized until July 5, nearly a month after seeding due to wet conditions that prevailed during the month of June. The delay in fertilizer application would make residual nutrients a tremendous resource advantage to growth and development.

Growth staging on bean was done as described in the Compendium of Bean Diseases (Hall, 1981) (Appendix, Table A6). There were no visual differences in physiological development of beans among treatments (Table 10) indicating that the previous forage crop appeared to have no effect on dry bean physiological development. Development of field pea was found to be unaffected in development by tillage system, while canola and wheat were influenced by tillage (Borstlap and Entz, 1994).

Carman

Growing forages before dry beans or sunflowers did not seem to have a detrimental effect on the physiological development of either crop (Table 11). Just as in Winnipeg, there was more residual nitrogen left in the barley plot (Appendix Table A5) compared to the forage grasses (15 to 18 kg ha^{-1} more available N). However, plots were fertilized prior to seeding at Carman, which would have provided the required nutrients and more similar conditions for plant growth and development.

Table 10. Plant development ratings in sunflower and bean test crops following annual ryegrass, perennial ryegrass, tall fescue and barley seed crops at Winnipeg, July 12, 2001.

	Annual ryegrass	Perennial ryegrass	Tall Fescue	Barley
	Sunflowers†			
Rep 1	V8	V7	V8	V8
Rep 2	V8	V8	V8	V9
Rep 3	V8	V8	V9	V9
Rep 4	V7	V7	V8	V10
	Beans‡			
Rep 1	V3	V3	V3	V3
Rep 2	V3	V3	V3	V3
Rep 3	V3	V3	V3	V3
Rep4	V3	V3	V3	V3

†Growth Stages are detailed in Appendix (Schneiter and Miller, 1981)
‡Growth Stages are detailed in Appendix (Hall, 1991)

Table 11. Plant development ratings taken in sunflower and bean test crops following annual ryegrass, perennial ryegrass, tall fescue and barley seed crops at Carman, July 13, 2001.

	Annual ryegrass	Perennial ryegrass	Tall Fescue	Barley
	Sunflowers†			
Rep 1	R1	R1	R1	R1
Rep 2	R1	R1	R1	R1
Rep 3	R1	R1	R1	R1
Rep 4	R1	R1	R1	R1
	Beans‡			
Rep 1	R5	R5	R5	R6
Rep 2	R5	R5	R5	R5
Rep 3	R5	R5	R5	R5
Rep4	R5	R5	R5	R5

†Growth Stages are detailed in Appendix (Schneiter and Miller, 1981)
‡Growth Stages are detailed in Appendix (Hall, 1991)

4.4.2 Test Crop Yield

4.4.2.1 Dry Matter Production

Winnipeg

Dry matter production was measured twice, once at fruit fill (August 15) and once at harvest (September 24). Sampling at fruit fill (Table 12) indicated that the sunflowers had more dry matter production when grown after barley, perennial ryegrass and tall fescue than when grown after annual ryegrass. However, different results were observed at the harvest sampling time, when sunflowers after barley had a significantly higher dry matter value than after any of the forage seed treatments. The higher dry matter in the barley-sunflower system is an indication of a higher yield potential compared to the forage-sunflower systems. The yield potential advantage could be attributed to residual nutrient benefits at the beginning of the growing season that allowed for rapid growth of sunflower in the barley-sunflower system.

No data was collected for the dry bean crop, as it did not reach maturity at the Winnipeg site due to excess soil water.

Carman

No dry matter variations due to previous crop were observed in either the bean or sunflower crops at Carman (Table 13). There are a number of possible reasons for this lack of rotation effect compared to the Winnipeg site, where some differences were observed. First, the Carman site was fertilized previous to seeding, whereas the Winnipeg site was fertilized a few weeks after seeding. Delaying fertilizer application at Winnipeg resulted in a noticeable difference in plant growth due to the varying amount of residual fertilizer. This was not the case in Carman as fertilizer was added to meet the need of the growing plants therefore plants had similar growth in all treatments. Second, the difference in soil texture may also have played a role. Perhaps, the rotational benefits of forages are greater on clay vs. sand soils. For example, Naeth et al. (1991) found grazing impact on litter and soil organic matter to be greater on clay-based soils compared to sandy soils. This may explain why the forage-bean or forage-sunflower systems in Carman failed to demonstrate differences in DM production, which is an indication of yield potential differences (Evans and Fischer, 1999).

Table 12. Dry matter production (Kg ha^{-1}) of beans and sunflower following annual ryegrass, perennial ryegrass, tall fescue and barley seed crops at Winnipeg, on August 15 (fruit-fill) and September 24 (harvest), 2001. Within sampling date, means with the same letter are not significantly different LSD ($p<0.05$).

	Beans		**Sunflowers**	
2000 Forage Crop	***August 15***	***September 24***	***August 15***	***September 24***
	Kg ha^{-1}		*Kg ha^{-1}*	
Annual Ryegrass	-	-	3801 b	6104 b
Perennial Ryegrass	-	-	4895 a	8131 b
Tall Fescue	-	-	4686 ab	7123 b
Barley	-	-	5746 a	11015 a
LSD	-	-	1065	2435
p – value	-	-	0.0177	0.0073

Table 13. . Dry matter production (Kg ha^{-1}) of beans and sunflower following annual ryegrass, perennial ryegrass, tall fescue and barley seed crops at Carman, on August 15 (fruit-fill) and September 24 (harvest), 2001. Within sampling date, means with the same letter are not significantly different LSD ($p<0.05$).

	Beans		**Sunflowers**	
2000 Forage Crop	***August 15***	***September 24***	***August 15***	***September 24***
	Kg ha^{-1}		*Kg ha^{-1}*	
Annual Ryegrass	6148 a	6500 a	10065 a	14381 a
Perennial Ryegrass	5513 a	5704 a	9314 a	15455 a
Tall Fescue	5759 a	5421 a	8826 a	12478 a
Barley	5785 a	6119 a	9293 a	16761 a
LSD	1758	1521	1373	3299
p – value	0.8754	0.4413	0.2988	0.0828

4.4.2.2 Seed Yield

Winnipeg

Sunflower seed yield varied across treatments at the Winnipeg location (Table 14). Sunflowers grown after barley had the highest yield (3322 kg ha^{-1}) compared to sunflowers after annual ryegrass, perennial ryegrass or tall fescue (1894, 1956, 2262, respectively). The yield advantage of barley was once again attributed to greater residual fertilizer available, rapid emergence due to less trash cover; factors that had also enhanced other yield building parameters. However, one other possibility may exist. The yield advantage from including barley in rotation may also be attributed to soil water. Although there was no significant difference in soil water (mm) present on the first sampling date (June 24) (Table 14), there was more water in the barley plots compared to the forage plots. Perhaps additional water earlier in the season (May, early June) in the barley plots resulted in greater growth and hence, greater seed yield of sunflower.

The cultivar of sunflowers used in this study (IS-6111) is a higher yield variety on average compared to other varieties commonly used in Manitoba (Angadi and Entz, 2002a), with the average yield of this variety found to be about 2940 kg ha^{-1}.

Beans were unable to reach maturity at the Winnipeg site due to untimely rainfall events. Much of the rainfall occurred during July (Table 2), which would have been close to the bud/flowering stage for the beans. Coupled with the fact that the Winnipeg site has predominately clay soil, a low infiltration rate, and high rainfall amounts for the month of July, there was unquestionably excess soil water. As mentioned earlier, because beans have a shallow root system they are sensitive to excess soil water and standing water. Peer and Kovec (1964) reported that beans were found to be most sensitive to excess soil water during flower bud formation and at flowering, which would explain why they were unable to survive at the Winnipeg site.

Carman

No significant differences in yield due to rotation crop were observed for either the beans or sunflowers at Carman (Table 14), indicating that all forages and barley had the same effect on yield. The lack of difference at the sandier Carman site may once again support the view that rotational benefits of forages are greater on clay vs. sandy soils (Naeth et al. 1991).

One important aspect to note is the exceptional yield obtained by the beans. The ten-year average bean yield in Manitoba is 1499 kg ha^{-1} (Manitoba Agriculture and Food, 2002), while the average bean yields for this study following annual ryegrass, perennial ryegrass, tall fescue and barley were 2668, 2743, 2498 and 2531, respectively. The high bean yield may be attributed to water removal by the previous tall fescue, perennial ryegrass, annual ryegrass and barley crops. Roder et al (1989), who evaluated yield and soil water relationships for a sorghum and soybean cropping system, found that soybean yield increased with crop rotation but not with increased nitrogen additions. The soybean yield advantage from rotation decreased as the amount of spring rainfall increased suggesting that the sorghum was de-watering the soil profile in the previous cropping year and providing mere favourable moisture conditions for the soybeans. In the present study, the Carman site had close to normal precipitation (Table 3), and as such the previous crop of forage grasses and barley were able to de-water the soil to adequate levels for bean production. However, the Winnipeg site, which didn't even reach maturity, supports the later part of Roder's findings, that stated as spring rainfall increased the yield advantage decreased.

Table 14. Yield (kg ha^{-1}) of sunflowers and beans grown after annual ryegrass, perennial ryegrass, tall fescue and barley seed crops at Carman and Winnipeg, 2001. Within crop, means with the same letter are not significantly different LSD ($p<0.05$).

	Carman		*Winnipeg*	
2000 Forage Crop	***Beans***	***Sunflowers***	***Beans****	***Sunflowers***
		Yield (kg·ha^{-1})		
Annual Ryegrass	2668 a	3803 a	-	1894 b
Perennial Ryegrass	2743 a	3857 a	-	1956 b
Tall Fescue	2498 a	3246 a	-	2262 b
Barley	2531 a	3877 a	-	3322 a
LSD	279	692	-	613
P value	0.2276	0.1932	-	0.0017

* No data collected on beans, as they were unable to reach maturity due to excess moisture

4.4.3 Crop Water Use

4.4.3.1 Growing season soil water content

Winnipeg

Volumetric water content did not differ in sunflowers grown after barley, annual ryegrass, perennial ryegrass or tall fescue (Figure 4). It is assumed that any differences that may have occurred were masked by high rainfall events that occurred during the first half of the growing season keeping the soil saturated (Table 2).

There were no significant differences in soil moisture at any depth in either the sunflower or bean plots following the forage grasses and barley (Table 15). The lack of a difference in soil moisture implies that under the extremely wet conditions at Winnipeg forage grasses were no better than barley in using excess soil moisture. Campbell et al. (1984) demonstrated that in years with above-average precipitation, significant amounts of nitrate-nitrogen can leach beyond the rooting zone of cereals. Previous research indicates wheat (Entz et al., 1992) and oats (Knaggs, 2002) use water to a depth of 120 cm which is similar to water use by tall fescue, which is <100 cm (Garwood and Sinclair, 1979). Hence the assumption can be made that a single year tall fescue crop has a rooting depth similar to that of wheat or oats. If nitrate-nitrogen can leach beyond the rooting zone of cereals like wheat and oats then under above-average precipitation such as at Winnipeg, it is possible that nitrates could be lost to deep leaching even in a high water use crop such as tall fescue.

Carman

Sunflowers

Volumetric water content was very different under drier conditions at Carman compared with the saturated soil conditions at Winnipeg. Results at Carman show a definite pattern throughout the first half of the growing season, where the sunflowers after tall fescue had much less water in the soil profile that in the other three forage treatments (Figure 5). Differences in soil water content were significant in the June and July sampling dates at depths of 60 cm, 80 cm, 100 cm and 120 cm. These observations suggest that the tall fescue had the ability to dry the soil in this zone of the soil profile in the previous year and this effect was still be obvious in the following cropping year. Results from the previous year (Figure 3 and Table 16), illustrate that soil in the tall fescue treatment did indeed have a drier profile than the other forage treatments. However, the residual drying effect of tall fescue diminished in sunflower plots in August and in September (Figure 5). Soil water measurements in August show a significant difference in soil water content at the 120 cm depth and September at the 100 cm depth. A University of Manitoba study, demonstrated that sunflowers have shown significant water use and rooting depth to 160 cm (Angadi and Entz, 2002b). Therefore, its likely that sunflower roots were active at the 120 cm depth and using water from this depth. The active sunflower water use could have caused the moisture reserves in the barley-sunflower, annual ryegrass-sunflower and perennial ryegrass-sunflower systems to be depleted to similar levels to the tall fescue-sunflower system during the second half of the growing season. Additionally high rainfall events in August (Table 3) could have recharged the tall fescue soil profile during the second half of the growing season, which would also explain why the "dry out" trend did not continue as strongly through August and September.

Beans

Volumetric water content results for the 2001 growing season demonstrate that tall fescue had a residual effect resulting in a drier soil profile at the beginning of the season and this trend carried through to fall (Figure 6). Unlike the sunflower soil profile (grown after tall fescue), soil profile water content in the bean crop following tall fescue did not display a consistent pattern. In the 50-70 cm and the 110-130 cm depth increments measured in June, beans grown after tall fescue had a significantly drier profile than beans grown after barley, which had the highest moisture content. The August soil water profile showed increased volumetric water content in bean following annual ryegrass, perennial ryegrass and tall fescue. This increase was likely due to large rainfall amounts at the end of July (Table 3) that recharged the soil. However in August and September, there was significantly less water in the 100 and 120 cm depths in bean plots following tall fescue than in the other bean plots that followed the remaining forage grasses and barley. This suggests that the tall fescue had a residual effect causing the soil profile to be drier in the following cropping year. The dewatering benefits were observed even at the end of the bean-growing season. Heavy rains in June, which damaged much of Manitoba bean crops in recent years, would be less susceptible to water damage when following tall fescue versus barley.

The question is why did the tall fescue-bean system remain drier at the 100 to 120 cm depth than the other systems even after the heavy rainfall events in July (Table 3) that could have re-charged the soil profile? Previous research indicates that bean roots typically do not exceed 81 to 102 cm in adequate watered crops (Stegman and Olsen, 1976). Based on weather conditions at Carman in 2001 (Table 3), crops were indeed adequately watered. One could assume that bean roots in fact did not exceed the 80 to 100 cm zone and therefore were not actively using water beyond this depth. A possible explanation for the drier soil profile at the 100 to 120 cm depth could be roots from the previous tall fescue crop created channels (biopores) that increased soil drainage. Previous studies have shown the explorative rooting properties of forage grasses to produce channels within the soil that can aid in water infiltration and drainage (Blackwell et al., 1990; Pavlynchenko, 1942). Channels created down to the 120 cm rooting depth of the previous tall fescue crop could have caused drainage of water from the 100 to 120 cm depth, which would create a drier soil profile at that depth. The drainage as a result of the biopore creation from the tall fescue roots could explain why, in the year of the bean crop, the 100 to 120 cm depth was drier.

At the end of the 2-year crop sequence, annual ryegrass/bean and tall fescue/bean had drier subsoil than the barley/bean rotation (Table 17). This means that the tall fescue and annual ryegrass had a residual effect on the moisture content of the soil in the following year, after forage termination. An added benefit of this phenomenon is prevention of deep nitrate-nitrogen leaching. However, the drying effect of annual ryegrass and tall fescue could have implications for rotation planning especially in drier years when water is limiting. The residual drying effects of these crops could worsen drought conditions in following crops.

4.4.3.3 Evapotranspiration

Evapotranspiration was determined only for the Carman site, where the assumption of no surface water run-off and deep drainage appeared reasonable. Excessive rain causing surface run-off and deep drainage at the Winnipeg site made it impossible to calculate water use with any confidence.

Evapotranspiration values for sunflower in this study ranged from 328 to 361 mm (Table 18), 39 to 79 mm higher than values reported by Angadi and Entz (2002a), who also tested the cultivar IS-6111 at the same site. Perhaps the difference in ET between these two studies could be attributed to soil moisture and greater precipitation in the present study (322 mm vs 310 mm in Angadi and Entz study).

Results show that there were no significant differences in ET of sunflower or beans grown after either the forage grasses or barley. Therefore, while including forages in the rotation affected the amount of soil water available during the sunflower and bean production years (i.e., less water after tall fescue), this did not affect the total water use by these crops. However, had growing conditions been drier, the extra water use by the previous forage crops may have adversely affected sunflower and bean production by limiting the amount of water available for production.

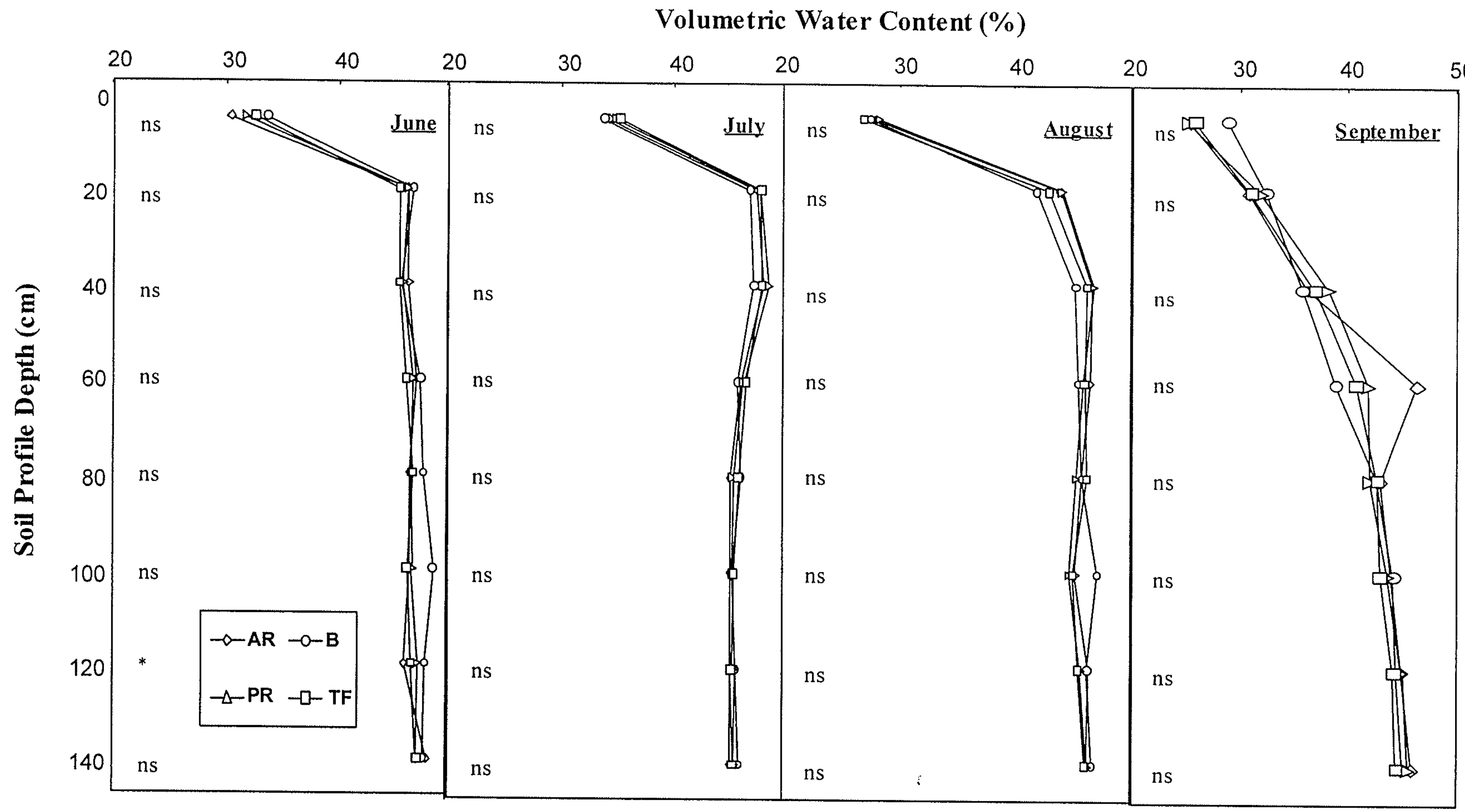


Fig. 4. Soil profile water content percent (cm^3 cm^{-3}) during 2001 growing season at Winnipeg, MB, representing a comparison of water use of sunflowers grown after forage seed crops (AR, annual ryegrass; B, barley (control); PR, perennial ryegrass; TF, tall fescue). Dates of water measurements were June 24, July 20, August 15, and September 24. Data points with numerical values represent LSD's that are significant at the 0.05 probability level (ns, non significant).

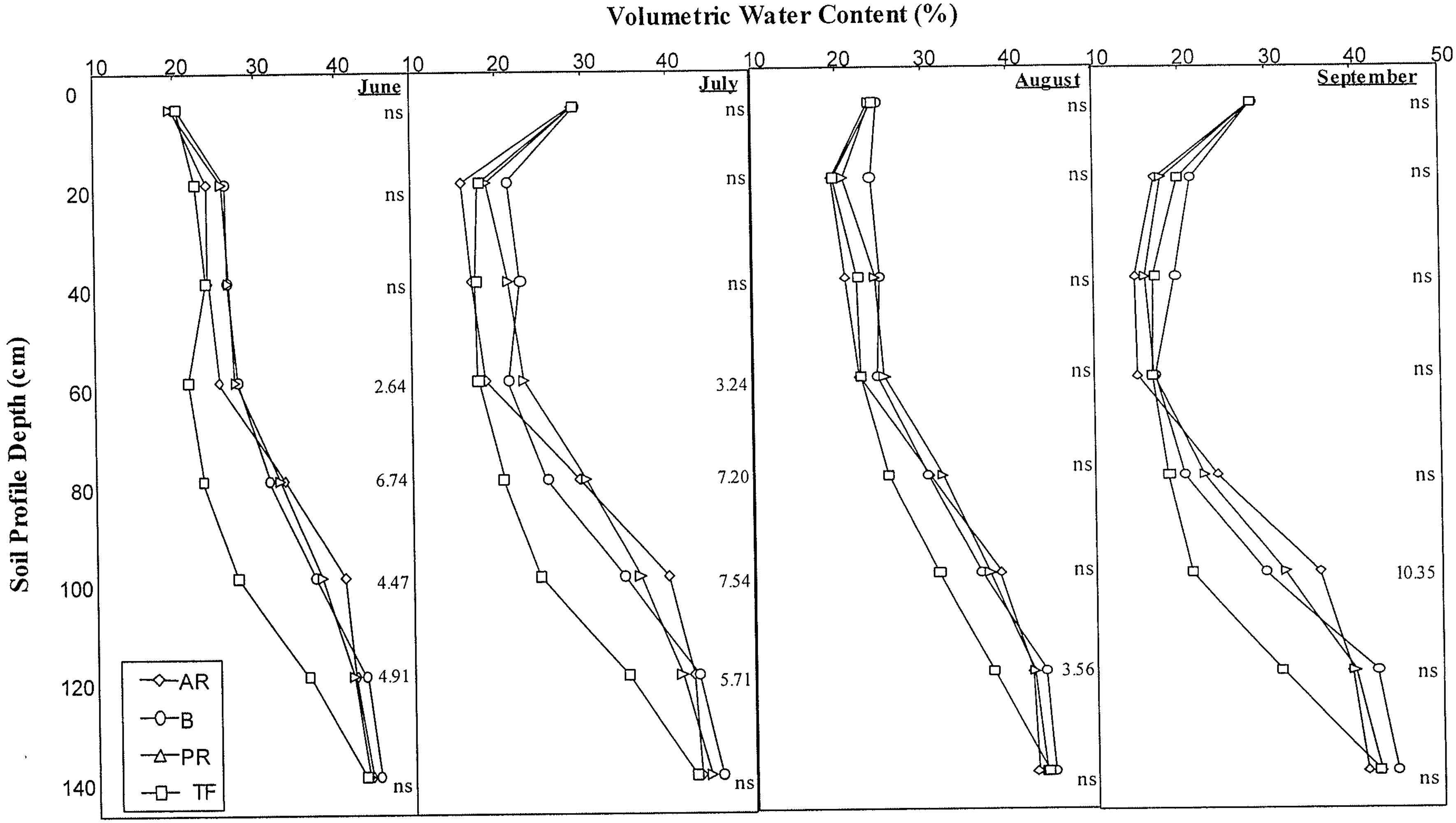


Fig. 5. Soil profile water content percent (cm^3 cm^{-3}) during 2001 growing season at Carman, MB, representing a comparison of water use of sunflowers grown after forage seed crops (AR, annual ryegrass; B, barley (control); PR, perennial ryegrass; TF, tall fescue). Dates water of measurements were June 24, July 20, August 15, September 24. Data points with numerical values represent LSD's that are significant at the 0.05 probability level (ns, non significant).

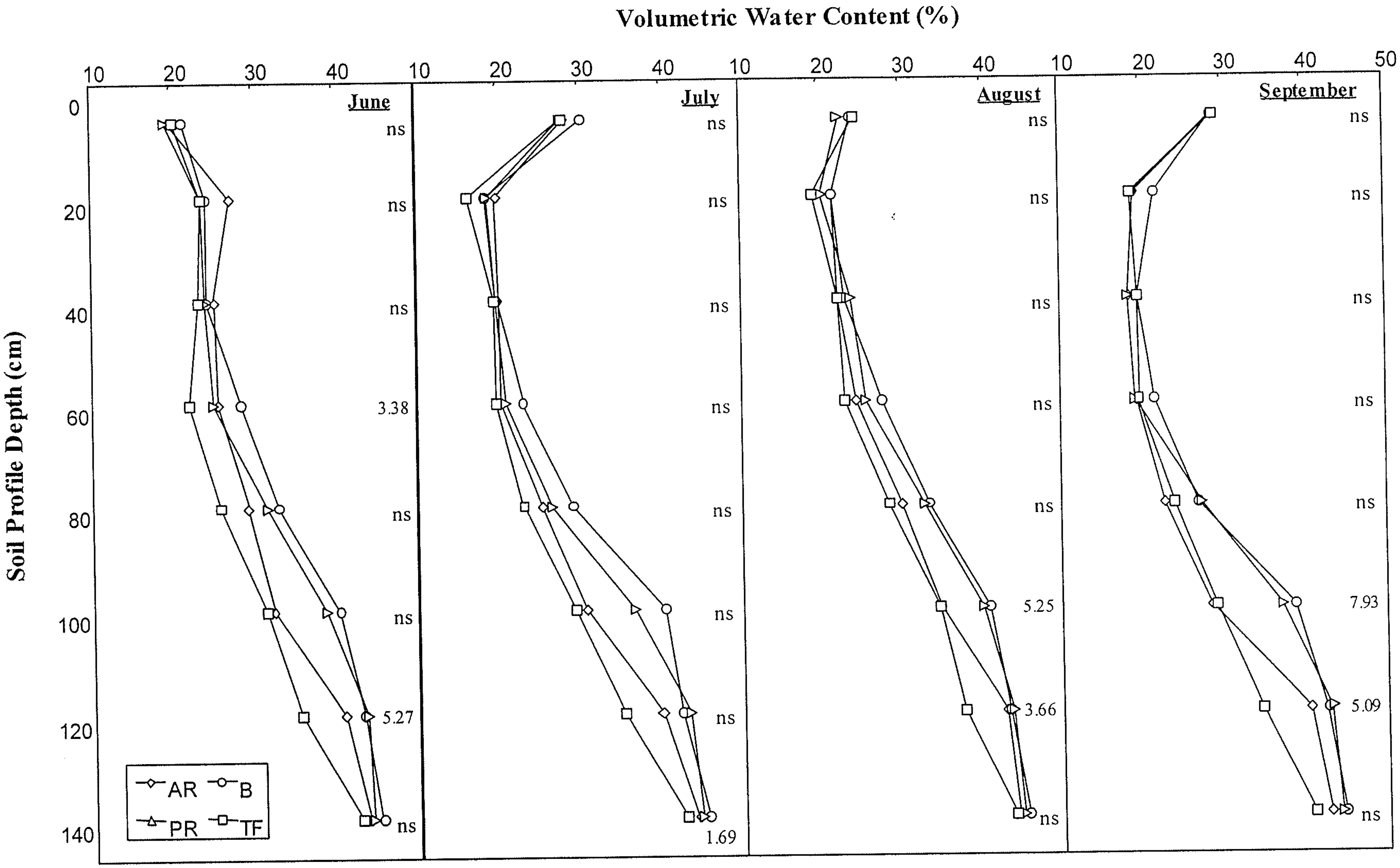


Fig. 6. Soil profile water content percent (cm^3 cm^{-3}) during 2001 growing season at Carman, MB, representing a comparison of water use of dry beans grown forage seed crops (AR, annual ryegrass; B, barley (control); PR, perennial ryegrass; TF, tall fescue). Dates water of measurements were June 24, July 20, August 15, September 24. Data points with numerical values represent LSD's that are significant at the 0.05 probability level (ns, non significant).

Table 15. Soil moisture content (mm) of the soil profile at 0-30 cm, 30-90 cm, 90-150 cm and 0-150 cm depth intervals of sunflowers grown after annual ryegrass, perennial ryegrass, tall fescue and barley seed crops at Winnipeg, 2001. Means with the same letter are not significantly different LSD ($p<0.05$).

	0 – 30 cm	**30-90 cm**	**90-150 cm**	**0-150 cm**
June 24				
Annual Ryegrass	122 a	278 a	279 a	681 a
Perennial Ryegrass	123 a	277 a	280 a	682 a
Tall Fescue	123 a	275 a	278 a	677 a
Barley	126 a	280 a	286 a	694 a
LSD	*6.78*	*8.47*	*7.77*	*16.89*
July 20				
Annual Ryegrass	128 a	277 a	270 a	677 a
Perennial Ryegrass	130 a	279 a	272 a	681 a
Tall Fescue	130 a	280 a	271 a	682 a
Barley	127 a	277 a	273 a	677 a
LSD	*6.38*	*4.21*	*3.21*	*9.66*
August 15				
Annual Ryegrass	115 a	278 a	275 a	668 a
Perennial Ryegrass	116 a	276 a	273 a	666 a
Tall Fescue	112 a	276 a	273 a	663 a
Barley	111 a	273 a	280 a	664 a
LSD	*7.90*	*6.36*	*5.25*	*12.09*
September 24				
Annual Ryegrass	87 a	251 a	269 a	607 a
Perennial Ryegrass	89 a	244 a	268 a	602 a
Tall Fescue	87 a	240 a	263 a	591 a
Barley	93 a	234 a	267 a	595 a
LSD	*15.73*	*23.77*	*7.81*	*42.01*

Table 16. Soil moisture content (mm) of the soil profile at 0-30 cm, 30-90 cm, 90-150 cm and 0-150 cm depth intervals of sunflowers grown after annual ryegrass, perennial ryegrass, tall fescue and barley seed crops at Carman, 2001. Means with the same letter are not significantly different LSD ($p<0.05$).

	0 – 30 cm	30-90 cm	90-150 cm	0-150 cm
June 24				
Annual Ryegrass	70 a	166 a	254 a	490 a
Perennial Ryegrass	71 a	173 a	247 a	492 a
Tall Fescue	65 a	137 b	214 b	417 b
Barley	73 a	171 a	251 a	495 a
LSD	*10.69*	*19.25*	*19.84*	*29.30*
July 20				
Annual Ryegrass	60 a	130 ab	252 a	444 a
Perennial Ryegrass	66 a	149 a	245 a	461 a
Tall Fescue	65 a	112 b	205 b	383 b
Barley	71 a	139 a	248 a	459 a
LSD	*12.86*	*24.87*	*28.79*	*51.40*
August 15				
Annual Ryegrass	62 a	147 a	248 a	458 a
Perennial Ryegrass	65 a	163 a	248 a	478 a
Tall Fescue	63 a	141 a	227 a	432 a
Barley	72 a	159 a	251 a	483 a
LSD	*8.86*	*25.80*	*18.20*	*39.60*
September 24				
Annual Ryegrass	62 a	107 a	233 a	404 a
Perennial Ryegrass	64 a	110 a	229 a	404 a
Tall Fescue	67 a	104 a	190 a	362 a
Barley	70 a	113 a	233 a	418 a
LSD	*9.46*	*27.55*	*39.60*	*63.95*

Table 17. Soil moisture content (mm) of the soil profile at 0-30 cm, 30-90 cm, 90-150 cm and 0-150 cm depth intervals of dry beans grown after annual ryegrass, perennial ryegrass, tall fescue and barley seed crops at Carman, 2001. Means with the same letter are not significantly different LSD ($p<0.05$).

	0 – 30 cm	**30-90 cm**	**90-150 cm**	**0-150 cm**
June 24				
Annual Ryegrass	74 a	160 a	234 ab	468 ab
Perennial Ryegrass	66 a	161 a	253 a	481 a
Tall Fescue	67 a	142 a	219 b	429 b
Barley	69 a	171 a	257 a	498 a
LSD	*12.09*	*22.52*	*28.63*	*42.88*
July 10				
Annual Ryegrass	67 a	131 a	228 ab	427 ab
Perennial Ryegrass	65 a	133 a	248 a	447 a
Tall Fescue	60 a	124 a	213 b	399 b
Barley	67 a	143 a	255 a	466 a
LSD	*12.42*	*21.86*	*29.99*	*40.68*
August 15				
Annual Ryegrass	67 a	153 a	242 ab	463 a
Perennial Ryegrass	63 a	164 a	255 a	483 a
Tall Fescue	62 a	147 a	231 b	493 a
Barley	67 a	168 a	258 a	441 a
LSD	*15.11*	*27.39*	*18.81*	*47.81*
September 24				
Annual Ryegrass	67 a	120 a	223 bc	411 a
Perennial Ryegrass	67 a	129 a	249 ab	445 a
Tall Fescue	66 a	125 a	208 c	401 a
Barley	72 a	135 a	251 a	459 a
LSD	*12.09*	*22.52*	*28.63*	*42.88*

4.4.3.5 Water Use Efficiency

Just as in the ET calculations, WUE was calculated for only the Carman site where we could confidently assume no loss of water to surface run-off or leaching.

There were no statistically significant differences between the different forage treatments in WUE for DM or seed yield in either the beans or sunflowers (Table 18). This indicates that neither of the forage grasses nor barley had an effect on the efficiency with which either bean or sunflower crops converted ET to yield.

Table 18. ET (mm), WUE_{yield} (kg ha^{-1} grain mm^{-1}), WUE_{DM} (kg ha^{-1} DM mm^{-1}), and Rotational Efficient Water Use (kg ha^{-1} DM mm^{-1}) of sunflower and dry bean test crops grown after annual ryegrass, perennial ryegrass, tall fescue and barley seed crops at Carman, 2001. Means with the same letter are not significantly different LSD ($p<0.05$).

	ET (mm)	WUE_{yield} *(kg ha^{-1} seed mm^{-1})*	WUE_{DM} *(kg ha^{-1} DM mm^{-1})*	Rotational Efficient Water Use *(kg ha^{-1} DM mm^{-1})*
		- Sunflowers -		
Annual Ryegrass	359.77 a	10.65 a	28.19 a	22.67 a
Perennial Ryegrass	361.61 a	10.70 a	25.91 a	20.54 a
Tall Fescue	328.41 a	9.91 a	26.88 a	21.39 a
Barley	350.28 a	11.12 a	26.49 a	17.97 b
LSD	*44.17*	*2.38*	*4.38*	2.53
		- Beans -		
Annual Ryegrass	329.75 a	8.11 a	19.70 a	18.95 a
Perennial Ryegrass	308.34 a	8.91 a	18.59 a	16.78 ab
Tall Fescue	300.90 a	8.32 a	18.02 a	17.84 a
Barley	311.95 a	8.13 a	19.75 a	14.65 b
LSD	*24.54*	*1.29*	*5.07*	*2.86*

4.4.3.4 Cropping System Water Use

Overall cropping system water use was investigated over the 2000 and 2001 seasons to determine how the different crops in the rotation affected the overall water use of the system (Figure 7, 8 and 9).

Winnipeg

Similar soil water content at all three depth increments (0-30 cm; 30-90 cm; and 90 – 150 cm) indicated no subsoil dewatering benefits of forages under the extremely wet conditions at Winnipeg (Figure 7). Where did all of the precipitation go if it was not used by the plants? Much of it was likely lost to surface run-off. In extreme cases, as much as one fourth of precipitation can be lost to run-off (Brady, 1990). Additionally, the fact that the soil profile was often near field capacity suggests that a portion of precipitation was likely lost to deep drainage. Once the water penetrates the soil, some of it is subject to downward percolation and eventual loss from the root zone by drainage (Campbell, 1994). This is a potential problem, as nitrate leaching into ground water can occur when deep drainage is experienced (Ridley et al., 1999). Therefore, one year forage seed crops were not entirely effective in reducing leaching risk under extreme precipitation conditions in Manitoba, even when the forage seed crop was followed by an annual crop which is known to use a great deal of water (i.e. sunflowers).

Carman

Conditions were drier at Carman than at Winnipeg (Figure 8 and 9), however, there was a reliable supply of precipitation throughout year 2 (2000) and most of year 3 (2001).

0 – 30 cm

Water in the surface layer (0 – 30 cm zone) is important for crop establishment and early growth (Lafond et al., 1992) and is most quickly influenced by changes in tillage system and crop water use. In the current study, grain barley didn't cause an increase soil water over the winter recharge period (Figures 8 and 9), suggesting that soil in the barley plot was already at or near field capacity in the fall. In contrast, all three forage plots (annual ryegrass, perennial ryegrass, and tall fescue) experienced an increase in soil moisture over the winter recharge period indicating that they were not saturated in the fall of 2000 (Bullied and Entz, 1999). Dry matter accumulation by the forage grasses (Table 4) in the late fall supports that the grasses were actively growing and using a significant amount of water late into the season in the 0 – 30 cm zone. Forage crops entered the winter with drier soil conditions. The forage systems were more reliant on over-winter water recharge. Typically, drier soils facilitate more water recharge over winter (Bullied and Entz, 1999). There was little variation in the amount of water used by either the sunflower or beans in the following year after forages in the 0 – 30 cm zone (Figures 8 and 9).

30 – 90 cm

The subsoil zone (30 – 90 cm zone) is important for sustained growth and yield potential in annual crops (Entz and Fowler, 1989). In the 30 – 90 cm zone all forage grass and the barley treatments increased soil water content over the winter recharge period (Figures 8 and 9). Barley plots had more water in the 30 – 90 cm zone entering the winter period. This may explain why barley plots had the least amount of recharge. The barley treatment still had higher soil water than the forages treatments at the beginning of the next growing season (2001) indicating that conditions were not sufficient to completely recharge the soil profile after the forages. Soil in the tall fescue treatment had the driest 30 – 90 cm profile throughout both seasons (2000 and 2001) while soil in the perennial ryegrass and annual ryegrass treatments had similar profiles throughout year 2 (2000) and year 3 (2001). If the 2001 season had been drier, the lack of full recharge in the forage systems might have limited water availablility for bean and sunflower production and therefore might have had a negative effect on the yield potential of these test crops.

90 – 150 cm

Most water between 90 – 150 cm is not retrievable by annual crops grown in this production region (sunflower being an exception) and accumulation of this deep water increases the risk of nitrate leaching under Canadian Prairie conditions (Campbell et al., 1994). In the 90 – 150 cm zone, the tall fescue treatment had the driest profile throughout year 2 (2000) and year 3 (2001). At the 90 – 150 cm depth, soil in the perennial ryegrass and annual ryegrass treatments had very similar water patterns to soil in the barley treatment in year 2 (2000) (Figures 8 and 9). However, the similarities end with the recharge of moisture during the winter of 2000/2001. Both soil in the barley and tall fescue treatments increase water over the winter proportionally, but soil in the annual ryegrass treatment does not recharge at all. This is due to the fact that the annual ryegrass plot already had a full soil water profile. This is supported by earlier observations that annual ryegrass plants used less water than the other forages.

The tall fescue system had the driest soil profile at the 90 – 150 cm depth (Figure 8 and 9). For example, tall fescue plots had approximately 40 mm less water at the 90 – 150 cm in the spring compared to the barley plots. At the 30 – 90 cm depth, tall fescue plots had approximately 25 mm less water than barley plots in the spring for a total difference of 65 mm (30 – 150 cm). This data suggests that one winter recharge period was not sufficient to replenish sub soil water in the tall fescue system.

Presumably, the tall fescue system was less likely to have deep leaching of nitrates or other soluble chemicals; therefore, under drier conditions dewatering benefits of tall fescue became obvious. The ability of tall fescue to intercept nitrates from leaching to groundwater would be especially important in lower elevations within fields where nitrates and soluble chemicals often enter the water table. However, if conditions had been drier in 2000 and 2001, the 65 mm water deficit might have been a disadvantage, limiting the amount of water available for growth and yield potential of beans and sunflowers.

4.4.3.5 Rotational Efficient Water Use (REWU)

The concept of efficient water use provides a means to quantify rotation effects on efficiency of water use (Pierce and Rice, 1988) over a determined length of time. In this study, efficiency of water use was determined from the beginning of the forage crop to the harvest of the bean or sunflower crop in the following year. The word "rotational" was chosen to be added to Pierce and Rice's EWU term because in this study the EWU provided a method to quantify the overall rotational effect of having forages and beans or sunflowers in rotation together. Only the Carman site data was used to calculate REWU.

Results in Table 18 indicate that there were statistical differences in REWU values in both the forage-sunflower and forage-bean systems compared to the barley-sunflower and barley-bean systems. The forage sunflower and forage bean systems had much higher REWU values compared to the barley (annual cereal) systems. This indicates that including forages in the rotation improves the efficient water use over the whole 18-month period (including the winter period) of the rotation of both the sunflower and bean systems, with the forage-sunflower system being the most efficient. Therefore, in an area with abundant moisture, the forage systems, especially the forage-sunflower system, will maximize the rotational efficient water use.

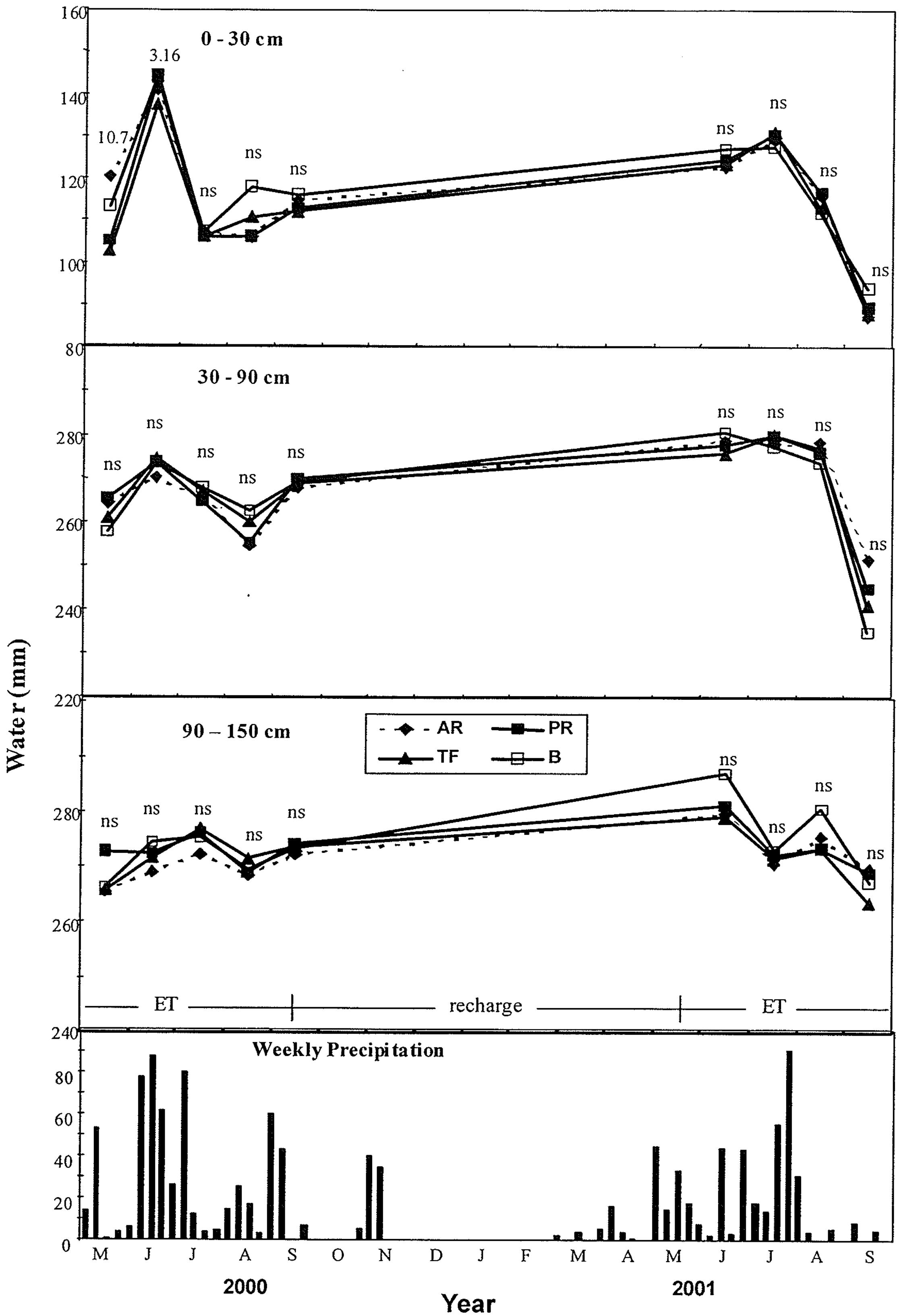


Fig. 7. Soil water content for profile increments of 0-30, 30-90, and 90-150 cm at Winnipeg, MB, from seeding of forage crops in 2000 to the harvest of the sunflower test crop in 2001 (AR, annual ryegrass; PR, perennial ryegrass; TF, tall fescue; B, barley). Data points with numerical values represent LSD's that are significant at the 0.05 probability level (ns, non significant).

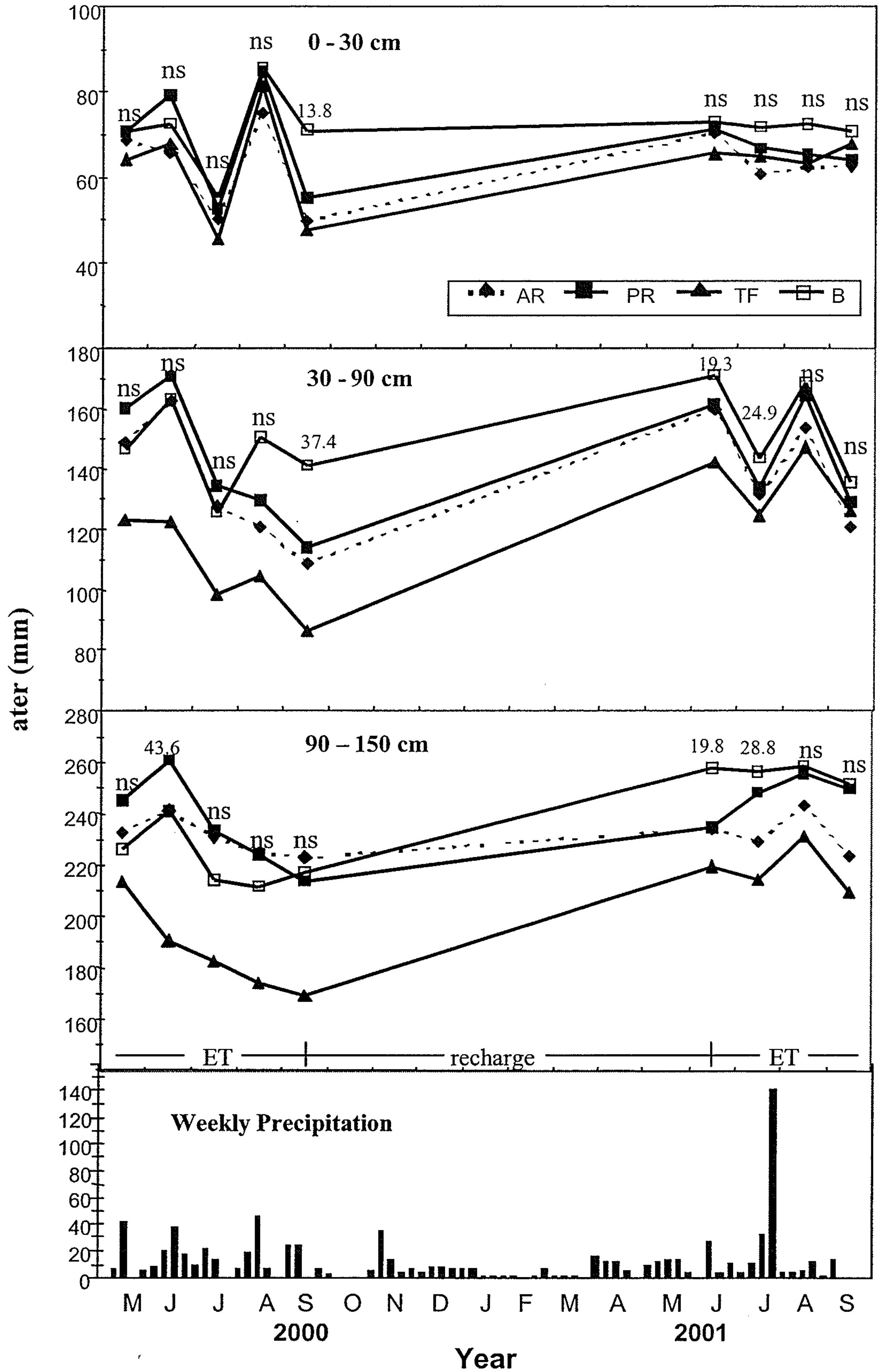


Fig. 8. Soil water content for profile increments of 0-30, 30-90, and 90-150 cm at Carman, MB, from seeding of forage crops in 2000 to the harvest of the sunflower test crop in 2001 (AR, annual ryegrass; PR, perennial ryegrass; TF, tall fescue; B, barley). Data points with numerical values represent LSD's that are significant at the 0.05 probability level (ns, non significant).

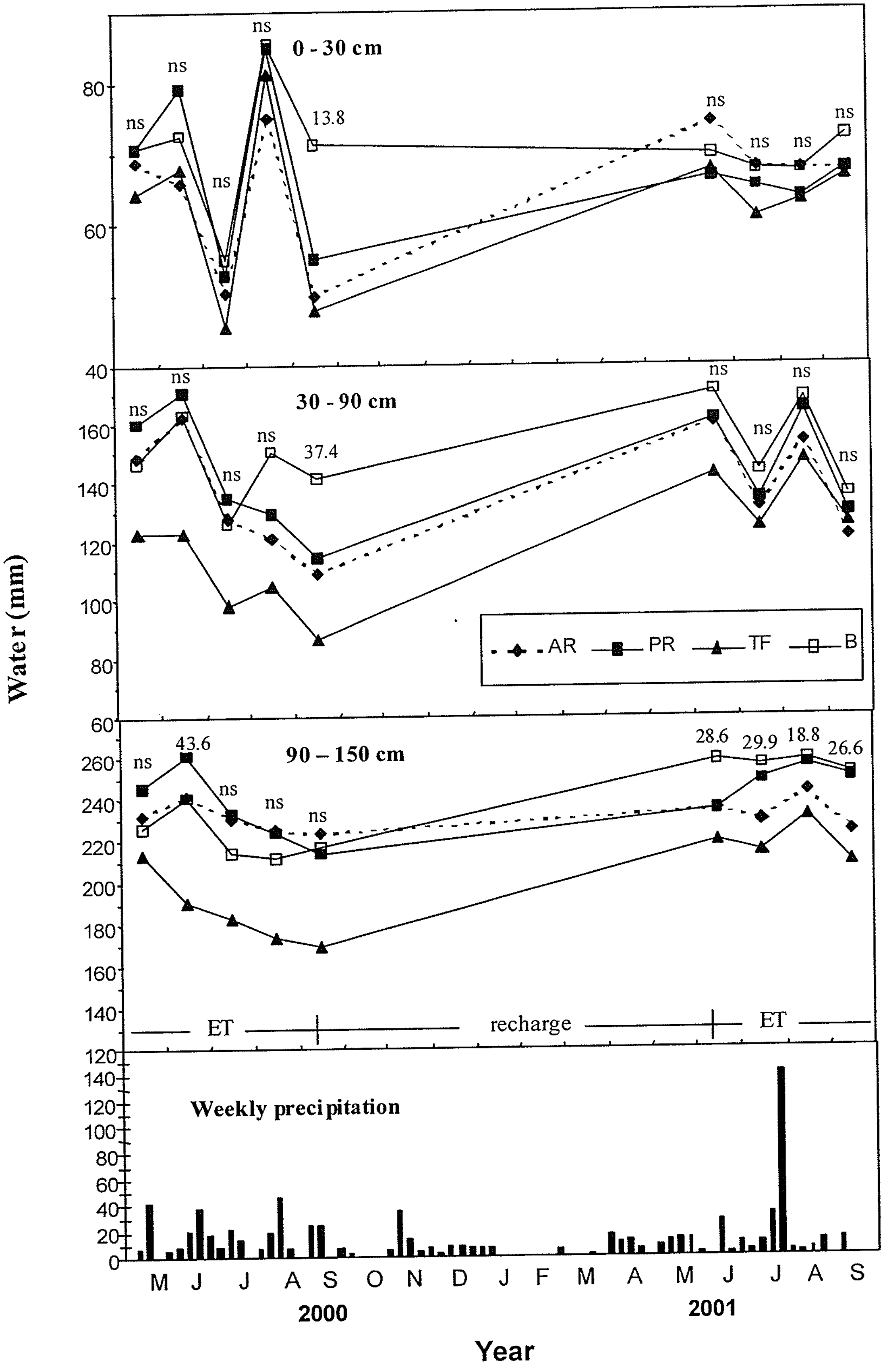


Fig. 9. Soil water content for profile increments of 0-30, 30-90, and 90-150 cm at Carman, MB, from seeding of forage crops in 2000 to the harvest of the bean test crop in 2001 (AR, annual ryegrass; PR, perennial ryegrass; TF, tall fescue; B, barley). Data points with numerical values represent LSD's that are significant at the 0.05 probability level (ns, non significant).

5.0 Summary and General Discussion

In this study we evaluated the role of single year forage seed crops in a cropping system that included beans (shallow-rooted crop) and sunflowers (deep-rooted crop) as subsequent crops in the rotation. Crops should be managed in a rotation sequence so that complementary root systems fully exploit available water and nutrients (Karlen and Sharpley, 1994). This was the rationale used for designing and testing the crop rotations in this study. It was thought that forage grasses would use water in the mid-soil profile and that beans in the following year would use water in the upper profile collected from winter recharge, and sunflowers would use water in the deeper soil profile. Information in Table 19 summarizes the basic rotational effects observed in this study.

Based on the results of this study, it can be concluded that under excessively wet conditions such as those seen at Winnipeg (Table 2), forage grass crops were not successful in using significant amounts of water at any depth (Table 19). All forage grass crop soil profiles remained around field capacity levels throughout the 2000 growing season.

However under average moisture conditions, as seen at Carman (Table 3), forage grass seed crops were able to deplete soil moisture at varying depths. Tall fescue and perennial ryegrass were found to use the most water as these forage grasses had the highest ET value compared to annual ryegrass which had the lowest. Previous findings have indicated that annual ryegrass has a lower water use capacity compared to other forages (Ripley, 1997), which is supported by findings in the present study. However, annual ryegrass had the highest $WUE_{(DM)}$ compared to the other forage grasses indicating its suitability for providing forage under water-limiting conditions, this is especially important in livestock production. Tall fescue had the deepest rooting depth of the forage grasses reflected by water use at the > 100 cm depth. This supports findings by Garwood and Sinclair (1979), who also found tall fescue to use water to a depth of > 100 cm.

Forage grass crops were unable to "de-water" the soil for bean production under extreme moisture conditions at Winnipeg, therefore including forage seed crops in the rotation did not help bean crops deal with the excess moisture in year 3 (2001) of the study (Table 19). Barley was the only crop that created a situation where a yield advantage was observed in sunflower production at Winnipeg, which had high soil moisture conditions. It was concluded that the yield advantage was a result of higher residual nutrients in the barley plots compared to the forage grasses, and that this enhanced early season sunflower growth. A similar outcome to Carman, which showed no yield advantage after barley, would be expected had the plots in Winnipeg been fertilized at the time of seeding.

Growing forage seed crops at Carman, under average moisture conditions, prior to beans or sunflower had no effect on crop yield (Table 19). However, the overall bean yield at Carman was well above the provincial 10-year average of 1488 kg ha-1 (Manitoba Agriculture and Food, 2001) perhaps suggesting the previous forage grasses (annual ryegrass, perennial ryegrass, and tall fescue) and barley created good conditions for bean production.

Under average soil moisture conditions, such as those experienced in Carman, forage grasses had the ability to use significant amounts of water with tall fescue demonstrating the greatest soil water use capacity (Table 19). The extra water use by tall fescue had a residual effect that continued to be evident in the following bean and sunflower crops (Figure 8 and 9), this effect was most evident at the 90 – 150 cm soil depth. Previous studies have shown the explorative rooting properties of forage grasses

Table 19. Summary of rotation effects from including single year forage seed crops (a.r., annual ryegrass; p.r., perennial ryegrass; and t.f., tall fescue) and barley on subsequent test crops, beans (shallow-rooted crop) and sunflowers (deep-rooted crop) at Carman and Winnipeg, Manitoba, 1999-2001.

	Carman (Dryland Conditions)					
	Water Dynamics in Forage Year	Crop Yield in Year Following Forages		Water Dynamics in Year Following Forages		Potential Environmental Impacts
		Sunflowers	Beans	Sunflowers	Beans	
Forages	- forages had the ability to "de-water" the soil profile in year of production (especially t.f.) - "de-watering" effect of t.f. continues into year 3 - a.r. has highest WUE (DM) - a.r. and p.r. little recharge from year 2 to year 3	- forage grass has no effect on sunflower yield	- forage grass has no effect on bean yield - overall bean yield high after forages	- forages improve REWU of system - by August and September, a.r, p.r. had similar water use to t.f. plots indicating sunflower was using the residual water in the deeper profile	- forages improve REWU of system - t.f. consistently drier profile at 90 – 150 cm - at the end of the season, t.f./beans and a.r./beans still had a drier profile than barley/beans	- likely no nitrate and other soluble compound lost to leaching, especially in tall fescue plots
Barley	- by fall, 0 – 30 cm depth recharged and saturated - highest WUE (seed), lowest WUE (DM) - no late season grazing potential	- no effect on sunflower yield	- barley has no effect on bean yield - overall bean yield high after barley	- by August and September similar water use to t.f. plots indicating sunflower was using the residual water in the deeper profile	- at the end of the season, still had more water than a.r. and t.f.	- possible for some leaching to have occurred.
	Winnipeg (Wet Conditions)					
	Water Dynamics in Forage Year	Crop Yield in Year Following Forages		Water Dynamics in Year Following Forages		Potential Environmental Impacts
		Sunflowers	Beans	Sunflowers	Beans	
Forages	- under wet conditions, unable to "de-water" soil profile	- similar effect on sunflower production	-under wet conditions, unable to create suitable moisture conditions for bean production	- water use not affected by forage grass under wet conditions	- conditions too wet for bean production	- nitrate and other soluble compounds likely lost to leaching
Barley	- under wet conditions, unable to "de-water" soil profile	- better conditions for bean prod. (higher residual fert.)	-under wet conditions, unable to create suitable moisture conditions for bean production	- water use not affected by barley under wet conditions	- conditions too wet for bean production	- nitrate and other soluble compounds likely lost to leaching

and this ability to produce channels within the soil that can aid in water infiltration and drainage (Blackwell et al., 1990; Pavlenchynko, 1942). The formation of macropores by tall fescue could explain the residual "drying" effect in the soil of the following bean crop after the tall fescue treatment even after high rainfall events that should have recharged the soil. Both annual ryegrass and tall fescue treatments had drier subsoil (90 – 150 cm) than the barley-bean system at the end of the 2-yr cropping sequence, indicating possible macropore formation in the ryegrass plots as well.

The water content in the soil profile of the various sunflower cropping systems varied at the beginning of the growing season with the tall fescue-sunflower system creating the driest soil profile. This indicates that, tall fescue had a residual effect on the water content in the soil profile of the following sunflower crop especially at the 90 – 150 cm depth. However, as time progressed, the other sunflowers systems (annual ryegrass-sunflower; perennial ryegrass-sunflower; and barley-sunflower) "caught up" to the tall fescue-sunflower system as was shown in soil moisture measurements from August and September. This suggests that the sunflower roots were using residual water deeper in the soil profile; water left by previous annual ryegrass, perennial ryegrass and barley crops. Sunflowers in Manitoba have been found to use water from as deep as 160 cm (Angadi and Entz, 2002b). This supports our suggestion, that in the present study sunflowers were actively using water left in the soil profile from the previous year.

Rotational efficient water use is expressed as a function of WUE modified by rotation's impact on water availability (Pierce and Rice, 1988). While, WUE calculations did not reflect the effect of forages on the water balance of sunflowers and beans, REWU did (Table 18). This is attributed to the fact that WUE only accounts for ET efficiency within a single crop. It does not account for water use in a whole cropping system. The inability for WUE calculations to reflect what is happening in the overall system stresses the importance of looking at water use of a crop rotation in an overall systems approach over years rather than by only looking at annual effects during a single growing season.

Evaluating the forage-bean and forage-sunflower crop rotations in an overall systems approach yielded interesting results. The REWU of the forage-bean and forage-sunflower systems proved to be much higher than the barley systems. Tall fescue-sunflower and annual ryegrass-sunflower were among the forages that had the highest rotational efficient water use making them excellent crops to consider in crop rotations where the goal is to maximize water use. It was also found that sunflowers complemented the crop rotation better than beans by using water left by the forage grasses creating more efficient water use in the overall cropping system (Karlen and Sharpley, 1994). This is important information for planning rotations, especially in drier years, or in areas where water is limited. In these situations including forages may have a negative impact on following crops in the rotation.

The most important factors that influence the amount of nitrate movement to ground-water or surface waters are the following: the amount of nitrate dissolved in the soil solution; the rate of its use by plants; the rate of immobilization into soil microorganisms or newly synthesized soil organic matter; the amount of water available for runoff and leaching through the soil; and the soil permeability (Miller and Gardiner, 2001). Plants can be used to capture residual nitrogen in an effort to reduce nitrate contamination. For example, Entz et al, (2001) observed that perennial grasses and alfalfa both extracted more subsoil nitrogen than continuous wheat. In a simulation model study in Sweden, ryegrass grown as a catch crop reduced simulated nitrate leaching by more than 60 % (Alvenäs and Marstorp, 1993). However, other research indicates that perennial pastures are only able to reduce nitrate leaching compared with annuals in drier than average years (Ridley et al., 1999). Through previous research it has been established that in humid areas, up to 50% of the precipitation may be lost as drainage water (Brady, 1990). Results from our study coincide with Ridley's findings, as the forages under wet conditions at Winnipeg were unable to alleviate soil moisture from field capacity (Figure 2) and it is likely nitrate leaching was occurring. On the other hand, the roots in the tall fescue plots at Carman were capable of intercepting water from deep drainage losses and as result nitrate leaching was almost certainly avoided (Figure 8 & 9). These findings have implications for crop rotation planning, especially in wet areas where soil conditions result in greater risk of nitrate leaching. In Manitoba, it is these wet areas where hog production predominates. Nitrate nitrogen management is a top priority for the environmental safety of the area. Therefore, under wet conditions, high water use crops would be desirable in all years of the rotation.

Soil salinity generally occurs in discharge areas where the water table is high, especially in fine texture soils (Haluschuk, 2000). Halverson and Black (1974) stated that by using flexible crop rotations involving small grains, grasses, and deep-rooted crops, and a minimum amount of summer fallow, soil water loss by deep percolation could be prevented and development of saline seeps could be alleviated. The crop rotation used in this study is very similar to what Halverson and Black describe as being ideal for salinity management. Under average moisture conditions at Carman (Table 3), the forage grasses were able to deplete moisture reserves in the year of production and in the following bean and sunflower crop, hence it is likely that salinity problems were being prevented at this site. However, in Winnipeg, under high moisture conditions (Table 2), the forage grasses were no better than barley for depleting soil moisture. Even following the forage grasses with a high water use crop (sunflowers) made little impact on the amount of water left in the soil profile. Hence, under wet conditions, the forage-bean and forage-sunflower systems were unsuccessful in using enough water from the profile to prevent possible salinity problems.

Vigorous plant growth is characteristic of annual ryegrass giving the crop excellent forage production potentials from straw and post-harvest re-growth (Manitoba Forage Seed Association, 2000). The re-growth of all of the forage seed crops were remarkable ranging from 2035 kg ha^{-1} for perennial ryegrass at Winnipeg to 3755 kg ha^{-1} for annual ryegrass at Carman. This provides a significant value for livestock producers. According to Cowbytes cow ration program (Alberta Agriculture, Food and Rural Development, 1999), a dry 635 kg cow consumes 2.5 % of her body weight, which would be approximately 16 kg of dry matter per day. However, cattle typically waste 1.5 % in trampling (Rodger Sheldon, personal comm.. Ste.Rose, MB) therefore, approximately 25.5 kg of total DM forage would be needed (4% of total cow weight). If a producer had 100 cows they would be able to graze the annual ryegrass residue at Carman (assuming it was a 25 ha field) for 37 days. Even the lower yielding perennial ryegrass would be able to sustain the same amount of cattle on the same area of land for 20 days. This is of significant value to livestock producers whose pastures typically have been depleted by fall time. However, care must be taken to avoid poisoning of livestock with toxins produced by the endophyte fungus infecting tall fescue (Hill et al., 1991) and perennial ryegrass (Gallagher et al., 1984).

Allelopathic toxins from certain genotypes of tall fescue have been implicated in inhibiting growth of new birdsfoot trefoil and red clover forage stands (Peters and Zam 1981). It would have been useful to evaluate the weed populations in the forage grass seed crops and in the following year when beans and sunflowers were grown. It would have been interesting to see if tall fescue had an effect on weed populations similar to the effect it has on trefoil and red clover. Ominski et al. (1999) found perennial alfalfa in Manitoba cropping systems shifted weed community composition away from wild oat and other summer weeds. It is not clear how forage grass seed crops would have affected weed communities in the cropping system in the present study.

In conclusion, under average moisture conditions, forage seed grasses in rotation followed by beans (shallow-rooted) or sunflowers (deep-rooted) complement root exploitation, resulting in greater rotational efficient water use over the entire cropping system compared to annual barley systems. Under excess moisture conditions even the combination of single-season forage grasses followed by a high water use annual crop (sunflower) did not provide sufficient water use intensity to deal with the extreme precipitation amounts.

6.0 References

Allen, C.L., and Entz, M.H. 1994. Zero-tillage establishment of alfalfa and meadow bromegrass as influenced by previous annual grain crop. Can. J. Plant Sci. 74:521-529.

Alvenäs, G., and Marstorp, H. 1993. Effect of a ryegrass catch crop on soil inorganic-N content and simulated nitrate leaching. Swedish J. Agric. Res. 23:3-14.

Alberta Agriculture, Food and Rural Development. Cowbytes 3.0.4. (1999) Edmonton, Alberta T6H 5TP

Angadi, S.V., and Entz, M.H. 2002a. Agronomic performance of different stature sunflower cultivars under different levels of interplant competition. Canadian Journal of Plant Science. 82: 43-52.

Angadi, S.V., and Entz, M.H. 2002b. Root system and water use patterns of different height sunflower cultivars. Agronomy Journal 94:136-145.

Anonymous. 1949. Soil Research Laboratory. Soil Moisture, wind erosion and fertility of some Canadian Prairie soils. Agric. Canada. Pub. No. 819, Ottawa.

Ash, G.H.B., Shaykewich, C.F., and Raddatz, R.L. 1992. Agricultural Climate of the Eastern Canadian prairies – A technical report. P.51, Environment Canada, Manitoba Agriculture and the University of Manitoba, Winnipeg, Canada.

Austenson, H.M., Wenhardt, A., and White, W.J. 1970. Effect of summer fallowing and rotation on yield of wheat, barley and flax. Can. J. Plant Sci. 50:659-666.

Bathke, G.R., Cassel, D.K., Hargrove, W.L., and Porter, P.M. 1992. Modification of soil physical properties and root growth response. Soil Sci. 154:316-329.

Beke, G.J., Janzen, H.H., and Entz, T. 1994. Salinity and nutrient distribution in soil profiles of long-term crop rotations. Can J. Soil Sci. 74:229-234.

Belanger, G., Gastal, F., and Warembourg, F.R. 1992. The effect of N fertilization and the growing season on carbon partitioning in a sward of tall fescue (*Festuca arundinacea* Schreb.) Ann. Bot. 70: 239-244.

Bell, C.C. 1985. Effect of defoliation frequency on simulated swards of ryegrass, tall fescue, and a 50/50 mixture of the 2 species. New Zealand J. of Agric. Res. 28: 307-312.

Bently, C.F., Peters, T.W., Hennig, A.M.F., and Walker, D.R. (eds.) 1971. Gray wooded soils and their management. Dep. of Extension Bull. No. B71-1, Univ. of Alberta, Edmonton.

Best, K.F., Campbell, J.B., Looman, J. 1971. Prairie grasses – identified and described by vegetative characters. Research Station, Swift Current, SASK. Publ. 1413, Canadian Dept. of Agriculture.

Bezdicek, D.F., and Granatstein, D. 1989. Crop rotation efficiencies and biological diversity in farming systems. Am. J. Alt. Agric. 4: 111-118.

Blackwell, P.S., Green, T.W., and Mason, W.K. 1990. Response of biopore channels from roots to compression by vertical stresses. Soil Sci. Soc. Am. J. 54: 1088-91.

Blaser, R.E., Taylor, T, Griffeth, W, Skrdla, W. 1956. Seedling competition in establishing forage plants. Agron. J. 48: 1- 6.

Bond, J.J. and Willis, W.O. 1969. Soil water evaporation: Surface residue rate and placement effects. Soil Sci. Soc. Am. Proc. 33: 445-448.

Borstlap, S, and Entz, M.H. 1994. Zero-tillage influence on canola, field pea and wheat in a dry subhumid region: Agronomic and physiological responses. Can. J. Plant Sci. 74:411-420.

Bouton, J.H., Gates, R.N., Belesky, D.P., and Owsley, M. 1993. Yield and persistence of tall fescue in the southeastern coastal plain after removal of it's endophyte. Agron. J. 85:52-55.

Bowren, K.E. 1974. Crop management on the Parkland soils of Saskatchewan. P 6-14. *In Proc.* 1974 Soil Fertility Workshop, Saskatoon, Sask. February. Extension Division Pub. No. 244, Univ. of Saskatchewan, Sask.

Brady, N.C. 1990. *The Nature and Properties of Soils* (Tenth Edition). MacMillan Publishing Company. New York, New York, USA.

Brede, A.D., and Brede, J.L. 1988. Establishment clipping of tall fescue and companion annual ryegrass. Agronomy Journal. 80:27-30.

Bremner, P.M., Preston, G.K., and Fazekas de St.Groth, C. 1986. A field comparison of sunflower (*Helianthus annuus*) and sorghum (*Sorghum bicolor*) in a long drying cycle. I. Water extraction. Aust. J. of Agric. Res. 37:483-493.

Brock, J.C., Anderson, L.G., and Lancastire, J.A. 1982. 'Grasslands Roa' tall fescue: seedling growth and establishment. New Zealand J. of Experimental Agric. 10: 285-289.

Bullied, W.J., and Entz, M.H. 1994. Using herbicides instead of tillage to remove forages stands. P. 177-183. *In Proc.* Manitoba AgriForum, Winnipeg. 5 and 6 Jan. Manitoba Institute of Agrologists, 16 Lowell, Pl., Winnipeg, MB R3T 4H8.

Bullock, D.G. 1992. Crop Rotation. Crit. Rev. Plant Sci. 11: 309-326.

Burns, J.C. and Chamblee, D.S. 2000. Summer accumulation of tall fescue at low elevations in the humid peidmont: II. Fall and winter changes in nutritive value. Agron. J. 92: 217-224.

Campbell, C.A., Lafond, G.P., Zentner, R.P., and Y.W. Jame. 1994. Nitrate leaching in a Udic Haploboroll as influenced by fertilization and legumes. J. Environ. Qual. 23:195-201.

Campbell, C.A., Zentner, R.P., Janzen, H.H., and Bowren, K.E. 1990. Crop rotation studies on the Canadian prairies. Agric. Canada Publ. 1841/E. Ottawa, ON.

Census of Agriculture. 2002. Available at www.statcan.ca/english/freepub./95F0301XIE (verified on February 18, 2002).

Chanasyk, D.S. and Naeth, M.A. 1988. Measurement of near-surface soil moisture with a hydrogenously shielded neutron probe. Can. J. Soil Sci. 68:171-176.

Chestnutt, D.M.B., Murdock, J.C., Harrington, F.J., and Binnie, R.C. 1977. The effect of cutting frequency and applied nitrogen on production and digestibility of perennial ryegrass. J. British Grassland Society. 32:177-183.

Conway, G.R. 1987. The properties of agro-ecosystems. Agric. Systems. 24: 95-117.
Cope, W.A. 1982. Inhibition of germination and seedling growth fo eight forages species by leachates from seeds. Crop Sci. 22: 1109-11.

Conner, D.J., and Hall, A.J. 1997. Sunflower physiology. Sunflower Technology and Production, Agronomy Monograph no. 35.

Conner, D.J., and Sadras, V.O. 1992. Physiology of yield expression in sunflower. Field Crops Res., 30:333-389.

Cook, R.J. 1984. Root health: importance and relationship to farming practices. In D.F. Bezdicek, J.F. Power, D.R. Keeney, and M.J. Wright (eds.). Organic farming: Current Technology and it Role in a Sustainable Agriculture. ASAS Publication 46, Madison, Wisconson. pp. 111-127.

Crookston, R.K. 1984. The rotation effect. Crops Soils. 36: 12-14.

Cruse, R.M. and Dinnes, D.L. 1995. Spatial and temporal diversity in production fields. P 73-93 *In* Olson et al. (eds) Exploring the role of diversity in sustainable agriculture. ASA-CSSA-SSSA, 677 S. Segoe Rd., Madison, WI 53711, USA

Dao, T.H. 1993. Tillage and winter wheat residue management effects on water infiltration and storage. Soil Sci. Soc. Am. J. 57: 1586-1595.

DeJong, E. and Cameron, D.R. 1980. Efficiency of water use by agriculture for dryland crop production. p. 109-144. *In* Prairie Production Symposium. Saskatoon, Saskatchewan. Canadian Wheat Board Advisory Committee.

DeJong, E., and Steppuhn, H. 1983. Water Conservation: Canadian Prairies. *In* Dryland Agriculture. Agron. Monogr. 23. ASA-CSSA-SSSA, Madison, Wisconsin.

Delgado, J.A., Riggenbach, R.R., Sparks, R.T., Dillon, M.A., Kawanabe, L.M. and Ristau, R.J. 2001. Evaluation of nitrate-nitrogen transport in a potato-barley rotation. Soil Sci. Soc. Am. J. 65:878-883.

DeWit, C.T. 1958. Transportation and crop yields. Agricultural Research Report no. 646. Wageningen, Netherlands.

Dexter, A.R. 1991. Amelioration of soil by natural processes. Soil Tillage Res. 20:87-100.

Donald, C.M. 1963. Competition among crop and pasture plants. Advanced Agron. 15: 1-118.

Dyke, G.G., and Slope, D.B. 1978. Effects of previous legume and oat cropson grain yield and take-all in spring barley. J. Agric. Science. 91:443-451.

Edwards, W.M., Norton, L.D., and Redmond, C.E. 1988. Characterizing macropores that affect infiltration into non-tilled soil. Soil Sci. Soc. Am. J. 52: 483-487.

Entz, M.H., Baron, V.S., Carr, P.M., Meyer, D.W., Smith, Jr., S.R., and McCaughey, W.P. 2002. Potential of forages to diversify cropping systems in the northern great plains. Agron. J. 94:240-250.

Entz, M.H., Bullied, W.J., Forster, D.A., Gulden, R., and Vessey, J.K. 2001. Extraction of subsoil nitrogen by alfalfa, alfalfa-wheat, and perennial grass systems. Agronomy Journal. 93:495-503.

Entz, M.H., Bullied, W.J., and Katepa-Mupondwa, F. 1995. Rotational benefits of forage crops in Canadian prairie cropping systems. J. Prod. Agric. 8:521-529.

Entz, M.H., Gross, K.G., and Fowler, D.B. 1992. Root growth and soil-water extraction by winter and spring wheat. Can. J. Plant Sci. 72:1109-1120.

Entz, M.H., and Fowler, D.B. 1989. Influence of crop environment and dry matter accumulation on grain yield of no-till winter wheat. Can. J. Plant Sci. 69:367-375.

Entz. 1988. Environmental and agronomic effects on the productivity of winter wheat in Saskatchewan. PhD thesis. Dept. of Plant Sc. University of Saskatchewan, Saskatoon, Canada.

Eriksen, J. 2001. Nitrate leaching and growth of cereal crops following cultivation of contrasting temporary grasslands. Journal of Agricultural Science. 136:271-281.

Evans, L.T., and Fischer, R.A. 1999. Yield Potential: Its Definition, Measurement, and Signficance. Crop Science. 39:1544-1551.

Fairbourn, M.L. 1982. Waater Use by Forage Species. Agronomy Journal. 74:62-66.

Fairley, N.A. and Lefkovitch, L.P. 1999. Crop density and seed production of tall fescue (*Festuca arundinacea* Schreb.) I. Yield and plant development. Can. J. of Plant Sc. 79:535-541.

Fairley, N.A. and Lefkovitch, L.P. 1993. Agronomic feasibility of producing seed of tall fescue in the Peace River region. Can. J. Plant Sci. 73:123-129.

Follett, R.F. 1989. Nitrogen management and groundwater protection. Developments in agricultural and managed. Forest Ecology 21. Elsevier, New York.

Forster, D.A. 1998. Rotational benefits associated with alfalfa. M.S. thesis. Dept. of Plant Sci., University of Manitoba, Winnipeg, MB.

Foster, A., Curry, P., McCarney, D., and Townley-Smith, L. 1996. Farm Facts: Annual Ryegrass Production in Saskatchewan.Sask Agriculture and Food Publication.

Gallagher, R.T., Campbell, A.G., Hawkes, A.D., Holland, P.T., McGaveston, D.A., and Pansier, E.A. 1982. Ryegrass staggers: The presence of lolitrem neurotoxins in perennial ryegrass seed. New Zealand Vet. J. 30:183-184.

Garwood, E.A. and Sinclair, J. 1979. Use of water by six grass species. J. Agric. Sci. 93:25-35.

Gauer, E., Shaykewich, C.F., and Stobbe, E.H. 1982. Soil temperature and soil water under zero tillage in Manitoba Canada. Can. J. Soil. Sci. 62:311-325.

Hall, R. 1991. Compendium of Bean Diseases. Pages 1-5. American Phytopathological Society Press. St. Paul, Minnesota, USA.

Halterlein, A.J. 1983. Bean. Crop – Water Relations. John Wiley and Sons. USA

Halvorson, A.D., and Black, A.L. 1974. Saline-seep development in dryland soils of northeastern Montana. J. Soil Water Conser. 29:77-81.

Haluschak, P. 2000. Soil Salinity. [Online]. Available at http://www.gov.mb.ca/agriculture/news/topcis/daa18d03.html (verified March 2, 2001).

Hayes, P. 1976. Seedling growth of four grasses. Journal of the British Grassland Society. 31:59-64.

Hattendorf, M.J., Redelfs, M.S., Amos, B., Stone, L.R., and Gwin Jr., R.E. 1988. Comparative water use characteristics of six row crops. Agronomy Journal. 80:80-85.

Hill, N.S., Belesky, D.P., and Stringer, W.C. 1991. Competitiveness of tall fescue as influenced by Acremonium coenophialum. Crop Science. 31:185-190.

Hill, M.J., Pearson, C.J., and Kirby, A.C. 1985. Germination and seedling growth of prairie grass, tall fescue and Italian ryegrass at different temperatures. Aust. J. of Ag. Res. 36: 13-24.

Hoeppner, J.W. 2001. The effect of legume green manure, perennial forages, and cover crops on non-renewable energy use in western Canadian cropping systems. M.Sc. thesis. Dept. of Plant Sci., University of Manitoba, Winnipeg, MB.

Hoveland, C.S., Schmidt, S.P., King Jr., C.C., Odom, J.W., Clark, E.M., McGuire, J.A., Smith, L.A., Grimes, H.W., and Holinan, J.L. 1983. Steer performance and association of Acremonium coenophialum fungal endophyte on tall fescue pasture. Agron. J. 75:821-824.

Hurd, E.A. 1974. Phenotype and drought tolerance in wheat. Agric. Meterol. 14:39-55.

Huyck, L and Francis, C.A. 1995. Designing a diversified farmscape. P. 95-120 *In* Olson et al. (eds.) Exploring the role of diversity in sustainable agriculture. ASA-CSSA-SSSA, 677 S. Segoe Rd., Madison, WI 53711, USA.

Jaafar, M.N., Stone, L.R., and Goodrum. 1993. Rooting depth and dry matter development of sunflower. Agron. J. 85:281-286.

Jackson, W. 1984. A search for the unifying concept for sustainable agriculture. P. 208 – 229. *In* W. Jackson, W. Berry, and B. Coleman (ed.) Meeting the expectations of the land. North Point Press, San Francisco.

Karlen, D.L., and Sharpley, A.N. 1994. Management strategies for sustainable soil fertility. *In* "Sustainable Agricultural Systems" (J.L. Hatfield and D.L. Karlen, eds.), pp. 47-108. Lewis Publ., CRC Press, Boca Raton, Florida.

Karlen, D.L., Varvel, G.E., Bullock, D.G., and Cruse, R.M. 1994. Crop rotations for the twenty-first century. Adv. Agron. 53:1-45.

Kay, B.D. 1990. Rates of change of soil structure under different cropping systems. Adv. Soil Sci. 12:1-52.

Kegode, G.O., Forcella, F., and Clay, S. 1999. Influence of crop rotation, tillage, and management inputs on weed seed production. Weed Science. 47:175-183.

Kelner, D.J., Vessey, J.K., and Entz, M.H. 1997. The nitrogen dynamics of 1-,2-,and 3-year stands of alfalfa in a cropping system. Agriculture, Ecosystems and Environment. 64:1-10.

Knaggs, P.J. 2002. Yield physiology, quality, and soil water dynamics of a semi-dwarf and tall oat (*Avena sativa* L.) cultivar. MSc. Thesis. Dept Plant Sc. University of Manitoba, Winnipeg, Canada.

Kramer, P.J., and J.S. Boyer. 1995. Water relations of plants and soils, 2nd Ed. Pp. 495. Academic Press Inc., Sand Diego.

Kunelius, T. 1991. Annual Ryegrasses in Atlantic Canada. Ag. Can. Pub. 1859/E.

Lafond, G.P., Loeppky, H., and Derksen, D.A. 1992. The effects of tillage systems and crop rotations on soil water conservation, seedling establishment and crop yield. Can. J. Plant Sci.72: 103-115.

Liebman, M., and Dyck, E. 1993. Crop rotation and intercropping strategies for weed management. Ecol. Appl. 3: 92-122.

Lindstrom, M.J., Warnes, D.D., and Evans, S.D. 1982. A water use comparison between corn and sunflowers. Journal of Soil Water Conserv. 37:362-364.

Looman, J. 1983. 111 range and forage plants of the Canadian prairies. Research Station, Swift Current, Saskatchewan. Research Branch, Agriculture Canada. Publication 1751:1-54.

Ludlow, M.M., and Muchow, R.C. 1990. A critical evaluation of traits for improving crop yields in water-limited environments. Adv. Agron. 43:107-153.

Luu, K.T., Matches, A.G. and Peters, E.J. 1982. Allelopathic effects of tall fescue on birdsfoot trefoil as influenced by N fertilization and season changes. Agron. J. 63: 614-17.

Lyon, T.L. 1927. Legumes and grasses in crop rotation. J. of American Society of Agronomy. 19:534-544.

Martens, Gary. Dept. of Plant Science. U of Manitoba. Winnipeg, Manitoba, Canada. Personal Communication.

Manitoba Agriculture and Food. 2002. [Online] Available at http://www.gov.mb.ca/agriculture/crops. (Verified on February 12, 2002).

Manitoba Field Bean Production Guide. 1998. Manitoba Agriculture and Food.

Manitoba Forage Seed Association. 2001.[Online]. Available at www.forageseed.mb.ca. (Verified on March 30, 2001)

Manitoba Forage Seed Production Guide. 1997. Forage Seed News. 3:22-24.

McCartney, Duane. 2001. Western Forage/Beef Group. Lacombe, Alberta, Canada. Personal Communication.

Mazurak, A.P., and Ramig, R.E. 1963. Residual effects of perennial grass sod on the physical properties of chernozem soil. Soil Science Society of America Proceedings. 27:592-595.

McCartney, D. 2000. Integrated backgrounding and finishing systems that target specific consumer markets. Final Report. Agriculture and Agri-Food Canada, Lacombe Research Centre, Lacombe, Alberta, Canada. T4L 1W1.

Meek, B.D., DeTar, W.R., Rolph, D., Rechel,E.R., and Carter, L.M. 1990. Infiltration rate as affected by an alfalfa and no-till coton cropping system. Soil Sci. Soc. Am.J. 54: 505-508.

Miller, R.W., and Gardiner, D.T. 2001. *Soils in our environment* (Ninth Edition). Prentice Hall. Upper Saddle River, New Jersey, USA.

Morrison, I.N., and Kraft, D. 1994. Sustainability of Canada's agri-food system: A prairie perspective. Faculty of Agricultural and Food Sciences, Univ. of Manitoba. Published by the International Institute for Sustainable Development, 161 Portage Ave., Winnipeg, Canada R3B 0X4, pp 192.

Moyer, J.R., and Boswall, A.L. 2002. Tall fescue or creeping foxtail suppresses foxtail barley. Can. J. Plant. Sci. 82:89-92.

Moyer, J.R., Blackshaw, R.E., Smith, E.G., and McGinn, S.M. 2000. Cereal cover crops for weed suppression in a summer fallow-wheat cropping sequence. Can. J. Plant Sci. 80:441-449.

Naeth, M.A., Bailey, A.W., Pluth, D.J., Chanasyk, D.S., and Hardin, R.T. 1991. Grazing impacts on litter and soil organic matter in mixed prairie and fescue grassland ecosystems of Alberta. Journal of Range Management. 44:7-12.

Norwood, C.A. 1999. Water use and yield of dryland row crops as affected by tillage. Agronomy Journal. 91:108-115.

Olson,R., and Francis, C. 1995. A hierarchical framework for evaluating diversity in agroecosystems *In* Exploring the role of diversity in sustainable agriculture. ASA, CSSA, SSSA, Madison, WI.

Olsen, R.J., Henster, R.F., Attoe, O.J., Witzel, S.A. and Peterson, L.A. 1970. Fertilizer nitrogen and crop rotation in relation to movement of nitrate nitrogen through soil profiles. Soil Sci. Soc. Am. Proc. 34:448-452.

Ominski, P.D., Entz, M.H. and Kenkel, N. 1999. The suppressive effects of Medicago sativa on weeds in subsequent cereal crops: a comparative survey. Weed Sci. 47: 282-90.

Passiora, J.B. 1991. Soil structure and plant growth. Aust. J. Soil Res., 29: 717-28.

Pavlynchenko, T. 1942. Root systems of certain forage crops in relation to management of agricultural soils. Publ. 1088. Natl. Res. Counc., Ottawa, ON, Canada.

Pearson, C.J. Mann, I.G. and Zhang, Z.-H., 1991. Changes in root growth with successive wheat crops in a cropping cycle using minimum and conventional tillage. Field Crops. Res. 28: 117-133.

Peer and Kolvec. 1964. *In* Halterlein, A.J. 1983. Bean. Crop – Water Relations. John Wiley and Sons. USA

Pierce, F.J. and Rice, W. 1988. Crop Rotation and Its Impact on Efficiency of Water and Nitrogen. ASA-CSSA-SSSA, Special Publication no.51:21-42. Madison, WI.

Peters, E.J. 1968. Toxicity of tall fescue to rape and birdsfoot trefoil seeds and seedlings. Crop Sci. 8: 650-53.

Peters, E.J., and Zam, A.H.B.M. 1981. Allelopathic effects of tall fescue genotypes. Agron. J. 73: 56-58.

Regnier, E.E., and Janke, R.R. 1990. Evolving strategies for managing weeds. In Sustainable Agricultural Systems" (Edwards, C.A., Lal, R., Madden, P., Miller, R.H., and House,G., eds.) pp. 174-202. Soil Water Conservation Soc., Akeny, Iowa.

Ridley, A.M., Simpson, R.J., and White, R.E. 1999. Nitrate leaching under phalaris, cocksfoot, and annual ryegrass pastures and implications for soil acidfication. Aust. J. Agric. Res. 50:55-63.

Ridley, A.M., White, R.E., Simpson, R.J., and Callinan, L. 1997. Water use and drainage under phalaris, cocksfoot, and annual ryegrass pastures. Aust. J. Agric. Res. 48:1011-1023.

Robinson, C.A., Cruse, R.M. and Ghaffarzadeh, M. 1996. Cropping system and nitrogen effects on mollisol organic carbon. Soil Sci.. Soc. Am. J. 60: 29-32.

Robinson, K.E.P., and Everett, N.P. 1990. Sunflower (Helianthus annus L.): Establishment of cultures, transformation, and the regeneration of plants. Biotechnology in Agriculture and Forestry 10. Legumes and Oilseed Crop I. Springer-Verlag., Germany. P 434.

Robson, M.J. 1968. The changing tiller populations of spaced plants of S. 170 tall fescue (*Festuca arundinacea*). J. Appl. Ecol. 5:575-590.

Roder, W., Mason, S.C., Clegg, M.D., and Kniop, K.R. 1989. Yield-soil-water relationships in sorghum – soybean cropping systems with different fertilizer regimes. Agron. J. 81:470-475.

Sadras, V.O., Hall, A.J., Trapani, N., and Vilella, F. 1989. Dynamics of rooting and root-length: leaf-area relationships as affected by plant population in sunflower crops. Field Crops Res. 22:45-57.

Schoofs, A., and Entz, M.H. 2000. Influence of annual forages on weed dynamics in a cropping system. Can. J. Plant Sci. 80: 187-198.

Schneiter, A.A., and Miller, J.F. 1981. Description of Sunflower Growth Stages. Crop Science. 21:901-903.

Shanholtz, V.O., and Lillard, J.H. 1969. Tillage system effects on water use efficiency. Journal of Soil and Water Conser. 24:186-189.

Sharp, W.C., Schertz, D.L., and Carlson, J.R. 1995. Forages for Conservation and Soil Stabilization. p. 243-262. In R.F. Barnes et al. (ed.) Forages II. The science of grassland agriculture. 5th ed. Iowa State Univ. Press, Ames.

Sheldon, Rodger. 2001. Agricultural Representative. Manitoba Agriculture and Food. Ste.Rose, Manitoba, Canada. Personal Communication.

Siemens, L.B. 1963. Cropping systems: An evaluative review of literature. Tech. Bull. 1. Faculty of Agric., Univ. of Manitoba, Winnipeg, MB.

Stegman, E.C. and Olsen, H.M. 1976. Res. Rep. No. 61 from Halterlein, A,J. Crop – water relations. 1983. Wiley – Interscience Publication, Toronto. P. 157-163.

Stevenson, F.C., Légère, A., Simard, R.R., Angers, D.A., Pageau, D, and Lafond, J. 1998. Manure, tillage, and crop rotation: effects on residual weed interference in spring barley cropping systems. Agron. J. 90:496-504.

Stevenson, F.C., and van Kessel, C. 1996. A landscape – scale assessment of the nitrogen and non-nitrogen benefits of pea in a crop rotation. Soil Sci. Soc. Am. J. 60:1997-1805.

Stone, L.R., Goddrum, D.E., Jaafar, M.N., and Kahn, A.H. 2001. Rooting front and water depletion depths in grain sorghum and sunflower. Agronomy Journal. 93:1105-1110.

Tanner, C.B. and Sinclair, T.R. 1983. Efficient water use in crop production: research or re-search? Pages 1-27 *in* Limitations to efficient water use in crop production (Taylor, H.M., Jordan, W.R., and Sinclair, T.T., eds) Madison, Wisconsin, USA: ASA, CSSA and SSSA.

Taylor, H.M. and Klepper, B. 1978. The role of rooting characteristics in the supply of water to plants. Adv. Agron. 30:99-128.

Tisdall, J.M. and Oades, J.M. 1982. Organic matter and water-stable aggregates in soils. J. Soil. Sci. 33:141-163.

Toai, T.V., and Linscott, D.L. 1979. Phytotoxic effect of decaying quackgrass (Agropyron repens) residues. Weed Sci. 27: 595-98.

Thiessen-Martens, J.R. and Entz, M.H. 2001. Availability of late-season heat and water resources for relay and double cropping with winter wheat in prairie Canada. Can. J. Plant Sci. 81:273-276.

Twerdoff, D.A., Chanasyk, D.S., Mapfumo, E., Naeth, M.A., and Baron, V.S. 1999a. Impacts of forage grazing and cultivation on near-surface relative compaction. Can. J. Soil Sci. 79:465-471.

Twerdoff, D.A., Chanasyk, D.S., Mapfumo, E., Naeth, M.A., and Baron, V.S. 1999b. Soil water regimes of rotationally grazed perennial and annual forages. Can. J. Soil Sci. 79:627-637.

Unger, P.W., Jones, O.R., and Steiner, J.L. 1988. Principles of crop and soil management procedures for maximizing production per rainfall. Pages 97-110. *In* Drought research priorities for the dryland tropics (Bidinger, F.R., and Johasen, C., eds) ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) Center, India.

Unger, P.W., Stewart, B.A. 1983. Soil management for efficient water use: An overview. p.419-460. *In* H.M. Taylor et al. (ed.) Limitation to efficient water use in crop production. ASA, CSSA, and SSSA, Madison, WI.

Viets, F.G. Jr. 1967. Increasing water use efficiency by soil management. p. 259-274. *In:* W.H. Pierre, D. Kirkham, J.Pesek, and R. Shaw (eds.) Plant environment and efficient water use. Am. Soc. Agron., Madison, Wisconsin.

Volenec, J.J. and Nelson, C.J. 1995 Forage Crop Mangement: Application of Emerging Technologies. p. 3-20. In R.F. Barnes et al. (ed.) Forages II. The science of grassland agriculture. 5th ed. Iowa State Univ. Press, Ames.

Wani, S.P., McGill, W.B., Haugen-Kozyra, K.L., Robertson, J.A., Thurston, J.J. 1993. Improved soil quality and barley yields with fababeans, manure, forages and crop rotation on a gray luvisol. Can. J. Plant Sc. 73:75-83.

Waterer, J.G., Vessey, J.K., Stobbe, E.H., and Soper, R.J. 1994. Yield and symbiotic nitrogen fixation in a pea-mustard intercrop as influenced by N fertilization addition. Soil Biol. Biochem. Vol 26:447-453.

Walster, H.L. 1933 Crop rotation in relation to grain production. World's Grain Exhibition and Conference. Regina, Canada.

Weston, L.A. 1996. Utilization of allelopathy for weed management in agroecosystems. Agronomy Journal. 88:860-866.

Willis, W.O., and Carlson, C.W. 1962. Conservation of winter precipitation in the northern plains. J. Soil Water Conservation. 17: 122-123.

Woodward, F.I. 1998. Do plants realy need stomata? J. Exp. Bot. 49:471-480.

Wright, A.T. 1990. Yield effect of pulses on subsequent cereal crops in the northern prairies. Can. J. Plant Sci. 70:1023-1032

Wright, G.C. and Smith, R.C.G. 1983. Differences between two grain sorghum genotypes in adaptation to drought stress. II. Root water uptake and water usage. Aust. J. Agric. Res. 34:627-636.

Yates, F. 1954. The analysis of experiments containing different crops. Biometrics 10:324-346.

Young, W.C. III. 1997. Festuca arundinacea Schreb. (tall fescue) in the U.S.A. Pages 287-296. *In*: D.T. Fairey and J.G. Hampton (eds.) Forage seed production. Volume 1. Temperate species. CAB International, Oxford, UK.

Young, W.C. III., Chilcote, D.O., and Youngberg, H.W. 1996. Annual ryegrass seed yield response to grazing during early stem elongation. Agronomy Journal. 88:211-215.

Young, C.C., and Bartholomew, D.P. 1981. Allelopathy in a grass-legume association. Crop Sci. 21: 770-74.

7.0 Appendix

Table A1. Field operations performed at Carman, Manitoba (1999 – 2001).

Date	Operation
1999	
May 27	Wheat and tall fescue seeded
July 29	Wheat taken for greenfeed
August 11	Perennial ryegrass seeded
August 27	Remaining wheat plots combined
2000	
April 27	Broadcast fertilizer
April 27	Annual ryegrass seeded
May 16	Barley seeded
May 25	Volumetric water content measurements
June 2	Dry matter samples taken
June 8	Volumetric water content measurements
June 8	Dry matter samples taken
June 28	Volumetric water content measurements
June 28	Dry matter samples taken
July 10	Volumetric water content measurements
July 10	Dry matter samples taken
July 24	Volumetric water content measurements
July 24	Dry matter samples taken
July 24	Tall Fescue harvested for seed. All tall fescue biomass removed by swathing and baling.
August 9	Dry matter samples taken
August 12	Volumetric water content measurements
August 15	Annual ryegrass, Perennial ryegrass and barley harvested for seed. All annual ryegrass, perennial ryegrass and barley biomass removed by swathing and baling.
September 7	Volumetric water content measurements
September 7	Dry matter samples taken
September 26	Volumetric water content measurements
September 26	Dry matter samples taken
October 1	All plots prayed with glyphosate at a rate of 5 L ha^{-1}
October 10	Swathed and baled and removed forage
October 11	Worked entire plot 3 times with disc
2001	
May 25	Edge and fertilizer applied, incorporated with cultivator
May 30	Sunflowers and Dry Beans seeded
June 19	All plots broadcast with additional N
June 21	Sprayed with Decis for sunflower beetles
June 22	Plant stand counts
June 24	Volumetric water content measurements
July 13	Plant development ratings
July 20	Volumetric water content measurements
August 15	Volumetric water content measurements
August 15	Dry matter samples taken
September 24	Volumetric water content measurements
September 24	Sunflowers harvested for yield
September 26	Beans harvested with combine

Table A2. Field operations performed at Winnipeg, Manitoba (1999 – 2001).

Date	Operation
1999	
June 3	Wheat and tall fescue seeded
July 5	Wheat sprayed with HoeGrass
August 11	Wheat harvested for greenfeed
August 11	Perennial ryegrass and tall fescue reseeded
September 22	Remaining wheat plots combined
2000	
April 27	Broadcast fertilizer
April 27	Annual ryegrass seeded
May 16	Barley seeded
May 26	Volumetric water content measurements
June 2	Dry matter samples taken
June 9	Volumetric water content measurements
June 8	Dry matter samples taken
June 28	Volumetric water content measurements
June 28	Dry matter samples taken
July 14	Volumetric water content measurements
July 10	Dry matter samples taken
July 31	Volumetric water content measurements
July 24	Dry matter samples taken
July 24	Tall Fescue harvested for seed. All tall fescue biomass removed with Haldrop Forage harvester
August 9	Dry matter samples taken
August 14	Volumetric water content measurements
August 15	Annual ryegrass, perennial ryegrass and barley harvested for seed
August 16	Annual ryegrass, perennial ryegrass and barley biomass removed using the Haldrop Forage harvester
September 8	Volumetric water content measurements
September 7	Dry matter samples taken
September 25	Volumetric water content measurements
September 26	Dry matter samples taken
September 30	Sprayed all plots with glyphosate at a rate of 5 L ha^{-1}
October 4	All biomass removed with Haldrop Forage harvester
October 4	Worked entire plot 3 times with disc
2001	
May 30	Edge applied and incorporated with tandem disc
June 4	Sunflowers and Dry Beans seeded
June 24	Volumetric water content measurements
July 5	Fertilizer broadcasted on all plots
July 12	Plant development ratings
July 13	Plant stand counts
July 20	Volumetric water content measurements
July 22	Sunflowers sprayed with Cymbush for sunflower beetles
August 15	Volumetric water content measurements
August 15	Dry matter samples taken
September 24	Volumetric water content measurements
September 24	Sunflowers harvested for yield.

Table A3. Dry Matter Production for forage grasses at Winnipeg and Carman, 2000. Statistical analysis was performed using log-transformed data. Means with the same letter are not significantly different ($p<0.05$).

	Winnipeg		Carman
	June 2	June 8	June 2
Annual ryegrass	5.18 b	6.75 b	5.98 c
Perennial ryegrass	7.70 a	8.47 a	7.25 b
Tall Fescue	7.97 a	8.60 a	8.17 a
Barley	3.42 c	5.68 c	6.14 c
LSD	*0.57*	*0.28*	*0.58*

Table A4. Nutrient analysis of annual ryegrass, perennial ryegrass, tall fescue and barley plots based on soil tests from NORWEST Labs for Winnipeg, Manitoba, 2001.

	Nitrogen	Phosphorous	Potassium	Sulphur
(2000 Crop)	- *Kg ha*$^{-1}$ -			
Annual Ryegrass	51.5	134.4	1015.6	50.4
Perennial Ryegrass	41.4	134.4	902.6	31.4
Tall Fescue	52.6	134.4	959.7	32.5
Barley	73.9	134.4	1007.8	83.9
Average	54.9	134.4	971.4	49.6

Table A5. Nutrient analysis of annual ryegrass, perennial ryegrass, tall fescue and barley plots based on soil test from NORWEST Labs for Carman, Manitoba, 2001.

	Nitrogen	Phosphorous	Potassium	Sulphur
(2000 Crop)	- *Kg ha*$^{-1}$ -			
Annual Ryegrass	25.8	29.1	253.1	12.3
Perennial Ryegrass	28.0	29.1	320.3	16.8
Tall Fescue	24.6	28.0	324.7	25.8
Barley	42.6	35.8	362.8	14.6
Average	30.3	30.5	315.2	17.4

Table A6. Developmental Stages of the Common Bean (Compendium of Bean Diseases (Hall, 1991)).

Stage	Description
V1	*Emergence:* from the appearance of cotyledons on the soil surface to the unfolding of the primary leaves.
V2	*Primary leaves*: from the full unfolding of the primary leaves to the unfolding of the first trifoliate leaf
V3	*First trifoliate leaf*: from the full unfolding of the first trifoliate leaf to the unfolding of the third trifoliate leaf
V4	*Third trifoliate leaf*: from the full unfolding of the third trifoliate leaf to the appearance of the first floral bud or raceme
R5	*Preflowering*: from the appearance of the first floral bud or raceme to the opening of the first flower
R6	*Flowering*: from the opening of the first flower to the expansion of the ovary after fertilization
R7	*Pod development*: from the expansion of the ovary to the elongation of the pod to its full size before increase in seed weight
R8	*Pod filling*: from the beginning of seed weight and size increase to the development of pigmentation of seeds and onset of leaf senescence
R9	*Maturity*: from initiation of senescence to complete senescence and drop in seed moisture to about 15%

Table A7. Description of Sunflower Growth Stages (Schneiter and Miller, 1981).

Stage	***Description***
Vegetative Stages	
VE	Hypocotyl arch and cotyledons have emerged through the soil surface and the first true leaf blade is < 4 cm
$V_{(n)}$	Number of true leaves (> 4 cm) are counted and expressed as V_1, V_2, V_3...
Reproductive Stages	
R1	Miniature floral head surrounded by immature bracts
R2	The internode directly below the base of the inflorescence elongates 0.5 to 2.0 cm above the nearest leaf
R3	Internode lifts inflorescence above 2.0 cm
R4	Inflorescence begins to open. Small ray florets are visible from the top.
R5	Beginning of anthesis. This stage is further divided into substages. Eg. 5.2, 5.5, 5.9 when 20, 50 and 90 % disk florets completed flowering or in anthesis
R6	Anthesis complete, ray florets wilting
R7	Back of inflorescence starts to turn light yellow
R8	Back of head is yellow. Bracts are still green.
R9	Bracts yellow and brown. Head may turn brown. Considered physiological maturity.