THE EFFECT OF NITROGEN MANAGEMENT ON DUAL-PURPOSE INTERMEDIATE WHEATGRASS (*Thinopyrum intermedium*) STANDS IN WESTERN CANADA

BY

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LIST OF ABBREVIATIONS

- ADF = Acid detergent fibre
- AMF = Arbuscular mycorrhizal fungi
- BIOM = Harvest biomass/Biomass at grain harvest yield
- BNF = Biological nitrogen fixation
- BRDC = Brandon Research and Development Centre
- CNDC = Critical nitrogen dilution curve
- CP = Crude protein
- DM = Dry matter
- FALL = Intermediate wheatgrass monoculture with 50 kg N ha^{-1} applied post grain harvest
- FERT = Intermediate wheatgrass monoculture with 50 kg N ha^{-1} applied post grain harvest
- FORCON = Stockpile grazing standard forage control
- FSB = Fall stockpiled biomass yield
- GDD = Growing degree days
- GPROT = Grain protein content
- GYLD = Grain yield
- HI = Harvest index
- INFD = Inflorescence density
- INTER = Unfertilized intermediate wheatgrass-alsike clover control
- IWG = Intermediate wheatgrass
- N = Nitrogen
- NDF = Neutral detergent fibre
- NOFERT = Unfertilized intermediate wheatgrass monoculture control
- RCBD = Randomized complete block design
- SPLIT = Intermediate wheatgrass monoculture with 35 kg N ha^{-1} applied post grain harvest and 15 kg N ha-1 applied in the subsequent spring
- SPRING = Intermediate wheatgrass monoculture with 50 kg N ha^{-1} applied in the subsequent spring
- TBIOM = Total aboveground shoot biomass yield
- TDN = Total digestible nutrient
- TSW = Thousand seed weight

ABSTRACT

Patrick M.J. Le Heiget, M.Sc., The University of Manitoba, 2025. The Effect of Nitrogen Management on Dual-Purpose Intermediate Wheatgrass (*Thinopyrum intermedium*) Stands in Western Canada. Advisor: Dr. Doug Cattani

Intermediate wheatgrass (IWG, *Thinopyrum intermedium* (Host) Barkworth & D. R. Dewey) is being bred for perennial grain production. This thesis investigated the dual-purpose use for grain and stockpiled forage production of IWG in western Canada. The first experiment, (Experiment 1), was conducted from 2019 to 2022. It consisted of four treatments tested for up to three production years at four locations in Manitoba and Saskatchewan. The objective was to determine the effect of nitrogen (N) fertility on IWG grain production (Chapter 3) and fall stockpiled biomass yield (FSB) and chemical composition (Chapter 4). Treatments were an unfertilized IWG control (NOFERT); IWG with 50 kg N ha^{-1} post grain harvest (FERT); an IWG-aliske clover (*Trifolium hybridum* L.) intercrop (INTER); and a stockpile forage control (FORCON) consisting of tall fescue (*Schedonorus arundinaceus* Schreb.) /alfalfa (*Medicago sativa* L.) /cicer milkvetch (*Astragalus cicer* L.). Nitrogen fertilization increased grain yield by 199.1 kg ha^{-1} compared with the grain yield of the NOFERT treatment in the third production year. On a dry matter (DM) basis, the FERT treatment produced a FSB and a crude protein (CP) that was similar in 3 of 5 site-years compared with that of the FORCON treatment, total digestible nutrient (TDN), NDF (neutral detergent fibre) and ADF (acid detergent fibre) were equal to or better than that of the NOFERT treatment in all 5 site-years. Fall stockpiled biomass of the FERT treatment had a TDN, NDF and ADF that was better than that of the NOFERT treatment in 2 of 5 site-years.

The second experiment, a fertility timing study (Experiment 2), consisted of four treatments at Carman, Manitoba, Canada (Chapter 5). The objective was to determine the effect of timing of N fertility applications on grain production, FSB and chemical composition. Treatments included:

unfertilized IWG control (NOFERT); IWG with 50 kg N ha^{-1} post grain harvest (FALL) or spring (SPRING) and an IWG with 35 kg N ha^{-1} post grain harvest and 15 kg N ha^{-1} the subsequent spring (SPLIT). Reported on a DM basis, the SPRING treatment produced biomass at grain harvest yield which was significantly lower than that of the NOFERT treatment. Total aboveground shoot biomass yield produced by the NOFERT treatment was significantly greater than that in the FALL treatment by 2000 kg DM ha^{-1}, and 3000 kg DM ha^{-1} more than that in the SPRING treatment. Both experiments at all sites encountered moisture limitations during the 2020 and 2021 growing seasons this occurred in 6 of the 9 site-years. The moisture deficits ranged from 50% to 93% of the 30-yr normal at Carman in the first production year and Brandon in the second production year respectively. Low moisture levels likely suppressed vegetative and reproductive development, restricting the uptake of nutrients leading to minimal, significant treatment differences. Timing of fertility changed within plant biomass allocations but did not influence grain production. These results indicate that stand age and fertility can influence grain production and biomass yield, however, stand age and fertility responses are mediated by growing conditions.

FOREWORD

This manuscript-styled thesis has been prepared according to the guidelines of the Faculty of Graduate and Postdoctoral Studies at the University of Manitoba. This thesis includes an introduction, a literature review chapter, three research chapters, and a synthesis chapter. The first chapter serves as an introduction to the core concepts and outlines the combined objectives and hypotheses examined throughout the thesis. Chapter 2 provides a review of the current literature on intermediate wheatgrass (IWG), highlighting the benefits of perennial systems, and grass-legume intercrops. Chapter 3 focuses on the effect of nitrogen sources on dual-purpose IWG systems, examining the effects on grain response variables prepared for journal submission. Chapter 4 is a research chapter of the same experiment, which studies the effect of the treatments on response variables pertaining to the yield and chemical composition of the fall stockpiled biomass. Chapter 5 examines the effect of the timing of synthetic fertilizer application on response variables considered in Chapter 3 and Chapter 4. Chapter 6 synthesizes the findings from the research chapters, discussing trends, implications, and potential directions for further research.

Contributions of Authors

The contributions of all authors are as follows for Chapters 3, 4, and 5

- Patrick M. J. Le Heiget: Conducted experiments, collected, organized, and analyzed data, interpreted results; wrote the original manuscript draft.
- Douglas J. Cattani: Acquired funding, conceptualized the experiments, provided primary administration and supervision of the project; assisted in field research; analyzed data; reviewed and edited manuscript drafts.
- Emma McGeough: Acquired funding, administered the project, assisted in field research, and reviewed and edited the manuscript draft.
- Rob Gulden: Advised on the framework for statistical analysis of the experiments.
- Bill Billigetu: Reviewed and edited Chapter 3 and oversaw the field site at Clavet, Saskatchewan.

1 INTRODUCTION

First cultivated in North America in the early 20th century (Crews & Cattani, 2018; Bajgain et al., 2023), intermediate wheatgrass (IWG, *Thinopyrum intermedium* (Host) Barkworth & D. R. Dewey) has been seeded for grazing, haying and in marginal landscapes for erosion prevention, (Favre et al., 2019). There is potential benefit for livestock producers to harvest the IWG grain and then utilize the stockpiled forage to feed cattle (Favre et al., 2019; Cattani & Asselin, 2017). Briefly, stockpile grazing is a strategy used by beef producers whereby forage is given the opportunity to accumulate following grazing or harvest towards the early-mid stage of the growing season (McGeough et al., 2017). As a perennial crop, IWG offers the advantages of perennial systems, including season-long groundcover which reduces the need for annual tillage (Duchene et al., 2019) and increased soil organic matter (Crews et al., 2016). A reduction in nitrogen (N) losses to the environment has been reported in IWG systems compared with annual cereal production (Huddle et al., 2023; Mulla et al., 2023). Soil erosion can be reduced in IWG cropping systems due to the vast root systems that the plants produce (Rasche et al. 2017; Tautges et al., 2018) and when these roots are broken down, they contribute to the soil organic carbon pool (Ryan et al., 2018; Ledo et al., 2020; Audu et al., 2022).

Grain production of IWG in Minnesota appears to rely on N rates ranging from 61 to 96 kg N ha^{-1} to meet demand (Jungers et al., 2017). While IWG can utilize higher levels of N to accumulate more biomass yield when available, the overall N required for survival is low (Fagnant et al., 2023). Increases in N rate to a maximum of 96.4 kg N ha^{-1} has been reported to increase seed yield, and vegetative biomass yield (Jungers et al., 2017); however, the positive effect of increased N on seed yields generally decreases when rates surpass 100 kg N ha^{-1}. Jungers et al. 2017 evaluated optimum N rates at five locations in Minnesota and, as a result, defined the optimum N rate as 60 to 100 kg N ha^{-1}; they reported that increased lodging frequency in the crop was likely the cause of diminishing yield at greater N rates. Yield reduction related to lodging has since been reported by additional research on N rate (Fernandez et al., 2020; Fagnant et al., 2024). Mulla et al. (2023) reported increased grain yields at two of three University of Minnesota Agricultural Experiment Station sites (Lamberton and Waseca) during the growing seasons of 2013 to 2015 in the medium rate treatment (60 kg N ha^{-1}) compared with an unfertilized treatment and an increased N rate of 120 kg N ha^{-1}. However, the higher N rate produced a greater biomass yield than the medium rate, suggesting a need to balance the two parameters. Considering the N requirements of the crop, a legume intercrop could help maintain consistent grain yields, provided interspecific interactions do not impede the development of the IWG crop.

When intercropped with a legume, ecosystem services of a perennial graminoid crop can be increased (Crews et al., 2016; Crews et al., 2018). In an intercrop system, grass can access plant-available N that has been released into the root zone by the companion legume (Tautges et al., 2018). Hayes et al. (2016) demonstrated that subterranean clover (*Trifolium subterraneum* L.) could release enough N into the root zone to support the annual N demand of a perennial grain if the grain yields were within 1.5-2.0 t/ha. An intercrop may serve to meet the N demand, while research has also demonstrated that it provides weed suppression benefits (Pinto et al., 2022). Interspecific competition should have a reduced negative impact on developing grass plants than intraspecific competition due to the differing requirements of companion plants in an intercrop (Müller et al., 2016). Therefore, matching the correct legume with IWG could serve to reduce the effect of competition on long-term grain yield. Previous research has reported that as stands aged, grain yields were more consistent in an intercrop; however, the overall grain yield achieved was lower in the intercrop than in the monoculture (Tautges et al., 2018; Favre et al., 2019). Under organic production conditions in Manitoba, intercrops with alfalfa (*Medicago sativa* L.) and yellow sweetclover (*Melilotus officinale* L.) reduced IWG grain yields while a white clover (*Trifolium repens* L.) intercrop, produced a higher grain yield, but was outcompeted by IWG (Dick et al. 2016). Therefore, further research is necessary to determine the best management practices for the system.

Intercropping of dual-purpose IWG may have a positive impact in forage chemical composition, as CP concentration of the forage produced can be increased by up to 6.5% when intercropped with a perennial legume species (Pinto et al., 2022), as well as the overall forage biomass yield can be increased compared with an IWG monoculture (Picasso et al., 2008; Mårtensson et al., 2022). Dual-purpose production refers to the ability to utilize the regrowth of IWG after grain harvest which can further increase revenue from the crop within a growing season, thereby offsetting cost associated with the grain yield deficit (Rusch et al., 2025). The stockpiled forage that accumulates after grain harvest could serve as a standing forage available for grazing later in the season (Cattani & Asselin, 2018). Based on the chemical composition concentrations reported by Favre et al. (2019), IWG stockpiled regrowth can be nutritionally adequate for growing heifers, lactating beef cows, and even dairy cows. However, this strategy should consider class and stage of cattle to ensure nutrient requirements are met (McGeough et al., 2017). This is of benefit to beef producers as grazing the forage could offer opportunity to lengthen the grazing season for mid-gestation cows (McGeough et al., 2017). Reducing the amount of confined feeding can result in significant cost savings for beef producers (McCartney et al., 2004; Baron et al., 2016; McGeough et al., 2017). With appropriate management, this dual-purpose system can provide beef producers with feed and thereby reduce the costs associated with late fall feeding of beef cattle.

Research Objectives and Hypotheses

Intermediate wheatgrass has been selected for grain production over the last few decades, with little research conducted on the dual-purpose potential of the cropping system. This novel system of dual-purpose perennial grain production has not been agronomically researched extensively on the Canadian Prairies. Therefore, the fertility requirements, the value of the stockpiled biomass yield, and grain yield characteristics need to be explored further. The experiments outlined in this thesis focus on the source and timing of additional N in the dual-purpose cropping system to maximize grain yield, forage biomass yield and chemical composition. The objectives of the experiments were:

1. Evaluate the effect of increased available N resulting from intercropping (*Trifolium hybridum* L., alsike clover) and from synthetic N application (single or split application) on grain yield, grain protein, fall stockpiled biomass yield (FSB), and chemical composition of the FSB. (Chapter 3, 4, and 5).
2. Compare the chemical composition concentrations of fall stockpiled biomass of IWG with the chemical composition concentrations of the perennial forage intercrop of tall fescue (*Festuca arundinacea* Schreb.) /alfalfa (*Medicago sativa* L.) /cicer milkvetch (*Astragalus cicer* L.) to serve as a control (Chapter 4)

The hypotheses of the experiments were that an increase in available N from synthetic application or N sharing in an intercrop would increase the grain yield, grain protein content, FSB and result in a positive effect on the chemical composition metrics considered. It was also hypothesized that the more N available in the fall from synthetic application would result in an increase in grain yield, grain protein content, FSB, and have positive effect on chemical composition metrics. The chemical composition metrics considered include total digestible nutrient (TDN), crude protein (CP) concentration, neutral detergent fibre (NDF), and acid detergent fibre (ADF). When more N is available to the IWG both overall (intercrop) and in the fall, it was hypothesized that the CP would increase, while the NDF and ADF were expected to decrease relative to the unfertilized treatment. Compared with the perennial forage control (FORCON) it was hypothesized that the fall stockpiled biomass of all IWG treatments would have a greater TDN and lower NDF and ADF, while the CP would be equal or greater than that of the FORCON treatment when more N is available to the IWG both overall (intercrop) and in the fall.

2 LITERATURE REVIEW

2.1 Current challenges in agricultural production

The intensification of annual agricultural production has been necessary to meet the global food demand as the population grows. Unfortunately, annual cropping has had adverse effects on soil, including soil erosion, which ultimately reduces overall soil quality (Crews, 2017). Currently, as a result of degradation of soil environments, the integration of perennial crops can benefit the agricultural system (Crews, 2017). Annual grain crops are grown more often than perennial grain crops, while the development and integration of perennial rice systems have improved the outlook for integration of perennial grain systems (Zhang et al., 2023). The disparity is primarily expected to result from the lower grain yield of perennial grains compared with annual grain crops (DeHaan et al., 2018; Daly et al., 2021). As perennial crops may result in economic losses, it is important to consider that financial programs may encourage more farmers to incorporate sustainable practices (Kröbel et al., 2021). Given that there are no programs to support sustainable practices, it is essential to develop dual-purpose use for human food and livestock feed to increase the value of perennial grain crops.

Drought is becoming an increasingly prevalent threat to agricultural production throughout the world (Cairns et al., 2012; Bista et al., 2018; Iqbal et al., 2020; Stutz et al., 2024). Drought can have numerous detrimental effects on production of both forage (Staniak & Kocon, 2015; Stutz et al., 2024) and grain (Cairns et al., 2012; Bista et al., 2018; Iqbal et al., 2020). When plants lack adequate moisture during development, they can experience suppressed vegetative growth which in turn reduces photosynthetic capacity and grain yield (Iqbal et al., 2020). Reduced vegetative growth also directly affects forage biomass yield, as it is the primary determinant of yield (Staniak & Kocon, 2015). The stress caused by drought can lead to the abortion of reproductive structures, limiting the number of seeds produced (Alqudah et al., 2010), or it can lead to reduced seed size (Cairns et al., 2012) thereby affecting the overall volume of seeds produced. Plants also rely on soil moisture to transport nutrients to the roots; when moisture is limited, this can lead to nutrient deficiencies (Bista et al., 2018). Finally, drought conditions can be favourable to the development of certain pest insects; when paired with the slowed crop growth rate, this can make plants more susceptible to significant damage (Li et al., 2008). When exposed to substantial drought stress, crop production can be hindered in several ways, impacting both forage and grain production systems.

2.2 Perennial cropping systems

2.2.1 Ecosystem benefits

Perennial systems can provide numerous valuable ecosystem services and environmental benefits that are generally not found in annual cropping systems (Crews, 2017; de Oliveira et al., 2020). Most of these benefits result from the protection of full season groundcover (de Oliveira et al., 2020) and the development of larger root systems which can benefit soil health (Crews, 2017). Soil health can be defined as “the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals and humans, and connects agricultural and soil science to policy, stakeholder needs and sustainable supply-chain management” (Lehmann et al., 2020). Nesting habitat for birds that nest in grasslands is an additional benefit that can be provided from cropping perennial grasses as the vegetative structure can be improved through biomass removal such as haying (Davis et al., 2017). Annual cropping systems are experiencing herbicide resistance in weeds (Duchene et al., 2019), and soil erosion (Crews et al., 2018), the prevalence of which can potentially be reduced through the management practices used in perennial cropping systems (Meiss et al., 2010; Crews et al., 2018; Ashworth et al., 2022). Due to the effects of climate change and degradation of natural resources such as soil organic matter, land-use conversion from annual to perennial cropping systems may slow the rate of organic matter loss (O'Mara, 2012; Crews & Rumsey, 2017).

2.2.2 Water Systems

Perennial crops can influence water systems in their environment. For example, in northern climates, this relationship includes the season-long groundcover previously described, which provides snow trapping, allowing winter precipitation to be held on-site, and providing plant access during the growing season (Nicholaichuk & Gray, 1986). The ability of perennial roots to penetrate to greater depths into the rooting zone distinguishes them from the annual counterparts (Crews, 2017; Rasche et al., 2017). This can be advantageous for perennials, as they can access parts of the soil that the roots of annual plants cannot. As a result, perennials generally have better water-use efficiency, which de Oliveira et al. (2020) defined as "the ratio of carbon assimilation or productivity to water loss". After individual roots die, they become available for microorganisms to break down, converting a portion to organic matter, which may result in greater soil water-holding capacity of the soil (Crews & Rumsey, 2017). Dead roots can create extensive channels in soil profiles, which can lead to quicker infiltration of surface water (Guo et al., 2019). This potential to increase infiltration rates can in turn limit surface runoff (Crews et al., 2018), which can transport of nutrients leading to contamination of waterways (Kleinman et al., 2006). Perennial plants can access greater soil depths during the growing season, allowing for increased nutrient uptake, and reducing the amount of nutrients susceptible to leaching losses (Crews, 2017).

2.2.3 Tillage practices and Soil Carbon

Shoulder-season fallow in annual systems exposes the soil surface to wind and water (Borrelli et al., 2021), thereby increasing the potential for erosion, carbon loss, and nutrient release (de Oliveira et al., 2020). Season long groundcover helps reduce tillage events over several growing seasons (Duchene et al., 2019). This reduction in tillage may be associated with higher concentrations of soil organic matter (Crews et al., 2016). Soil organic matter can influence microbial communities including symbiotic microorganisms that work with plants to increase yield and productivity (Crews et al., 2018). Live roots continuously deposit exudates into the soil profile which are then utilized by microorganisms, stimulating their growth (Ma et al., 2018). Extensive root systems can be associated with soil erosion prevention (Rasche et al. 2017; Tautges et al., 2018), as well as long term soil organic carbon sources in soil profiles (Ryan et al., 2018; Ledo et al., 2020; Audu et al., 2022). Carbon that is deposited deep into the soil by roots is decomposed and is more likely to be used in the formation of soil aggregates than surface litter (Crews et al., 2018). Based on measurements conducted by the Conservation Reserve Program in the United States, Bruce et al. (1999) estimated that establishing perennial grasses in cropped fields would result in the average deposition of approximately 0.8 Mg/ha/year of carbon in the first decade. Ultimately, the ecosystem services provided by perennials result in numerous benefits that may enhance the sustainability of agricultural systems.

2.2.4 Nitrogen retention

Intermediate wheatgrass stands are more effective at limiting N losses to the environment compared with annual cereals (Huddle et al., 2023; Mulla et al., 2023). Culman et al. (2013), reported that IWG resulted in significantly less nitrate leaching into groundwater than annual wheat (*Triticum aestivum* L.) in the second and final year of the study. These authors reported that IWG plots with 120 kg N ha^{-1} resulted in 22% less nitrate leaching than annual wheat at the same fertility rate (Culman et al., 2013). Initiatives focused on reducing N losses paired with the rising N fertilizer costs have increased the demand for alternative sources of N for crop production. Intercropping perennial legumes with IWG to facilitate N sharing in the root zone has been a focus of recent research in North America (Tautges et al., 2018; Dick et al., 2018; Olugbenle et al., 2021; Law et al., 2021; Reilly et al., 2022). Supplying N for the developing grass could reduce N losses via leaching by reducing synthetic N applications (Jensen et al., 2020). Choosing to grow a perennial grain can access nutrients at greater soil depths while limiting nutrient loss to the environment.

2.2.5 Weed suppression

Perennials can shift weed populations in a stand from persistent annual weed species in the community to a greater proportion of perennial weeds (Schipanski et al., 2017; Lanker et al., 2019; Zimbric et al., 2020). Reductions in the prevalence of herbicide resistant annual weed species could occur with a competitive perennial stand. Gill and Holmes (1997) observed the suppression of resistant ryegrass (*Lolium rigidum* Gaudin) populations in grazing research (Meiss et al., 2010). Therefore, a cropped area could experience a shift to susceptible communities if the perennial weeds are not herbicide resistant. Additionally, in certain instances the overall biomass of weeds was significantly reduced as IWG intercropped stands aged (Pinto et al., 2022). Intercropping has other potential benefits, including the ability to suppress and reduce survivorship and prominence of certain weed communities (Picasso et al., 2008; Crews et al., 2018; Ryan et al., 2018; Li et al., 2019; Law et al., 2021). The suppression of weeds observed may be due to increased shading in intercropped stands (Weik et al., 2002), and diverse plant populations may also reduce the availability of water and nutrients for weeds (Ryan et al., 2018). Efficient usage of nutrients by the crop can reduce available resources that weeds could otherwise capitalize on (Crews, 2017). Perennial crop management practices and biodiversity can reduce the relative population of annual weed species in a field.

2.3 Development of intermediate wheatgrass germplasm

2.3.1 Early development of intermediate wheatgrass cultivars

Intermediate wheatgrass has been grown in North America for pasture, hay cropping, and erosion prevention (Favre et al., 2019) since the early 20th century (Crews & Cattani 2018; Bajgain et al., 2023). Intermediate wheatgrass has been researched as a perennial forage grass in western Canada for decades. Heinrichs (1953) described the genetic variability within available populations, which provided the potential for breeding efforts to make selections to further improve the forage capability of the crop on the Northern Great Plains. Troelsen & Campbell (1959) outlined that the main benefits of IWG in Saskatchewan included strong forage biomass yield and rapid emergence. At that time, programs reported IWG seed production as low (Heinrichs, 1953; Heinrichs et al., 1962); however, this challenge has been addressed by breeding efforts. Within two decades, the new IWG cultivar named Clarke was released, boasting seed yields that were greater than the industry standards, surpassing Greenleaf and Chief by 45% and 20%, respectively (Lawrence et al., 1981). Improved seed yield did not reduce forage biomass yield; which produced dry matter (DM) yields equal to that of Chief and 7% greater than Greenleaf, and with equal or better winter hardiness than the other cultivars (Lawrence, 1981). Research has shown that the crude protein concentration (CP) of IWG forage fell within the lower groupings (Troelsen & Campbell, 1958; Lawrence et al., 1960), whereas forage biomass yield was in the top ranked groupings in most seasons (Lawrence et al., 1960). In the experiment by Troelsen & Campbell (1958) IWG that was topdressed with 50 lbs N ac^{-1} had a CP of only 5.78%, while the greatest CP of the forage grasses was recorded by topdressed Russian wild ryegrass (*Psathyrostachys juncea* Fisch.) with a value of 9.18%. The experiment by Lawrence et al (1960) was conducted to evaluate the suitability of Altai wild rye (*Leymus angustus* Trin.) for forage production. In the first year, IWG yielded 2.53 tons ac^{-1}, which was significantly greater than the other three species ranging from 1.26 to 2.12 tons ac^{-1} (Lawrence et al., 1960). For the duration of the experiment, IWG yields were not significantly different from the top yield for three of the four years of study (Lawrence et al., 1960). High forage biomass yield was crucial for further development of the forage crop, with varieties producing significantly different forage biomass yields at a post heading forage harvest; however, protein concentrations of the forage were consistent (Vogel et al., 1986). Selection allowed for the development of varieties that remained high yielding decades later (Bittman et al., 2000; Glover et al., 2004). After more than 70 years of breeding efforts in western Canada, and the United States, high quality IWG germplasm has been developed with efforts shifting focus to seed and ultimately grain yield.

2.3.2 Intermediate wheatgrass as a dual-purpose crop

The focus on developing IWG as a perennial grain crop has increased over the last few decades (Wagoner 1990; Bajgain et al., 2020; Bajgain et al., 2023). The dual-purpose aspect of the crop would allow for livestock to graze stockpiled regrowth following a grain harvest (Cattani & Asselin, 2018). Beef production contributes substantially to the Canadian GDP, generating $24 billion annually (Canadian Cattle Association, 2025). Forage stockpiling is a management system where the regrowth is left to accumulate after a harvest and then grazed in fall/early winter (McGeough et al., 2017; MacTaggart et al., 2023). This method of providing feed allows for cost savings compared with confined feeding in cow-calf operations (Baron et al., 2016) which requires harvesting of feed for later use (Baron et al., 2016) and cleaning of waste from the confinement area the following season (McGeough et al., 2017). Beef producers can also benefit by reducing costs related to seeding and harvesting that are usually encountered with annual species, as well as avoiding the requirement to have feed stored or delivered as the forage would be grazed (McGeough et al., 2017). The economic benefits of stockpile grazing can be increased when using a perennial as the cost of establishing a stand is spread over multiple growing seasons (Baron et al., 2016; McGeough et al., 2017). Dual-purpose perennial crops are valuable as they can provide ecosystem services for agricultural production systems while producing grain and forage for livestock (Pinto et al., 2022). Ongoing challenges with grain production must be addressed through advancements in crop management, and genetic selection to increase seed yield (Bajgain et al., 2023). Improved knowledge of how to manage the crop to support the development of yield components will also aid in this goal.

Before utilizing this feeding strategy, it is important to ensure nutrient requirements can be met by considering the stage and class of cattle (McGeough et al., 2017). Environmental stress such as frost and drought often result in increased nitrate levels (Hewitt, 2018, p.53) and can influence forage biomass yield and quality (Dickson, 2022, p. 99). Nitrates are of concern when feeding livestock, perennial species have a tendency for lower nitrate levels compared with annual species (Hewitt, 2018, p.53). The nutritive value of IWG has been reported to be similar to other cool-season grasses and was deemed adequate when harvested in both the spring and fall in Minnesota to meet the nutritional requirements of growing heifers and lactating beef cows (Favre et al., 2019). A study by Reilly et al. (2022) suggests intercropping IWG with legumes could help to increase nutritive value for feed. Allowing adequate time for forage to regrow must also be considered, as the growing season and length of time left for the stand to rest can impact yield and quality of the forage (McGeough et al., 2017).

2.4 Intermediate wheatgrass cropping systems

2.4.1 Nitrogen demand

Harvest and sale of agricultural products requires the input of environmental resources, one of the most prominent being N fertilizer (Crews et al., 2016). Nitrogen is a limiting nutrient for IWG grain yield (Jungers et al., 2017; Reilly et al., 2022) and the application of synthetic N has been shown to increase both vegetative biomass yield (Fernandez et al., 2020) and seed yield (Jungers et al., 2017; Fernandez et al., 2020). The seed yield increases with increasing N applications are not infinite (Jungers et al., 2017) and yield generally decreases at rates exceeding 100 kg N ha^{-1}, which is likely due to increased lodging in the crop. Based on these findings, Fernandez et al. (2020) used lower N rates (incremental increases below 80 kg N ha^{-1}) and illustrated a more linear relationship between seed yield and N rate. Fernandez et al. (2020)

reported that depending on the time of year the crop is seeded, seed yield is generally positively influenced by N application only in seasons following the first grain production year (the second year after establishment). This relationship is further supported by research from Dobbratz et al. (2023) which reported that residual N content in fertile soils can provide adequate N in younger (1-2 yr old) IWG crops, suggesting the need to customize fertility applications to specific soil conditions. Therefore, the application of supplemental N may not be necessary early in the production cycle to maximize yield, allowing for reduced inputs throughout the life of the crop.

When considering the development of the crop and a critical nitrogen dilution curve (CNDC) rather than seed yield, N demands of the crop tissue are low for maintenance and survival; however, the crop can utilize high rates of N for forage biomass yield (Fagnant et al., 2023). The CNDC refers to the minimum concentration of nitrogen required at different developmental stages to support plant growth (Gislum & Boelt, 2009). Based on this concept, the relationship is not as simple as increasing N increases grain yield; therefore, developmental characteristics need to be considered. Fagnant et al. (2023) reported that the N used in IWG grain production is invested in plant development which in turn increases the grain yield. Other research has reported that grain yield was increased when a N rate of 60 kg N ha^{-1} was applied in two of three locations in Minnesota compared with both an increased N rate and no fertility treatments (Mulla et al., 2023). The biomass yield produced in the moderate N treatment was lower than what was produced in the increased N rate treatment, this indicates a trade-off between growth and grain yield (Mulla et al., 2023). The rate of N is therefore a compromise between biomass yield of the crop and grain production.

2.4.2 Intercropping to employ biological nitrogen fixation

Producers can enhance the ecosystem benefits of perennial plants by intercropping a grass species with a legume as the biological nitrogen fixation (BNF) can reduce reliance on external N inputs (Ryan et al., 2018). Biological nitrogen fixation is achieved through symbiotic interactions between specific bacteria and the roots of legumes; this symbiotic relationship involves an exchange of sugars from plants, and plant available N from the bacteria (Khan et al., 2019). In addition to the symbiosis with bacteria, the roots of legumes, as well as those of grasses, can interact with arbuscular mycorrhizal fungi (AMF), another symbiotic organism found in soil that develops networks with plant roots (Pires et al., 2021). This relationship can result in the direct transfer of N from legume roots to grass roots via these connections (Reilly et al., 2022). When the tissues of the legume decompose, they deposit plant-available N in the root zone, which is spatially available to neighbouring plant roots in an intercropped environment (Reilly et al., 2022). The benefit of available N in the root zone from intercropped legumes has been reported to come at the expense of the overall grain yield potential (Tautges et al., 2018). However, intercropping with forage legumes could meet the annual N demand of perennial grains yielding between 1.5-2.0 t ha^{-1} (Hayes et al., 2016). The use of legumes in intercrops may serve as a suitable N source as only moderate levels of N, as low as 60 kg N ha^{-1}, are necessary to achieve peak grain yields (Mulla et al., 2023). Ryan et al. (2018) reported that intercropping a legume with perennial grass may increase the rate of BNF due to soil N reserve depletion by perennial grasses. Pinto et al. (2022) reported that intercropping IWG with spring-seeded kura clover (*Trifolium ambiguum* M. Bieb.) produced an IWG grain yield that was not significantly different than the IWG monoculture grain yields. Conversely, spring seeded red clover (*Trifolium pratense* L.) resulted in a significant reduction in IWG grain yield (approximately 1/30 of the yield achieved in the monoculture), while an intercrop with spring frost seeded red clover produced an IWG grain yield that was not significantly different than the monoculture (Pinto et al., 2022). This illustrates the importance of selecting a companion legume species that is less competitive with IWG and the timing of establishment of the intercrop in the dual-purpose system to benefit IWG establishment (Pinto et al., 2022). The development of more perennial grain crops for large-scale field production is underway (Crew & Cattani, 2018), including perennial pulses that can serve as a companion crop for perennial cereal grains. This novel grain system, i.e. intercropping grass and legume species that are both grains, could potentially result in overyielding of grain due to the effects of BNF (Li et al., 2007). The potential reduction in the use of external N inputs during the life cycle of the crop, would be expected to reduce the cost of production of the system (Hayes et al., 2016). Therefore, there is potential for intercropped legumes in perennial grain stands to provide many important ecological goods and services while increasing the economic value of the crop.

2.4.3 Crop development

A better understanding of the development of dual-purpose IWG is needed to increase the harvest index and grain yield potential. Intermediate wheatgrass is a photosensitive perennial grass that is adapted for cool-season environments (Mitchell et al., 1998). Like many other perennials, IWG relies in part on the development of rhizomatous structures for survival (Fagnant et al., 2023). A two-step induction process is necessary for the initiation of the reproductive process of many perennial temperate grasses (Heide, 1994; Aamlid, 2000). Intermediate wheatgrass is reliant on this process, with the first step of reproductive induction of IWG beginning with autumn vernalization with secondary induction in the spring when exposed to the appropriate short nights, which in turn activates the dormant reproductive structures (Cattani & Asselin, 2018; Duchene et al., 2021). These reproductive tillers are capable of producing grain, thus contributing to overall yield if timed correctly (Heide, 1994). Therefore, reproductive development and induction are time sensitive processes (Jónsdóttir, 1991; Sylvester & Reynolds, 1999). Recent research has focused on the minimum requirements needed to develop viable inflorescences including increased period of cold temperatures for vernalization, and number of growing degree days (GDD) required prior to secondary induction (Duchene et al., 2021; Fagnant et al., 2023). Growing degree days is a method of quantifying thermal time to predict the rate of crop development (McMaster &Wilhelm, 1997), determining the requirement for viable reproductive development is imperative. Autumn vernalization and spring day length cannot be controlled, therefore activation and recruitment of tillers by means of agronomic management need to be considered. A possible agronomic approach to initiating reproductive development can be related to N concentrations in the soil, as increased concentrations have been reported to activate dormant apical meristems of grass species (Williamson et al., 2012). This relationship highlights the potential to enhance crop yield through effective agronomic management; however, the emphasis on investing resources in vegetative growth rather than reproduction complicates this practice, making timing of application critical.

Clonal development has an evolutionary benefit in many species (Yun et al., 2014). However, when grain yield is the primary production goal, clonal growth appears to be a potential limitation as some farmers who were interviewed explained that they believe the cause of yield decrease in IWG stands is related to tiller populations (Lanker et al., 2019). This perception is consistent with research in Europe, where the optimum inflorescence density is reported as 400 - 660 inflorescences m^{-2}, with greater densities increasing intraspecific competition (Fagnant et al., 2024). Research on IWG grain yield has shown that the trend of decreasing grain yield as the stand ages may result from limited soil nutrient resources as the crop depletes soil reserves over multiple seasons (Tautges et al., 2018). This decline in grain yield is a recurring issue, typically observed after two production years (Tautges et al., 2018; Lanker et al., 2019; Li et al., 2019). However, Fagnant et al. (2024) reported in an experiment that was conducted over four grain production seasons that maintaining a favourable tiller density, which can be influenced by N fertility, may reduce the effects on grain yield as the stand ages.

2.4.4 Crop management

To enhance the use of IWG in forage and grain production systems, consideration of alternative production strategies including intercropping and grazing, is necessary, and therefore the effects on subsequent grain yields should be evaluated. Intercropping can help increase the value of the crop by increasing the quantity and enhancing the chemical composition of forage (Favre et al., 2019). Species diversity provided through intercropping may prove to be a means of maintaining long-term grain yield of the IWG crop; grain yield of IWG has shown greater consistency when grown as an intercrop with alfalfa (*Medicago sativa* L.), with a 65% yield reduction from the first to the third production year, compared with 90% yield reduction in the unfertilized monoculture control (Tautges et al., 2018). This may be achieved by reducing intraspecific competition and replacing it with interspecific competition. Interspecific competition is expected to be less detrimental to a plant than intraspecific competition, particularly in terms of niche utilization and coexistence (Müller et al., 2016). Intercropping would then be expected to be optimal for a perennial IWG stand. As previously described, intercropping without a yield penalty occurred when red clover was seeded in the fall; however, spring seeding of red clover resulted in a significant reduction in grain yield (Pinto et al., 2023). Given benefits of delayed seeding, intercropping for the entire life of the stand may not be the ideal strategy, however it may be an effective tool to use at some point in the system. With that in mind, disruption caused by direct seeding a legume into an established stand could be beneficial, similar to what producers Lanker et al. (2019) reported where interrupting the stand via tillage had maintained productivity in some instances. Therefore, specialized intercropping could be necessary to produce maximum yields while maintaining consistency in subsequent growing seasons.

2.5 Marketable attributes

As a perennial crop, the producer can harvest and sell their grain for human consumption across multiple growing seasons with reduced mechanical interventions and labour requirements. However, as previously described grain yields are lower what can be achieved by their annual counterparts (Ryan et al., 2018; DeHaan et al., 2018). Fortunately, producers should be able to harvest and then stockpile feed, and graze cattle on the regrowth that has accumulated following a grain or forage harvest during the same growing season (Cattani & Asselin, 2018). Stockpile grazing can reduce the costs and labour associated with confined feeding during the winter (Baron et al., 2016; McGeough et al., 2017). The economics of the perennial grain production system are a limiting factor given the reduced grain yield (Law et al., 2022) and lack of payments for ecological goods and services. To compensate for the grain yield deficit, the biomass yield produced by the crop can serve as another potential source of revenue (Rusch et al., 2025).

2.5.1 Grain quality and utilization

"Kernza®" IWG grain is characterized by high protein levels and other dietary benefits compared with annual wheat (Zhang et al., 2015; Bharathi et al., 2021; Cetiner et al., 2023). Although the protein levels are higher in IWG, the proteins consist of lower levels of glutenins, and a higher proportion of gliadins, leading to weaker complex formations (Cetiner et al., 2023). Annual wheat marketing systems allow for premiums for increased grain protein (Dick et al., 2016); therefore, there is potential for premiums based on protein content in IWG production. Proteins that are present in IWG grain are generally not as effective as wheat gluten proteins for bread making (Marti et al., 2016). However, Zhang et al., (2015) reported differences in dough chemical composition among different populations, suggesting cultivar-specific variation in suitability for bread making. With an increased emphasis on agricultural sustainability, there is growing interest in the end uses for the grain, including bread dough enriched with IWG flour (Marti et al., 2016; Cetiner et al., 2023) and malted beverages (Marcus & Fox, 2022). Unfortunately, studies have suggested that the addition of IWG flour may reduce the structural and chemical composition of bread; however, the nutritional profile of the flour contains elevated levels of antioxidants, carotenoids, and phenolic compounds (Cetiner et al., 2023). Kernza® flour is now available on a larger scale with the release of the first cultivar (Bajgain et al., 2020) and other end products including pancake batters, pastas, and crackers, continue to be developed.

2.5.2 Chemical composition of stockpiled biomass yield post grain harvest

The forage produced in grass monoculture systems can benefit from supplemental N fertility (Sauvé et al., 2010). Grass species generally produce forage with lower CP concentrations and higher NDF concentrations than legumes, however, there is potential for some cool-season grasses to achieve similar CP concentrations to legumes (Collins & Fritz, 2003). Increased synthetic N rate can benefit CP concentration of forages (Sauvé et al., 2010; Teuber et at., 2020; Antunes et al., 2021; Erketin et al., 2022). The application of synthetic N at a relatively low rate of 50 kg N ha^{-1} resulted in no significant effects on NDF and ADF as demonstrated in the experiment studying Italian ryegrass (*Lolium multiflorum* Lam.) with a rate of 150 kg N ha^{-1} needed to improve NDF and ADF concentrations (Ertekin et al., 2022). Increasing the rate of synthetic N has also demonstrated no significant effect on TDN in an experiment that tested cutting frequency and N rate on orchardgrass (*Dactylis glomerata* L.) forage (Reynolds et al., 1969).

Intercropping grasses with legumes can benefit the forage produced (Favre et al., 2019). Forage CP concentration may be increased when intercropped with a perennial legume species (Pinto et al., 2022); however, this can limit grain yield of IWG (Tautges et al., 2018; Favre et al., 2019). Biligetu (2014) reported that the DM yield of alfalfa-grass intercrops was increased in comparison with grass monoculture and grass-legume intercrops with sainfoin (*Onobrychis viciifolia* Scop.) or cicer-milkvetch (*Astragalus cicer* L.). A study in Alberta evaluated stockpiling potential of perennial forages, from October to April reported the leaf loss of the alfalfa was 43%, timothy (*Phleum pratense* L.) was 3%, and Kentucky bluegrass (*Poa pratensis* L.) was 7% (Baron et al., 2014). It is likely that leaf loss is related to the increased NDF concentration from October to April in all forage species included in the study, most notable was alfalfa, losses were as follows: alfalfa (255g/kg), meadow bromegrass (*Bromus biebersteinii* Roem. & Schult.)/alfalfa (149g/kg), meadow bromegrass (150g/kg), 151 g/ka for smooth bromegrass (*Bromus inermis* Leyss.), orchardgrass (139g/kg), timothy (150g/kg), 145 g/kg for crested wheatgrass (*Agropyron cristatum* L.), Kentucky bluegrass (105g/kg), 145 g/kg for creeping red fescue (*Festuca rubra* L.), and 133 g/kg for quackgrass (*Elymus repens* (L.) Gould). Due to the increased NDF that results with leaf loss, grazing is recommended to take place prior to leaf loss to ensure suitability for cattle (Peng, 2017). Results from an experiment conducted in Manitoba with 23 forage treatments (8 monoculture and 15 grass-legume intercrop) under a stockpile system reported greater yield and lower nutritive value in grasses compared with grass-legume intercrops and legumes, with the lowest yield in the legumes (Hewitt, 2018). A study in Saskatchewan evaluated stockpiled forage potential of several species and reported an increased CP concentration and TDN in legume species compared with grasses (Peng, 2017). Forage chemical composition is important as it allows producers specializing in grain production to sell feed/straw to the livestock sector.

The ability to produce feed for livestock (either as hay or grazed pasture) from the same area in the same growing season as a grain harvest is a benefit that should be considered in the economic/environmental value of IWG (Bell et al. 2008). As IWG grain is generally harvested in late summer, and pending sufficient fall moisture, the accumulation of regrowth could provide an alternative to traditional grasses and legumes for shoulder season grazing of the cow-calf herd. A nutritious stockpiled forage with sufficient yield could extend the time on pasture into the late fall/winter in western Canada (McGeough et al. 2017). It is also important to note that removal the of regrowth conducted as a surrogate to grazing in experimental research appears to not damage the subsequent development (Sakiroglu et al., 2020) and instead potentially serve as a benefit in terms of grain yield and forage biomass yield in the following growing season (Pugliese et al., 2019). It was reported that additional biomass removal initiates greater root production thereby benefiting subsequent yields (Pugliese et al., 2019). In Minnesota, Rusch et al. (2025), reported a significant grain yield increase (27%) in four-year-old IWG stands grazing by 31 cow-calf pairs and 2 heifers was incorporated, compared with their control system that consisted of grain harvest and straw removal. Therefore, making full use of the forage by grazing stockpiled regrowth can increase revenue within the seasons and benefit the subsequent grain yields. Producers will need to determine the most efficient strategies for their cropping system and remain flexible to generate the greatest revenue from the crop.

2.6 Summary

Perennial cropping systems offer potential environmental benefits over annual systems (Crews et al., 2018); however, the economic value of perennial systems are difficult to assess (Kröbel et al., 2021). Producers have numerous decisions to make, including the use of forage, landscape management, and intercropping with N fixing legumes when integrating perennials into an annual rotation (Ryan et al., 2018). It is critical to consider the effects of climate as moisture limitations can cause reduced growth rates and ultimately forage biomass yield (Staniak & Kocon, 2015) as well as reduce grain yield (Iqbal et al., 2020). Ultimately, maximizing economic return of the field will likely be a significant influence for adoption (Kröbel et al., 2021). Intermediate wheatgrass has a lower N demand to meet its grain yield potential than annual cereal crops such as corn (*Zea mays* L.) and annual wheat (Jungers et al., 2017) paired with its ability to mitigate N loss to the environment (Mulla et al., 2023). Intercropping with a legume species can increase the chemical composition of grain (Li et al., 2019), as well as the forage produced in perennial grain cropping systems (Ryan et al., 2018, Favre et al., 2019) and potentially support the long-term grain yield of the stand (Tautges et al., 2018). Forage biomass yield can also increase in grass-legume intercrops (Pinto et al., 2022), leading to greater income, provided the producer has the means to utilize it effectively. Intermediate wheatgrass is a crop to consider including in agricultural production systems in western Canada as it can combine ecosystem benefits with management flexibility to potentially optimize yields of grain and forage produced.

3 Grain yield potential of intermediate wheatgrass in western Canada

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3.1 Abstract

Intermediate wheatgrass (*Thinopyrum intermedium*; IWG) is a temperate perennial grass capable of performing in dual-purpose perennial grain cropping systems. It is valued for its ecosystem services and forage yield and quality that can be utilized in many livestock systems. Development for potential perennial grain yield has been the focus of breeding programs for more than two decades and agronomic management is becoming important as commercialization of the crop has occurred. This research focused on nitrogen management and intercropping of IWG on grain yield and yield components in western Canada. Treatments consisting of a non-fertilized control, an interseeded crop with IWG/*Trifolium hybridum* and a fertilized treatment (50 kg N ha^{-1}) were investigated at four locations. Drought conditions were experienced in some years resulting in the loss of the interseeded crop at three locations. Fertilization with nitrogen increased grain yield in harvest years two and three and influenced yield components in at least one instance across locations. Third year grain harvests were higher or equal to year one yields at the two locations harvested with applied N increasing yield on average by 200 kg ha^{-1} in year three. Inflorescence density is an important yield component after the first production year. Potential for consistent grain yields across three reproductive years was demonstrated, enhancing the potential for sustained productivity.

Keywords: intermediate wheatgrass; perennial grain; intercropping; grain production; *Trifolium hybridum*; nitrogen management

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3.2 Introduction

Intermediate wheatgrass (*Thinopyrum intermedium*, (Host), Barkworth and Dewey; IWG) has been gaining interest over the last decade for dual-purpose perennial grain production (Bajgain et al., 2020; Bajgain et al., 2022). Perennial dual-use crops allow for production of a grain crop and the potential to graze the regrowth (Cattani & Asselin, 2018b). They are valued for their flexibility within a production system as well as the potential ecological benefits that they can provide (Hunter et al., 2020). First cultivated in North America in the early 20th century (Bajgain et al., 2022; Crews & Cattani, 2018), IWG has been sown on marginal landscapes for erosion prevention, in pastures for grazing, and in fields for hay cropping (Favre et al., 2019). Institutions in North America and Europe have been working to increase the grain yield through breeding efforts and management (Bajgain et al., 2022). Advancements have been made, with a cultivar being commercialized in the last few years (Bajgain et al., 2020). However, challenges include increasing seed yield of this obligate outcrossing species through a combination of genetic selection and better within crop management (Bajgain et al., 2022). Grain yield must be increased and be consistent across years to allow for large-scale production and adoption. Improved knowledge of important yield components will aid in this goal.

The ecological benefits of perennials such as IWG include the ability to influence soil health, and when intercropped with legumes, the system can employ biological nitrogen fixation which provides nutrients and reduces reliance on external inputs (Crews, 2017). Widely practiced annual systems are experiencing herbicide resistance (Duchene et al, 2019), erosive events (Ashworth et al., 2022) and water limitations (Crews et al., 2018) all of which can potentially be mitigated by perennial cropping with appropriate management (Ashworth et al., 2022; Crews et al., 2018; Meiss et al., 2010). At this time, due to the rate of degradation of natural resources, agriculture can benefit from such a land-use change with some experts suggesting that the implementation and regeneration of perennial systems can slow the rate of organic matter degradation and potentially restore what has been lost (O'Mara, 2012; Crews & Rumsey, 2017).

Perennial crops are rarely being grown compared with their annual counterparts although the recent success of perennial rice has increased expectations (Zhang et al., 2023). Grain yield deficit when compared with annual grain crops is the primary reason for lack of adoption (DeHaan et al., 2018; Daly et al., 2021). As a result, the added economic value of perennial grain crops such as dual-purpose IWG for food and feed are critical to their adoption as ecological benefits are not currently compensated for (Klitgaard, 2020).

As with annual cereal production, nitrogen is a limiting nutrient for IWG grain yield (Jungers et al., 2017; Reilly et al., 2022). A recent report illustrated that the nitrogen required by IWG for grain production does not directly affect the grain, but rather the development of the plant, increasing the grain yield potential (Fagnant et al., 2023). The addition of synthetic nitrogen in modest amounts has proven to benefit grain yield in IWG stands (Jungers et al., 2017). Recently, a report demonstrated that 60 kg N ha^{-1} provided a higher grain yield with lower biomass production than a higher rate or if no fertility added, indicating a balance between grain production and growth (Mulla et al., 2023). Increasing input costs and initiatives to reduce nitrogen losses has led to a demand for alternative sources of nitrogen that can meet the crop needs. Research has evaluated the effect of intercropping IWG with perennial legumes to benefit from nitrogen sharing in the root zone (Reilly et al., 2022; Tautges et al., 2018; Dick et al., 2018, Olugbenle et al., 2021). Intercropping has demonstrated some potential to provide more persistent grain yields as the stand ages (Tautges et al., 2018). As moderate levels of N appear to provide good grain yields (Mulla et al., 2023), the use of legumes appears to have some potential. Therefore, the incorporation of a legume could serve as an effective alternative to limit the need for N inputs throughout the life of the stand.

The developmental pattern for many perennial temperate grasses includes a two-step induction process (Heide, 1994; Aamlid, 2000). Reproductive induction of IWG follows that rule; starting with vernalization in the autumn and completing reproductive induction when exposed to the appropriate short nights during the spring months (Duchene et al., 2021). Factors driving induction in the field cannot be easily controlled, therefore it is necessary to explore interventions that can influence the activation and recruitment of tillers, providing materials for this process. Activation of dormant apical meristems of certain grass species can be affected by the nitrogen level in the soil (Williamson et al., 2012). This alternative presents potential agronomic avenues to increase the yield potential, however IWG as a crop has a low reliance on nitrogen to produce aboveground biomass (Fagnant et al., 2023), leading to a more complex relationship than initially envisioned.

The harvest index of IWG can be potentially increased with a better understanding of the development of the crop. *Th. intermedium* is a cool-season, perennial grass that is photoperiod sensitive (Mitchell et al., 1998). Development of rhizomatous structures is a survival strategy that many perennials, IWG included (Fagnant et al., 2023), utilized to increase their presence and prominence in a stand (Crews et al., 2016). This growth habit can result in the development of reproductive tillers from rhizomes in concert with axillary buds from existing aerial tillers

(Sylvester & Reynolds, 1999), potentially resulting in inflorescences that may contribute to overall grain yield (Heide, 1994). However, requirements needed for timing of reproductive induction and timing of development (Sylvester & Reynolds, 1999; Jónsdóttir, 1991) are only now being uncovered (Fagnant et al., 2023; Duchene et al., 2021).

The focus of this research was on nitrogen management in the production system and the effect that intercropping with a perennial legume can have on grain yield and yield components in western Canada. Three treatments consisting of a non-fertilized control, an interseeded crop with *Trifolium hybridum* and a fertilized treatment (50 kg N ha^{-1} post grain harvest) were evaluated at four locations in Prairie Canada.

3.3 Materials and Methods

3.3.1 Experimental locations

The experiment was conducted at four locations in western Canada over four growing seasons, with location, soil types seeding dates, and plot sizes are found in Table 3.1. In 2019, small plot trials were established. The first small plot trial was located at the University of Manitoba's Ian N. Morrison Research Farm near Carman, Manitoba (hereafter known as Carman). The second location was Agriculture and Agri-Food Canada's Brandon Research and Development Centre near Brandon, Manitoba (hereafter known as Brandon). The third small plot location was at the University of Saskatchewan's Livestock and Forage Centre of Excellence located near Clavet, Saskatchewan (hereafter known as Clavet). The large plot grazing study was established at the University of Manitoba's Glenlea Research Station in 2020 near Glenlea, Manitoba (hereafter known as Glenlea) which was grazed by beef cattle in Fall 2021. However, due to catastrophic flooding in the region in the spring of 2022, which resulted in the loss of the field trial, only one production year occurred.

Table 3.1. Location, soil and plot information for the four experimental sites in Manitoba and Saskatchewan.

Location	Location	Soil factors			Seeding date	Years in stand	Plot size
		Series	Texture	Description			
Brandon[*]	(49.869264, 99.978605)	Wheatland	Sand	Orthic Black Chernozem	May 28, 2019	2019-2022	73 m^2
Carman[*]	(49.501523, 98.027554)	Denham	Loam	Orthic Black Chernozem	July 19, 2019	2019-2023	60 m^2
Clavet[**]	(51.935479, 106.381302)	Bradwell	Loam	Dark Brown Chernozem	May 15, 2019	2019-2021	50 m^2
Glenlea[*]	(49.649324, 97.119810)	Scanterbury/ Red River	Clay	Gleyed / Gleyed Rego Black Chernozem	May 27-29, 2020	2020-2021	1.11 ha

[*] Manitoba Agriculture, Food and Rural Initiatives (2010)
[**] Saskatchewan Soil Information System (2018)

3.3.2 Experimental design

The experiment was arranged in a randomized complete block design (RCBD) with four replicates and was designed to test the effects of the presence of nitrogen in both synthetic and organic forms on grain yield characteristics of dual-purpose IWG systems. It consisted of three treatments; an unfertilized intermediate wheatgrass (IWG; *Thinopyrum intermedium,* (Host), Barkworth and Dewey) monoculture (NOFERT), an IWG monoculture that was fertilized with 50 kg of nitrogen ha^{-1} after grain harvest (FERT), and an IWG-alsike clover intercrop seeded at 50:50 IWG: alsike (INTER). The IWG seed sourced for these studies was Syn2 seed of a ten-clone synthetic developed at the University of Manitoba from selections for long-term grain yield capability (Cattani, 2017). At Carman and Brandon, there were two plots of each treatment in each replicate as a fall and spring biomass and feed quality sample for was planned to look at the forage quality of the regrowth. The lack of significant differences between these two regrowth harvest treatments allowed for the removal of this level of treatment.

The trials were conducted under dryland conditions and each location varied in terms of plot size as outlined in Table 3.1 due to limitations with seeding equipment. All sites were soil tested pre-planting and nutrient levels were brought to those for perennial forage establishment in western Canada. All plots were planted at 30 cm row spacings for IWG. The intercrop treatment had alsike clover and IWG planted in alternate 15 cm (IWG every 30 cm). The IWG was seeded at a rate of 6 kg ha^{-1} in all plots, and the alsike clover was seeded at 1 kg ha^{-1} alongside the IWG in the intercropped plots. To reduce the risk of interspecific competition in the emergence and seedling stage, alternate row planting was utilized. The FERT treatments received 50 kg N ha^{-1} of broadcasted urea post grain harvest, before September each season, similar to the fertility regime used in the selection nursery for the parentals (Cattani, 2017).

3.3.3 Experimental conditions

Drought was a widespread problem throughout the Canadian Prairies from 2019-2022. Some locations experienced it for several consecutive years while others experienced single growing seasons of drought conditions. Based on the data in the Tables 3.2-3.5 and Fig. 3.1, each of the locations experienced at least one growing season with below normal annual precipitation totals with some receiving slightly over 50% of the 30-yr average. It is worth noting that at BRDC in 2020, the precipitation total for the season was near normal, however over 25% of the total precipitation that season fell in a 24-hr period (June 28) and 50% within the seven-day period of June 28-July 4, 2020 (Fig. 3.1).

Table 3.2. Mean daily temperature and total monthly precipitation for 2019-2022 at Carman MB, and 30-year average (1989-2018).

	Mean daily temperature (°C)					Total precipitation (mm)				
Month	**2019**	**2020**	**2021**	**2022**	**30 yr***	**2019**	**2020**	**2021**	**2022**	**30 yr***
January	-17.1	-12.4	-9.3	-17.7	-15.2	12.9	14.0	2.5	13.8	15.5
February	-20.6	-12.4	-17.0	-18.9	-12.5	35.1	1.6	3.8	20.6	13.8
March	-7.0	-4.9	0.0	-7.6	-5.3	1.4	2.6	2.6	18.9	21.4
April	4.8	1.6	3.4	-1.0	4.1	17.8	24.7	9.4	127.3	28.9
May	9.6	10.8	10.8	10.8	11.5	36.9	27.8	27.2	110.1	78.5
June	17.3	18.3	19.3	17.5	17.1	37.9	70.2	102.9	39.4	98.0
July	19.5	20.3	21.2	19.2	19.3	57.7	52.9	17.2	82.8	70.4
August	18.1	18.4	18.2	19.3	18.6	61.7	24.3	78.0	48.9	68.6
September	12.6	12.3	15.7	14.3	13.5	150.7	10.8	16.5	26.7	51.4
October	2.9	2.1	8.4	6.4	5.6	54.1	17.2	79.6	27.5	39.0
November	-5.5	-3.2	-1.6	-4.4	-4.0	16.6	4.2	23.8	14.4	23.5
December	-11.4	-6.9	-12.7	-13.9	-11.7	2.7	17.5	17.6	9.8	22.3
Mean/Total	1.9	3.7	4.7	2.0	3.4	485.5	267.8	381.1	540.2	531.3

Table 3.3. Mean daily temperature and total monthly precipitation and for 2019-2022 at Brandon, MB, and the 30-yr averages (1989-2018).

	Mean daily temperature (°C)					Total precipitation (mm)				
Month	**2019**	**2020**	**2021**	**2022**	**30 yr***	**2019**	**2020**	**2021**	**2022**	**30 yr***
January	-18.1	-13.8	-10.8	-18.1	-16.3	20.3	11.1	8.7	36.2	17.6
February	-22.6	-12.6	-19.4	-19.5	-14.0	24.4	1.8	12.1	25.1	13.8
March	-8.2	-5.4	-1.0	-7.7	-6.5	2.6	5.0	6.8	8.3	26.3
April	4.2	0.9	3.0	-0.7	3.6	14.0	23.8	13.7	44.5	25.9
May	8.9	10.4	10.0	10.2	10.9	43.2	8.2	26.2	125.8	63.9
June	16.3	17.5	18.3	16.5	16.4	78.2	217.0	102.7	98.8	94.0
July	19.1	20.0	20.4	19.3	18.9	41.2	59.1	29.6	85.7	66.9
August	16.8	18.3	17.1	18.9	18.0	74.9	58.6	159.9	28.4	58.6
September	12.4	11.4	14.9	13.5	12.6	176.2	13.8	20.7	23.8	39.8
October	2.4	0.8	7.2	5.5	4.5	50.0	10.1	23.3	16.1	32.4
November	0.6	-4.5	-3.2	-6.0	-5.3	17.6	1.5	15.2	10.3	20.0
December	-12.7	-8.7	-15.6	-16.5	-13.9	3.1	19.6	27.9	9.6	22.9
Mean/Total	1.6	2.9	3.4	1.3	2.4	545.7	429.6	446.8	512.6	482.1

Table 3.4. Mean daily temperature and total monthly precipitation and mean daily temperature for 2019-2021 at Clavet, SK, and the 30-yr average (1989-2018).

	Mean daily temperature (°C)				**Total precipitation (mm)**			
Month	**2019***	**2020**	**2021**	**30 yr****	2019*	2020	2021	30 yr**
January	-14.1	-13.3	-10.7	-13.9	7.2	24.3	3.0	9.5
February	-24.2	-10.8	-19.3	-15.0	11.1	3.5	2.3	6.8
March	-6.1	-6.6	-1.2	-6.2	2.7	30.2	15.2	10.8
April	4.8	0.0	4.5	3.2	0.4	27.4	8.5	18.3
May	9.7	11.4	10.6	11.4	4.4	47.0	41.2	39.3
June	16	15.3	18.8	16.2	84.8	94.6	39.0	73.9
July	17.8	18.8	21.9	18.8	67.6	34.6	8.5	51.3
August	15.4	18.6	17.8	17.6	20.3	26.5	42.2	31.2
September	12.3	12.3	13.8	12.9	39.5	17.1	23.8	24.3
October	0.8	1.4	5.5	3.9	11.2	7.7	6.7	16.8
November	-5.5	-5.7	-3.6	-6.6	13.1	58.5	10.2	15.7
December	-12	-9.5	-18	-13.3	4.1	7.3	9.9	6.7
Mean/Total	1.2	2.7	6.5	2.4	266.4	378.7	183.7	304.6

*Observations recorded at the Saskatoon water treatment plant.

Table 3.5. Mean daily temperature and total monthly precipitation and mean daily temperature for 2020-2021 at Glenlea, MB and the 30-yr average (1990-2019).

	Mean daily temperature (°C)			**Total precipitation (mm)**		
Month	**2020***	**2021***	**30 yr****	**2020***	**2021***	**30 yr****
January	-12.4	-10.4	-16.4	7.1	3.6	19.9
February	-13.1	-17.7	-13.2	0.9	2.9	13.8
March	-4.8	-0.1	-5.8	3.9	7.3	24.5
April	2.0	3.7	4.4	15.9	24.8	30.0
May	11.0	11.5	11.6	11.6	18.3	56.7
June	19.2	20.2	17.0	49.4	60.6	90.0
July	21.1	22.1	19.7	43.9	9.6	79.5
August	19.3	19.0	18.8	88.7	95.1	77.0
September	12.3	16.2	12.7	20.8	11.8	45.8
October	2.1	9.0	5.0	11.7	52.6	37.5
November	-3.3	-2.6	-4.9	3.4	32.7	25.0
December	-8.2	-13.3	-13.2	16.7	14.2	21.5
Mean/Total	3.75	4.8	3.0	274.0	333.5	521.2

*Observations recorded at the Government of Manitoba St. Adolphe weather station.
**30-yr average based on Environment Canada recordings at the Richardson International Airport in Winnipeg, Manitoba from 1990-2019.

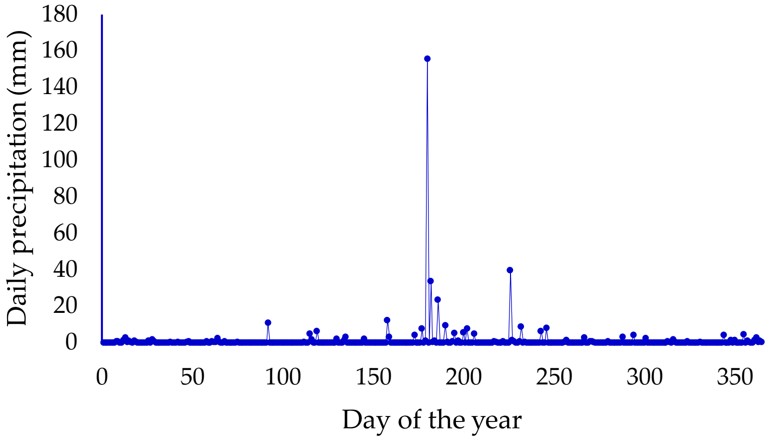

Figure 3.1. Daily precipitation amounts at Brandon Research and Development Centre for 2020.

3.3.4 Measurements

3.3.4.1 Inflorescence Density (INFD)

After anthesis, two (small plots) or eight (grazing location) randomly selected 1 m of row were counted within the plots to determine the inflorescence density. The values were expressed as inflorescences m^{-2}.

3.3.4.2 Biomass at Stand Maturity (BIOM)

Immediately prior to harvest or swathing, two randomly selected 1m rows of IWG were harvested in the small plots and 10 randomly selected 1 m rows of IWG in the large plots were harvested at 4 cm to determine plant biomass at stand maturity. Harvest samples were then bagged and placed on drying beds for 3-5 d to remove any excess moisture. Once the samples were dry, they were weighed to determine the dry matter per unit area.

3.3.4.3 Grain yield (GYLD)

In the small plot trials, grain yield was determined by total plot yield excluding outermost rows to serve as treatment buffers. Before the end of August, the year of harvest dependent, plots were straightcut using a Wintersteiger plot combine. Samples were then processed by passing through a Westrup Laboratory Air-Screen Cleaner (LA-LS) to clean the samples to seed alone and were subsequently weighed to determine the mass of grain harvested per unit area.

In the large plot trial, grain yield was determined by subsampling the large plots. The plots were swathed for harvest to ensure a more accurate yield representation. Then, using a plot=combine with a pick-up header, three 10 m lengths of 8 m-wide swaths were harvested in each plot. The subsamples were kept separate and put through a Blount Ferrell-Ross made Clipper M2BC until they were seed only. Subsamples were then combined and weighed to determine the mass of grain harvested per unit area.

3.3.4.4 Thousand Seed Weight (TSW) & Protein (GPROT)

For all trial locations, an approximately 20 g subsample of grain was dehulled by hand by threshing with rub-bars, with hand sieves used to separate seed and chaff and fine material removed with a model 67 Hoffman Seed Blower. Once reduced to bare seed, samples were passed through a seed counter to determine the number of seeds in the subsample, then weighed to determine the thousand seed weight. Seed was then milled to pass through a 1 mm sieve on a Wiley Mill. Protein was determined by measuring nitrogen in the seed using a FP-528 LECO and converted to percent protein using a multiplication factor of 5.75.

3.3.4.5 Harvest Index (HI)

Harvest index was calculated using the grain yield and the biomass at stand maturity. To do that, the mass of grain per unit area was divided by the mass of plant material per unit area to determine the proportion of plant material that was grain.

3.3.4.6 Path Analysis

Path analysis was run to look at the influence of components of grain yield on grain yield realized. GYLD, BIOM and INFD were expressed on a g m^2 basis for this analysis. Analysis investigated the direct effects of BIOM, INFD, and TSW on grain yield and the direct effect of INFD on TSW and will be described in the next section.

3.4 Statistical Analysis

The data were analyzed using SAS Studio software. The first assumption was tested by using the GLIMMIX procedure to generate a dataset of the residuals and then running univariate procedure to test for normal distribution. It was determined that the residuals had a normal distribution if the Shapiro-Wilk value exceeded 0.90 and the skewness measurement was between +/- 1. Once it was confirmed that the data was normally distributed, the raw data was analyzed using PROC GLIMMIX to verify whether the variances were homogeneous. When the assumptions were met, the analysis was run using the PROC GLIMMIX function to generate an ANOVA. In the cases where normal distribution was not achieved, a lognormal transformation was used if it satisfied the Shapiro-Wilk criterion. If the variances were heterogeneous and the lognormal transformation did not correct it, then a "random _residual_" function was employed to achieve a homogeneity of variance based on AIC and Chi-square values (between 0.5 and

2.0). When running the GLIMMIX procedure, treatments and locations were analyzed as fixed effects and the replicate factor was nested within location and considered a random effect. The degrees of freedom were based on the Kenward Rodgers framework, and the Tukey-Kramer LSD test was used to determine statistical significance ($p = 0.05$) between sample means.

Path coefficient analysis was conducted using PROC CALIS in SAS 9.4 with each site-year being calculated separately utilizing covariance structure analysis: maximum likelihood estimation. The model was the direct effects of INFD, BIOM and TSW on GYLD, and the indirect effect of INFD on TSW was used to look at the indirect effect of TSW on GYLD through INFD.

3.5 Results and Discussion

3.5.1 Grain Yield (GYLD)

3.5.1.1 Location effects

Grain yield performance at the individual locations varied throughout production years (Figure 3.2A) and was impacted by drought and timing of the precipitation received. A significant location x treatment interaction ($p = 0.017$) was found for the second production year (Figure 3.3). The first production year showed little yield differences between most locations, regardless of the year of establishment. However, significant differences were recorded for first year GYLD at Brandon (322 kg ha^{-1}) and both Carman (643 kg ha^{-1}) and Glenlea (536 kg ha^{-1}), with Brandon yielding half of Carman. In the second production year, there were significant location x treatment interactions, and data is presented by location in Figure 3.3. In the third production year, there were no significant differences in GYLD between the remaining Carman and Brandon locations. Carman provided mean grain harvests of approximately 643, 845 and

760 kg ha^{-1} with the treatment (FERT) providing the greatest grain yield approximately 200 kg ha^{-1} higher than the other treatments in both the last two years of the study (845 kg ha^{-1} at Carman in year two and 760 kg ha^{-1} at Brandon and Carman in year three). This relatively consistent performance under conditions of moisture scarcity provides for a good base upon which to build an agronomic program for the production region. However, annual precipitation amounts were not entirely informative as was illustrated in Brandon in year 2 (Figure 3.1). A better understanding of the critical periods of plant development and the influence of the availability of moisture is required to provide for development of both agronomic practices and for decisions surrounding the use of inputs such as fertility. The fertility regime used in the current study was based upon the rate used in the selection nursery (Cattani, 2017) and from other perennial grass seed experience in Manitoba (Entz et al. 1994, Cattani et al. 2004).

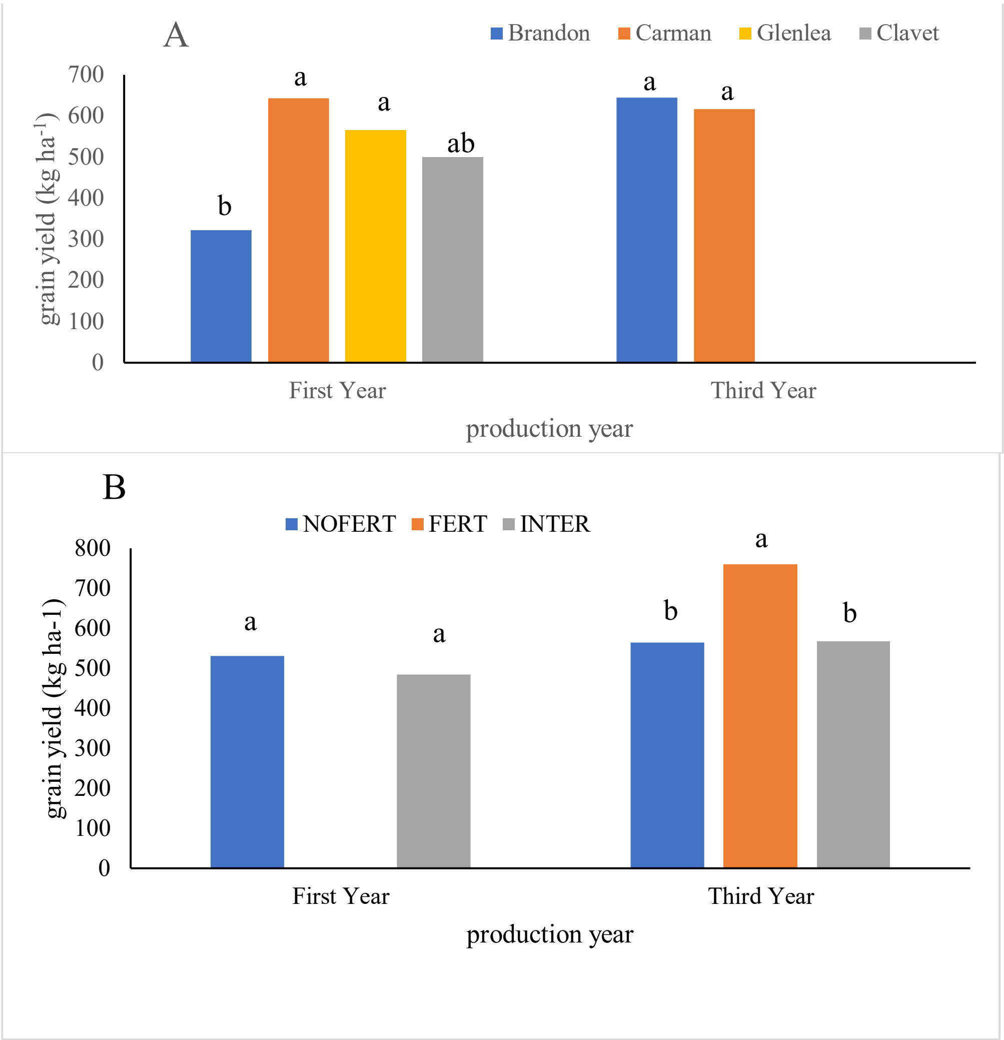

Figure 3.2. Grain yield (GYLD) of intermediate wheatgrass (IWG) for the four locations (A) and three treatments+ in western Canada for the first and third reproductive years. The same letter over bars within individual locations are not significant using Tukey-Kramer LSD at P = 0.05.

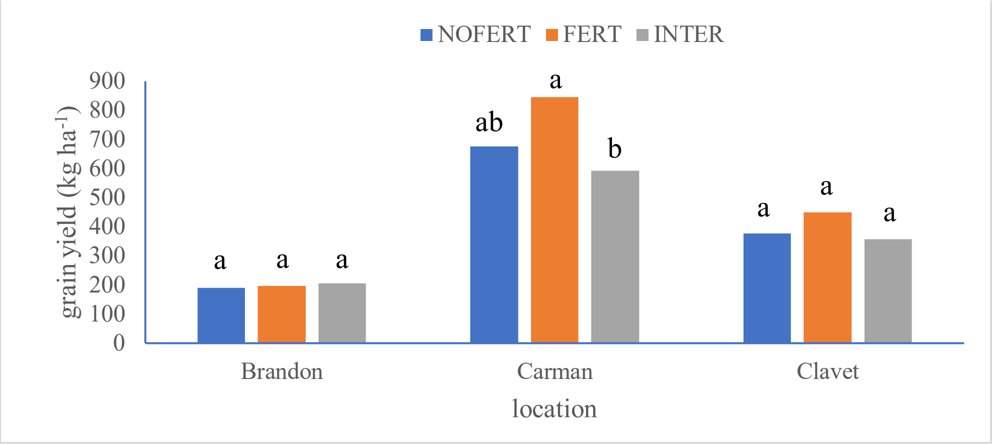

Figure 3.3. location x treatment effects for grain yield in the second production year. The same letter over bars within individual locations are not significant using Tukey-Kramer LSD at P = 0.05.

A cutworm infestation at Brandon led to reduced GYLD in the first production year. Due to institutional COVID-19 restrictions governing entry to the field site, damage was noticed too late for a successful intervention and GYLD was impacted. Figure 3.4 illustrates the nearly complete girdling of the reproductive tillers by cutworm feeding. Death of early developing tillers resulted in the impact on grain yield components determining factors at Brandon. Cutworm thresholds for IWG do not exist, however annual cereals can handle populations of approximately 600 cutworms m^{-2} and for alfalfa it is 21 cutworms m^{-2} and under ideal precipitation, threshold values may increase (Gavloski, 2019). Ideal precipitation was not the case at Brandon for the 2020 growing season (Table 3.3). The reproductive induction cycle of IWG may have compounded the impact (Duchene et al., 2021), with new tiller production to replace those lost (Hendrickson et al., 2005), competing with the reproductive effort. New tillers would likely result in reproductive tillers in the subsequent growing season (Duchene et al., 2019; Duchene et al., 2021; Ivancic et al., 2021).

Figure 3.4. Extensive cutworm damage to intermediate wheatgrass at Brandon in 2020 during reproductive tiller development. A. (left) damage to stem bases; B. (right) undamaged plants.

In the following reproductive year, the moisture conditions were less favorable at Brandon (Table 3.3), and GYLD remained much lower than other locations. Drought and residual stand damage from cutworms, with the threshold for cutworm in cereals is approximately 600 m^{-2} while the threshold for a new alfalfa stand is 21 m^{-2} in Manitoba (Gavloski, 2019), the potential thinning experienced in 2020 may have inhibited adequate tiller recruitment to produce a satisfactory GYLD the following year.

By the third production year, the GYLD at Brandon did not differ from Carman, with the latter remaining relatively consistent across all years. It is possible that there was little cutworm activity resulting from an increase in beneficial insect pressure (Gavloski, 2019; Schipanski et al., 2017). The potential cumulative impact of the above, coupled with the greater precipitation resulted in yields at Brandon equal to Carman.

3.5.1.2 Treatment effects

The GYLD was not significantly influenced by treatment in the first production year (Figure 2B). There were only two treatments in this production year, as FERT was first applied after first harvest. In the second production year, Carman recorded a FERT GYLD (845 kg ha^{-1}) more than four times greater than all Brandon treatment means (206 kg ha^{-1} for INTER) (Figure 3.3) and significantly greater than the INTER treatment. Brandon yielded the lowest means for all treatments, with this location and Clavet presenting no treatment differences in GYLD while significant GYLD differences were found between treatments at Carman in the second production year, with FERT at 845 kg ha^{-1}, significantly higher than INTER at 646 kg ha^{-1} and NFERT similar to both other treatments at 763 kg ha^{-1}. In the third production year, FERT resulted in a significantly higher GYLD than the other treatments (Figure 3.2B). The FERT GYLD was almost 200 kg ha^{-1} greater than the other treatments, which in turn did not differ. In the third production year, GYLDs were greater at Brandon than the two previous years combined, while remaining relatively static at Carman across all years. NOFERT and INTER were statistically similar in all years, indicating that there was little grain yield advantage to seeding IWG alone.

The differences found at Carman in the second and third production years and at Brandon for the third production year illustrate the potential impact of added fertility. Nutrient sharing between the IWG and alsike clover for the INTER treatment was not sufficient to enhance GYLD. Competition has been an issue in numerous studies when legumes were intercropped in the early stages of the IWG grain production cycle (Reilly et al., 2022; Tautges et al., 2018; Dick et al., 2018; Olugbenle et al., 2021). Although this issue arises early in stand life, research indicated that intercropping provided a GYLD benefit in the third production year in some instances (Tautges et al., 2018). By the end of the first production year at Brandon and Clavet, there was little alsike clover remaining in INTER and at Carman by the end of the second production year. The INTER and NOFERT treatments were similar and no GYLD benefit was observed through intercropping. This lack of INTER effect was contrary to what was expected, with a reported correlation between legume biomass in the first production year and the GYLD of IWG in the third production year (Reilly et al., 2022). The implication here may be that a positive effect requires that the legume survives into the third production year, continuing to contribute nitrogen, thus helping meet the nitrogen demand of the IWG stand.

Grain yield for the third production year demonstrated the impact of FERT and the potential for consistency of production, with FERT yielding approximately 200 kg ha^{-1} more than the other treatments. Other reports on the impact of synthetic nitrogen applications at similar rates have resulted in increased GYLD in later production years (Jungers et al., 2017; Fernandez et al., 2020). Nitrogen rates higher than that used in this study generally did not result in greater GYLD (Fagnant et al., 2023). Nitrogen requirements and the timing within the crop still require greater fine-tuning with growth environment. Nitrogen and its timing in the current study had a positive effect on GYLD and was expected to be a key factor in maintaining grain productivity (Fagnant et al., 2023; Williamson et al., 2012). Rates may differ, likely dependent growing season length, moisture amounts and timings, and any harvesting of vegetative biomass for feed or by animals.

Grain yield at Brandon fluctuated while at Carman a consistent yield was realized through the three production years. Consistent or increasing GYLD in year three, coupled with the impact of fertility applications, indicates a long-term yield potential for this crop. This was the first report we are aware of indicating this consistency, and it may be attributed to the selection criteria of taking materials through three grain harvests prior to final selections being made

(Cattani, 2017). As expected, drought appears to have had a large impact on GYLD at locations throughout these studies. Precipitation pattern may be as important as precipitation amount and may be critical to the maintenance of GYLD potential in IWG. At Brandon in 2020, this location received approximately 90% of the average 30-yr precipitation amounts (Table 3.3). However, timing of the precipitation is important, with 217 mm in June of 2020 accounting for >50% of the annual amount. Between June 28, 2020, and July 4, 2020, 217.4 mm of precipitation was recorded, again >50% of the total annual precipitation (Figure 3.1). Future research, possibly a synthesis from reported studies, may determine critical periods for moisture. In Manitoba, where four to six months of winter can be experienced, the timing of precipitation to coincide with crop requirements, especially during periods of active growth, will likely inform the timing of agronomic applications for crop productivity.

3.5.2 Harvest Biomass (BIOM)

Biomass yields were different between years but did not demonstrate any significant differences between the locations and treatments throughout the study (Figure 3.5). Biomass yield at all locations decreased in the second production year, with drought conditions experienced at each site. Brandon, where cutworm damage occurred, did not significantly differ in BIOM from the other locations in the first two production years (year one, Brandon 8846 kg ha^{-1}, vs. Carman 9780 kg ha^{-1}, Clavet 10920 kg ha^{-1}, and Glenlea 8174 kg ha^{-1}. This suggested that although insect damage reduced GYLD, maintaining a comparable BIOM was possible for IWG. The plants were likely able to generate new vegetative tillers to compensate for the loss of reproductive tillers due to the cutworms (Hendrickson et al., 2005; Kemp et al., 1994). Timing of herbage removal and the presence of adequate moisture affects tillering potential, with early removal in the growing year resulting in higher potential tillering (Hendrickson et al., 2005).

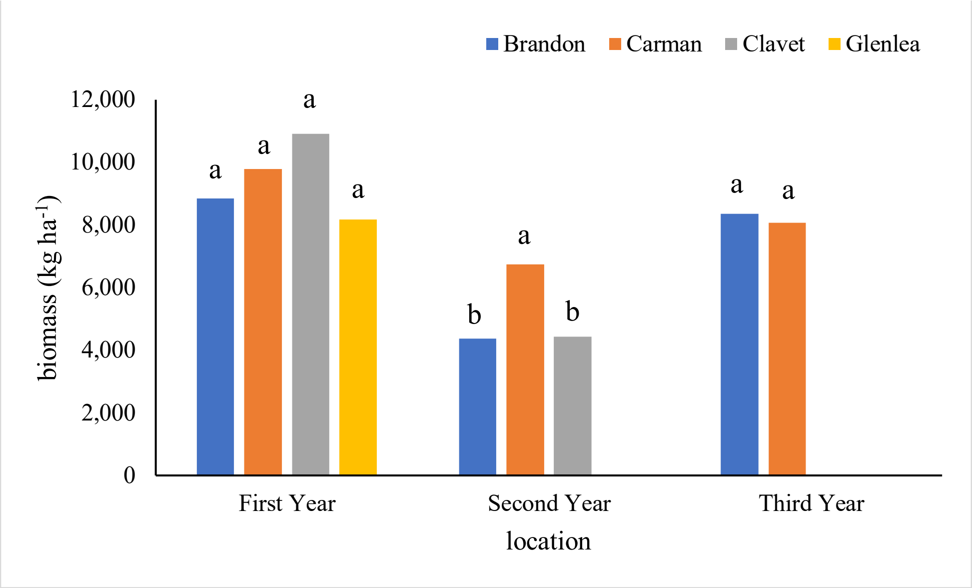

Figure 3.5. Biomass at harvest of intermediate wheatgrass (IWG) for the four locations in western Canada for the first, second and third reproductive years. The same letter over bars within individual production years are not significant using Tukey-Kramer LSD at P = 0.05.

Biomass yield in the third production year was at levels approaching the first production year (Brandon 8636 kg ha^{-1} and Carman 8067 kg ha^{-1}), likely due to the better moisture conditions experienced. Treatments were not significantly different suggesting that the addition of nitrogen the previous fall did not affect BIOM (data not shown), consistent with another report (Frahm et al., 2018). However, it is worth noting that a positive BIOM response to spring fertilizer additions has been reported (Fernandez et al., 2020). Fall application was used in this study, therefore timing of application may be a necessary consideration when looking at the forage yield aspect of the dual-purpose system.

3.5.3 Harvest Index (HI)

Unlike the previous two measures upon which HI is calculated, HI showed significant differences amongst locations in the first production year (Figure 3.6). Glenlea at 6.86%, had a

HI that was almost twice what was recorded in Brandon in 2021 (3.51%), however the latter location experienced reproductive tiller predation as previously outlined. and Carman at 6.54% was similar to Glenlea and Clavet (4.73%) did not differ significantly from Brandon. In the second production year, Carman (10.80%) and Clavet (8.95%) were not statistically different, and while Brandon was significantly lower (4.62%). In the third production year, HI at Brandon (7.76%) was similar to Carman (7.86%). Treatment had no significant effect on HI in any production year (Figure 3.6b) with means of 5.42% in the first production year, 8.00% in the second production year and 7.81% in the third production year.

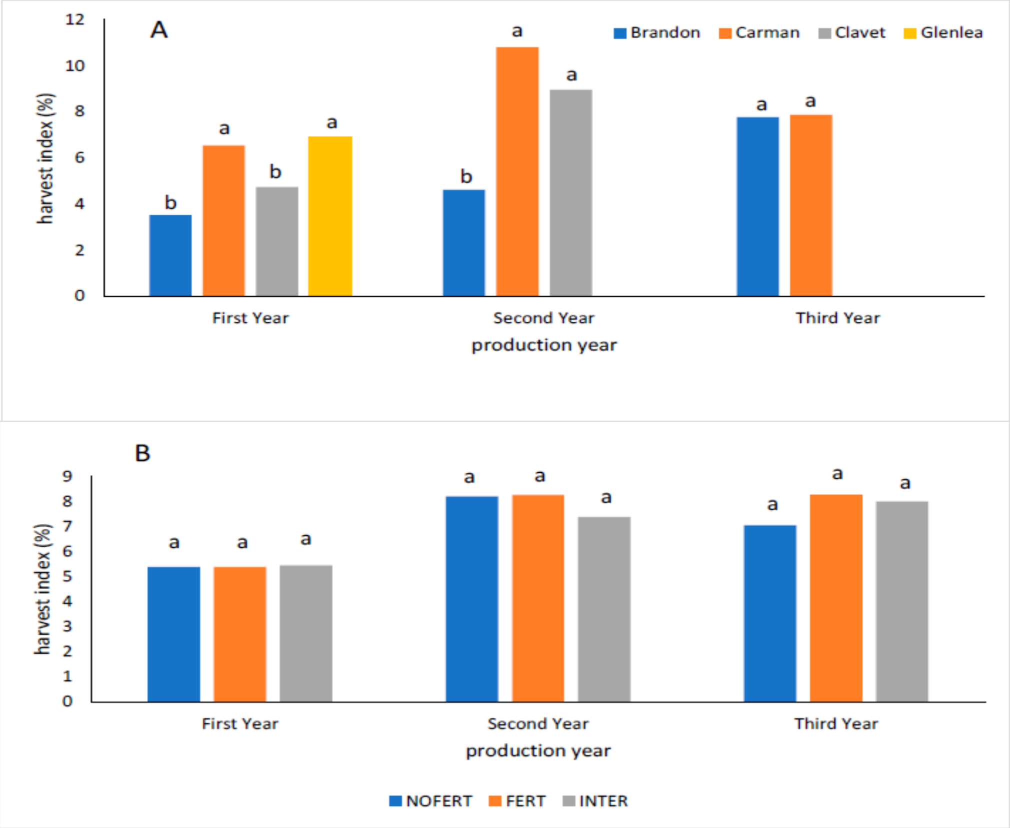

Figure 3.6. Harvest Index (HI) of intermediate wheatgrass (IWG) for the four locations (A) and three treatments (B) in western Canada for the first, second and third reproductive years. The same letter over bars within individual production years are not significant using Tukey-Kramer LSD at P = 0.05.

Harvest index was likely influenced by drought conditions that were present during the experiment. Additionally, there are a few reports indicating that harvest index of IWG shows consistent reductions as the stand ages (Crews & Cattani, 2018; Tautges et al., 2018; Duchene et al., 2023). This reduction has been attributed to increased BIOM, while the GYLD remained stagnant or decreased (Duchene et al., 2023). Looking at the trends previously outlined, BIOM declined in the second production year and increased in the third at both Brandon and Carman. However, HI at the latter location increased in the second year and decreased in the third, remaining higher than the first production year. Harvest index at Brandon continuously increased, doubling in the third production year compared with the first production year (Figure 3.6). This location was impacted in the first year by cutworm damage and drought in the second, however as conditions became more favorable, HI responded positively.

Significant differences between treatments were not found. Nitrogen fertilizer application in older IWG grain stands was found to increase HI at one of five locations in a US study with two locations (northern Minnesota) experiencing an increase in HI with an alfalfa intercrop and the other two locations (southwestern Minnesota) showing little difference between treatments (Tautges et al., 2022). In spring wheat, HI increased significantly with a higher rate of nitrogen fertilizer, (200 kg ha^{-1}; (Wang et al., 2020)). Therefore, this relationship requires further research in IWG.

3.5.4 Thousand Seed Weight (TSW)

In the first production year, TSW at Carman (6.64 g) and Clavet (6.69 g) were significantly greater than Brandon (5.73 g) and Glenlea (5.95 g) (Figure 3.7A). In the second production year, while TSW decreased at all locations harvested, Carman (5.02 g) and Clavet (4.84 g) remained significantly higher than Brandon (2.87 g). Both Carman and Clavet experienced notable moisture limitations during that production year (Table 3.2 & 3.4), however, Brandon did not appear to experience a detrimental moisture limitation based on data presented in Table 3.3. Notwithstanding, as previously noted, the annual value is misleading. In the third production year, Carman (6.28 g) and Brandon (6.27 g) produced similar TSW, slightly lower than the TSW recorded at Carman in the first production year. This increase fits the moisture change experienced at Carman and aligns with other increases experienced at Brandon in the third production year.

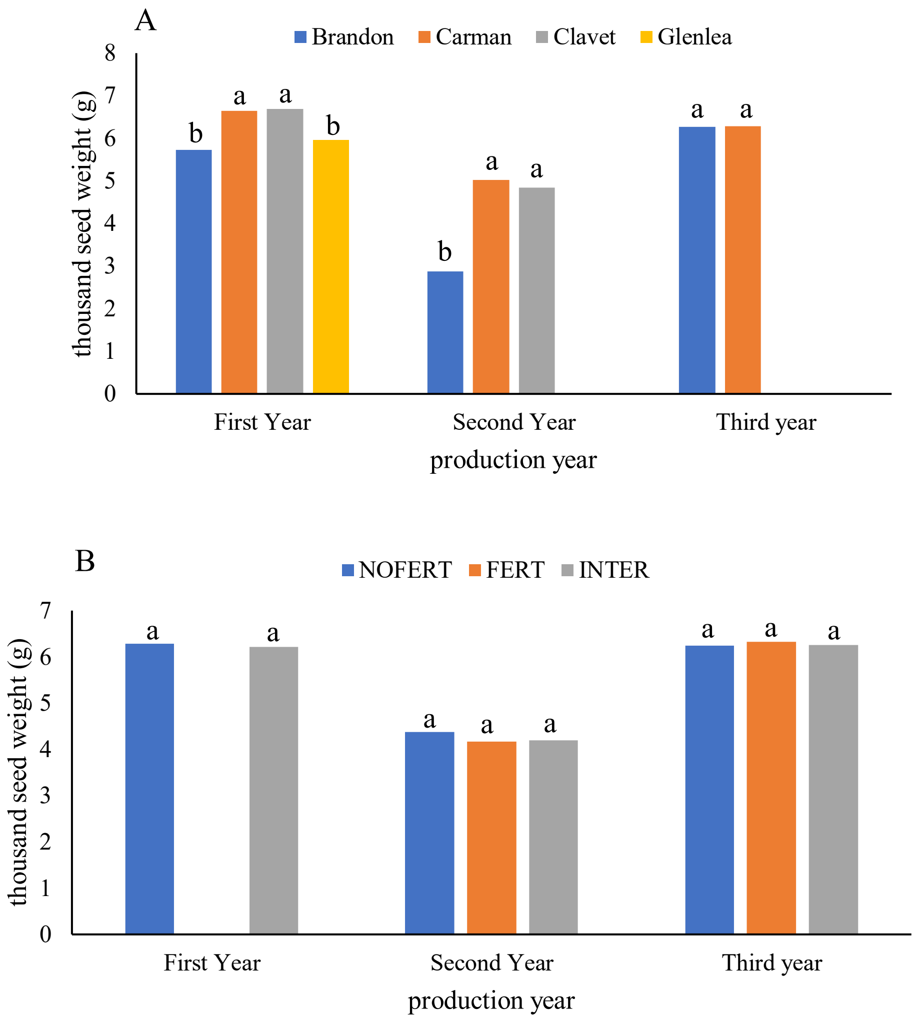

Figure 3.7.Thousand seed weight of intermediate wheatgrass (IWG) for the four locations (A) and three treatments (B) in western Canada for the first, second and third reproductive years. The same letter over bars within individual production years are not significant using Tukey-Kramer LSD at P = 0.05.

No treatment effects were found through the course of this study for TSW which appears to indicate that growth environment was likely the primary influence on TSW in IWG (Figure 3.7B) (6.25 g, 4.22 g and 6.28 g) for the first, second and third production years, respectively). A connection between nitrogen applications and seed weight has been reported in both annual grain (Hussain et al., 2006) and perennial ryegrass seed production (Cookson et al., 2000). Seed weight was previously noted to be related to seed yield in IWG on space plants (Cattani & Asselin, 2018a), however the current study was from a crop perspective. However, more research is needed to determine the influences on TSW in IWG crop systems.

3.5.5 Inflorescence Density (INFD)

Treatment differences for grain yield were matched by similar increases in INFLD, which varied significantly between locations in the first production year (Figure 3.8A). At Glenlea (566 m^{-2}), INFD was significantly higher than the other three locations (Carman, 357 m^{-2} and Clavet, 355 m^{-2}) and more than double what was observed at Brandon (267 m^{-2}). In the second production year, the INFD increased at all locations and differences between treatments changed. At Carman, INFD (683 m^{-2}) was significantly higher than Brandon (468 m^{-2}), with Clavet (557 m^{-2}) not differing from either of the other locations. This was consistent with the Brandon GYLD trends outlined previously, and the moisture limitations at Clavet. First-year INFD at Glenlea was in the same calendar year as the second production year at the other locations, therefore, the increase seen in second production year may be due to environmental conditions and not stand age. In the third production year, treatment was the only significant effect.

Application of fertilizer in the fall appears to increase INFD, increasing the grain yield potential and in this study, treatment had a significant effect on INFD in the last two production years. Treatments were similar in the first production year (averaging 386 m^{-2}). In the second production year FERT (625 m^{-2}) was significantly higher than INTER (533 m^{-2}), while NOFERT (550 m^{-2}) was not different from either. In the third production year, FERT (534 m^{-2}) was significantly greater than NOFERT (448 m^{-2}) and INTER (461 m^{-2}) was similar to both other treatments.

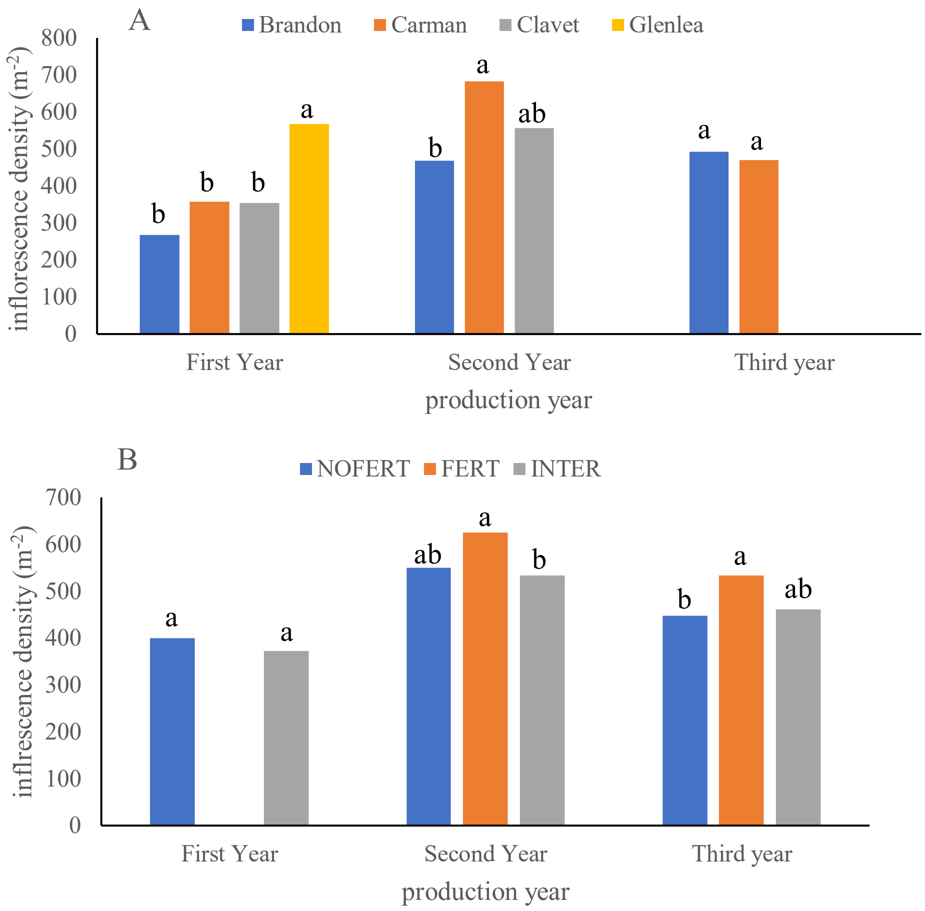

Figure 3.8. Inflorescence density of intermediate wheatgrass (IWG) for the four locations (A) and three treatments (B) in western Canada for the first, second and third reproductive years. The same letter over bars within individual production years are not significant using Tukey-Kramer LSD at P = 0.05.

The treatment differences in these two years support the idea that the drought induced competition between alsike clover and IWG in INTER treatment, with the amount and timing of fall precipitation potentially being a critical factor. As a species with a vernalization requirement, fall regrowth should provide tillers for conversion to reproductive primordia over the winter. The INFD in the third production year was significantly greater for FERT versus NFERT, similar to the increase in GYLD. However, the gap between FERT and NFERT was greater for GYLD, indicating that fall fertility influenced more than INFD. Good plant nutrient status appears to enhance seed set as TSW were similar between treatments, especially where water was not in scarce supply. Further studies, including density manipulations, may provide a better understanding of these relationships. One other possibility could be loss of the legume provided some nitrogen which benefited the IWG in INTER, providing an advantage over the NOFERT treatment in the third production year. This postponed benefit was similar to findings previously outlined in the GYLD discussion (Reilly et al., 2022) where earlier legume biomass was correlated to later IWG GYLD, but unlike GYLD, a latent effect was observed. A significant increase of bud activation in C_3 perennial grass species has been reported when increasing the nitrogen rates (Williamson et al., 2012). This concept is further supported as it has been noted that the number of inflorescences increase with the rate of nitrogen application in grasses that require dual induction, similar to IWG (Heide, 1994; Peterson & Loomis, 1949; Newell, 1951; Calder & Cooper, 1961). The INFD observed at Brandon was similar to Carman in the third production year.

3.5.6 Grain Protein (GPROT)

Differences in GPROT were inconsistent during both growing seasons where protein was measured. In the first production year, significant differences were only found at Glenlea where GPROT of INTER (20.03%) was significantly greater than NOFERT (18.63%) (Figure 3.9A). Other sites ranged from 18.37% for Brandon to 20.34% for Clavet. Successful establishment and regrowth of the alsike clover (Figure 3.10) unlike the other locations, appears to benefit IWG, similar to successful nitrogen transfer by red clover to IWG (Reilly et al., 2022). In the second production year, no significant differences were found between treatments at Carman (average 18.48%) (Figure 9B). At Brandon, FERT (17.88%) was significantly higher than NOFERT (16.94%) and INTER (17.30%), while at Clavet, FERT (22.99%) was higher only than INTER (20.29%). In general, the increases observed with FERT, implies that the application of nitrogen has a significant positive effect on the GPROT in IWG, similar to winter wheat (Saint Pierre et al., 2008). Grain protein at Clavet in the second production year was at the high end of reported values in IWG (Zhang et al., 2015). It is possible that drought concentrated the grain protein, again similar to what was observed in winter wheat (Saint Pierre et al., 2008) and was likely due to reduced seed size.

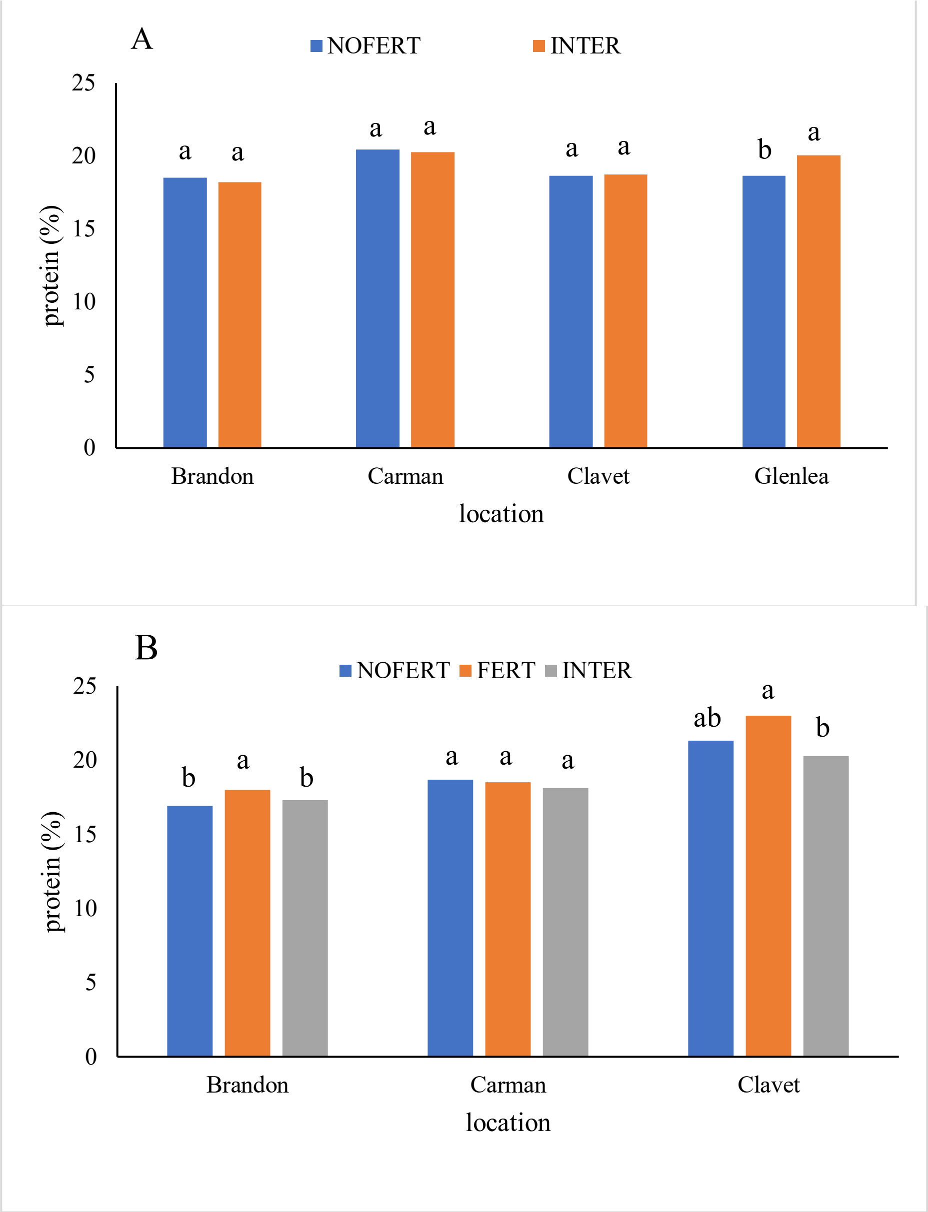

Figure 3.9. Grain protein % for the treatments at the locations in the first production year (A) and second production year (B) of intermediate wheatgrass (IWG) for the four locations in western Canada. The same letter over bars within individual locations are not significant using Tukey-Kramer LSD at P = 0.05.

Figure 3.10. The Interseeded treatment at Glenlea illustrates the development of intermediate wheatgrass and alsike clover in May of the first production year (2021).

3.5.7 Path Analysis

Path analysis was carried out on a site-year basis. No consistent effects were noted across all site years (Table 3.6). In the first production year, biomass m^{-2} had the largest direct effect on grain yield m^{-2} for all sites, however Clavet, did not have any significant direct effects. In the second and third production years, inflorescence density had a significant direct effect on seed yield for all site-years. These results were similar to results from the selection nursey upon which the plants materials used in this study were developed from (Cattani & Asselin, 2018a). TSW had a significant direct effect on grain yield in two site-years only. TSW had a significant direct effect on inflorescence density in two years, an indication of some yield component compensation. Inflorescence density as the stand ages appears to be a good indicator of yield potential within the stand. This has been previously seen in another cool-season perennial grass species, (*Agrostis stolonifera* L.) produced in Manitoba (Cattani et al., 2004). Tiller development after heading in *A. stolonifera* provides for the vegetative tissue that undergoes vernalization in that species (Jónsdóttir, 1991), effectively dictating yield potential. Additional work is required to validate this in IWG, however, this work would lead to a greater understanding of development and ultimately, to better agronomic practices.

Table 3.6. The direct effects of inflorescence density m^{-2} (density), biomass m^{-2} and thousand seed weight (TSW) on seed yield m^{-2} and of thousand seed weight on inflorescence density for each site-year studied.

	Direct effect on yield m^{-2}	Direct effect on density m^{-2}	Direct effect on yield m^{-2}	Direct effect on density m^{-2}	Direct effect on yield m^{-2}	Direct effect on density m^{-2}	Direct effect on yield m^{-2}	Direct effect on density m^{-2}
	Brandon		Carman		Clavet		Glenlea	
	First production year							
Density m^{-2}	0.138		0.173		0.383		0.445^{**}	
Biomass m^{-2}	0.766^{**}		0.491^{**}		0.253		0.569^{***}	
TSW	0.059	$.452^{**}$	0.343^{*}	-0.077	0.169	0.139	0.231	0.122
	Second production year							
Density m^{-2}	0.292^{*}		0.717^{***}		0.774^{**}			
biomass m^{-2}	0.030		0.179		0.068			
TSW	0.813^{***}	-0.215	-0.048	0.142	-0.117	0.315		
	Third production year							
Density m^{-2}	0.312*		0.758^{***}					
Biomass m^{-2}	0.582^{***}		0.051					
TSW	0.100	0.080	0.008	0.695^{***}				

*,**,*** indicate significance at P = 0.05, 0.01 and 0.001 levels.

3.6 Other Considerations

The western Canadian provinces are the major producer of forage seed in Canada (Cattani & Asselin, 2018b). Providing producers with an agronomic program which aims to provide a sustainable grain yield across years is a good first step to commercialize this new crop. Crop age and soil type did not appear to impede GYLD through three production years with growth environment having the major role. However, GYLD is a limitation to the uptake of IWG as a perennial grain (DeHaan et al., 2023), with breeding on this species is in its infancy (Bajgain et al., 2022; Wagoner, 1990) compared with its annual counterparts. As such, lower yields would need to demand a higher commodity price to be financially viable for producers. Breeding progress on many traits may be achieved more rapidly than for grain yield as we are just beginning to determine which characteristics contribute to grain yield sustainability. Additionally, the protein concentrations seen in the current study (approximately 17-23%) do add a potential premium for this grain.

Net zero carbon is currently a major aim for agriculture in Canada by 2050, although agriculture as a provisioning activity can justify some carbon usage. Sustainable productivity is a key goal for agricultural systems and allows for the accumulation of more ecosystem services (e.g., carbon sequestration potential). The perennial grain system used in this study with its low inputs, could help reduce agriculture's carbon footprint, especially in marginal areas where annual crop production is limited. Carbon sequestration is one of the purported benefits of perennial grain systems (Hunter et al., 2020; Daly et al., 2021), however this will be dependent upon a range of factors including the duration of the stand, soil type and environmental conditions. Enhancing or at worst maintaining soil health and quality should be seen as positive outcomes of perennial grain production and this study indicates that the potential for consistent reproductive efforts enhancing the outlook for long-term crop stands and the potential benefits derived from them (Hunter et al., 2020). Quantification of these benefits may provide incentives for producer uptake, especially if monetary values can be attached (e.g., carbon credits). Changes in policy to allow this will likely be slow; however, it also allows for the development of higher yielding cultivars and better agronomic practices.

Economic return is the primary driver for producer adoption of a new crop. As yield of IWG is still low compared with annual grains, other incentives are likely needed for widescale adoption. Carbon credits of carbon sequestration, soil health benefits and reduced tillage have potential economic value to growing this crop, however they are not recognized (e.g. carbon credits) nor available in the two provinces in which we tested this crop. The potential to garner support for and the assignment of an economic value to the individual product or practice is dependent upon the value society will place upon them. A change in the attitude (Dyck et al., 2023) or in the measurement and costs (Jungers et al., 2017) of crop production will be required. This will need societal approval, but it will be critical to have producers on board and propose these changes rather than their implementation through government directives.

3.7 Conclusions

The range of soils upon which these studies took place did not disadvantage the crop, with drought and an insect infestation being the major factors limiting grain yield. Nitrogen resulted in increased GYLD, especially as the stand aged, in part due to increased inflorescence density, however the loss of the interseeded alsike clover due to drought resulted in an inability to evaluate the nitrogen transfer potential from a perennial legume.

Biomass influenced grain yield in the first production year with inflorescence density having the greatest direct effect on grain yield in subsequent production years.

Greater in season precipitation in the third production year led to GYLD similar to the first production year, indicating a consistent perennial grain yield potential of IWG in western Canada. Further development of our understanding of the crop and the factors that influence yield potential and yield is greatly needed to provide producers with agronomic programs which may provide a sustainable grain yield of this dual-purpose crop and is a good first step to commercialization.

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3.9 Transition to Chapter 4

The results in the previous chapter illustrate positive effects from the application of synthetic N fertilizer on grain yield, and yield components in IWG perennial grain cropping systems. The drought conditions appeared to have affected the results in 2020 and 2021, while the favourable precipitation in 2022 appears to have allowed for treatment effects to be significant. The research focused on the effect of additional nitrogen in both synthetic and organic forms on grain yield and yield components. The grain yield in the third production year indicates the potential for grain yield to be sustained as the stand matures. Considering the limited grain yield of IWG, the need to increase the economic value of the overall system is paramount. The following chapter outlines research of the same experiment locations during the 2020 and 2021 growing seasons and effects on forage biomass yield and chemical composition of the fall stockpiled biomass for grazing.

4 YIELD AND CHEMICAL COMPOSITION OF THE FALL STOCKPILED FORAGE BIOMASS IN DUAL-PURPOSE INTERMEDIATE WHEATGRASS STANDS AS INFLUENCED BY FALL FERTILITY APPLICATION AND INTERCROPPED WITH A LEGUME

4.1 Abstract

Intermediate wheatgrass (IWG, *Thinopyrum intermedium* (Host) Barkworth & D.R. Dewey) germplasm has been selected for dual-purpose perennial grain systems. This novel multifunctionality allows producers to harvest human-grade grain and graze the stockpiled biomass in the same growing season. This experiment evaluated the effect of nitrogen in both synthetic and organic forms on the yield and chemical composition of stockpiled biomass. Experimental locations included one large scale grazing location in Manitoba sampled for one growing season, and two small plot locations in Manitoba each sampled for two growing seasons. Four main treatments were arranged in a randomized complete block design (RCBD). The treatments were: an unfertilized IWG monoculture control (NOFERT); IWG monoculture with 50 kg N ha^{-1} post grain harvest (FERT); an unfertilized IWG-aliske clover (T*rifolium hybridum* L.) intercrop (INTER), an intercrop of tall fescue (*Festuca arundinacea* Schreb.) /alfalfa (*Medicago sativa* L.) /cicer milkvetch (*Astragalus cicer* L.) as a single use-stockpiled forage control (FORCON). The two small plot sites in Manitoba used a split-plot factorial design with plots doubled in each replicate block for sampling stockpiled biomass yield in both fall and subsequent spring. The fall stockpiled biomass yield (FSB) and chemical composition metrics including crude protein (CP), total digestible nutrient (TDN), neutral detergent fibre (NDF), and acid detergent fibre (ADF), and total aboveground shoot biomass yield (TBIOM) observations were recorded and reported in this chapter. The FERT treatment produced an FSB that was similar to that of the FORCON treatment in 3 of 5 site-

years. The CP of the FSB reported in the FERT treatment was significantly greater than or equal to that of FORCON in 3 of 5 site-years. In all five site-years, the TDN of the FSB of the FERT treatment was greater than or equal to that of the FORCON treatment, while in 2 of 5 site-years, it was greater than that of the NOFERT treatment. The NDF and ADF of the FSB of the FERT treatment was less than or equal to that of the FORCON treatment in all five site-years. The FSB in the FERT treatment produced an NDF concentration less than the NDF of the NOFERT treatment in 2 of 5 site-years, and an ADF that was significantly lower than that of the NOFERT treatment in 3 of 5 site-years. The TBIOM did not differ significantly among treatments in all site-years. The results indicate that supplemental N fertility may be beneficial in dual-purpose IWG systems by increasing the FSB, as well as CP and TDN concentrations to amounts equal or greater than that of the FORCON treatment, while decreasing NDF and ADF concentrations.

4.2 Introduction

Soil quality in agricultural landscapes has degraded over time due to management practices associated with annual cropping systems (Crews, 2017). Perennial cropping systems can provide ecosystem services which can benefit soil health in the system (Crews, 2017). Soil health is defined as “the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals and humans, and connects agricultural and soil science to policy, stakeholder needs and sustainable supply-chain management” (Lehmann et al., 2020). Intermediate wheatgrass (*Thinopyrum intermedium,* (Host), Barkworth and Dewey, IWG) is being bred for perennial grain production and considered for dual-purpose use. The dual-purpose perennial lifecycle while focusing on grain yield includes the added benefit of stockpiled biomass after grain harvest available for livestock grazing (Cattani & Asselin, 2018). The stockpiled biomass yield refers to forage regrowth that is grazed by livestock in fall/early winter, which has accumulated following a harvest (McGeough et al., 2017; MacTaggart et al., 2023). Throughout this experiment, fall stockpiled biomass yield (FSB) will be used to refer to stockpiled biomass sampled after grain harvest and the chemical composition of the stockpiled biomass; stockpile grazing refers to livestock consumption of the FSB; stockpiled regrowth refers to the standing forage that has accumulated. Integrating perennial cropping systems can help address issues prevalent in annual cropping systems, including degradation of soil organic matter and soil erosion (Crews et al., 2016), but viable options need to be available for producers to consider.

The yield of both grain and forage in dual-purpose IWG systems may benefit from supplemental nitrogen (N) applications (Fernandez et al., 2020). Fertility requirements for IWG plant maintenance and survival are generally low (Fagnant et al., 2023). As N availability increases, however, IWG accumulates more biomass and thereby greater forage biomass yield (Fernandez et al., 2020), and this is also true at lower N rates for seed production (Jungers et al., 2017; Fernandez et al., 2020). Intercropping with a perennial legume serves as an alternative N supply to synthetic application which shares N fixed through biological nitrogen fixation (Ryan et al., 2018). An IWG-legume intercrop has the potential to meet the N demand of IWG for grain production for grain yields up to 2.0 t ha^{-1} (Hayes et al., 2016) and sustain constant grain yields as the stand ages compared with an IWG monoculture (Tautges et al., 2018; Favre et al., 2019). These benefits can reduce reliance on external inputs, thereby reducing costs for the producer.

The stockpiled biomass yield produced in dual-purpose IWG systems may provide feed of adequate quality for beef cattle in early/late fall (Favre et al., 2019). The crude protein (CP) concentration of stockpiled biomass can be enhanced by increasing N availability; with studies reporting that increased rates of synthetic N can increase the CP concentration of forages (Sauvé et al., 2010; Teuber et al., 2020; Antunes et al., 2021; Erketin et al., 2022). There can also be a benefit to the forage biomass yield (Pinto et al., 2022), and the CP of the forage produced if a legume is added (Hackman et al., 2008). By increasing the yield and enhancing the chemical composition, the regrowth is more desirable as a feed source; for example, this can be achieved by increasing the crude protein concentration. Grazing forage is another way to derive revenue from the system, and research has shown that the mechanical removal of biomass can positively affect grain yields in the following season (Pugliese et al., 2019). The combination of economic value of fall stockpiled biomass and the potential for grazing to positively effect subsequent grain yield makes integrating livestock an important consideration for the dual-purpose system. Soil properties combined with climatic factors may lead to negative impacts due to compaction from animal traffic related to grazing.

The beef sector is an important industry for the Canadian economy. Based on averages from 2020 to 2022, the beef industry contributes $24 billion a year to Canadian GDP, with 50% of the beef exported (Canadian Cattle Association, 2025). As of 2020, the beef cattle herd in Canada consisted of approximately 10.4 million animals (Statistics Canada, 2021), the majority of which were farmed in the Prairie provinces, with the most in Alberta, followed by Saskatchewan and Manitoba (Statistics Canada, 2024). A major portion of the costs incurred (>60%) in cow-calf production is associated with the reliance on confined housing and feeding during the winter (McCartney et al., 2004). Following grain harvest, IWG stockpiled biomass may be utilized for grazing beef cattle (Favre et al., 2019; Rusch et al., 2025; Puka-Beals et al., 2022). Therefore, this alternative system which focuses on grazing could serve as a cost saving strategy, provided the nutritional requirements of the target class of cattle are met (McGeough et al., 2017). Beef production is a significant industry in Canada, and a cropping system that can provide more opportunities for grazing of stockpiled biomass is an important tool for producers.

To determine the value of the stockpiled forage biomass in terms of yield and the chemical composition, a forage control (FORCON) treatment was included in the experiment as a forage standard. Research conducted at the University of Manitoba studying three perennial forage intercrops reported on a dry matter (DM) basis that this intercrop of tall fescue/alfalfa/cicer milkvetch had the highest CP concentration (10.29% DM) and total digestible nutrient (TDN) (54.93% DM), lowest neutral detergent fibre (NDF) (59.35% DM) and similar yield to all other perennial treatments (Dickson, 2022). A direct comparison of IWG stockpiled biomass with a high performing stockpile forage is critical to determine its suitability for production in western Canada.

4.2.1 Research Objectives and Hypotheses:

The experiment outlined in this chapter focuses on the source of additional N in the dual-purpose cropping system to maximize FSB and chemical composition characteristics. The objectives of the experiment were to:

1. Evaluate the effect of increased available N resulting from intercropping (*Trifolium hybridum* L., alsike clover) or from synthetic N application on FSB, and chemical composition of the FSB.
2. Compare the chemical composition metrics of FSB of IWG with the chemical composition metrics of the FSB of the FORCON treatment.

The hypothesis of the experiments was that an increase in available N from synthetic application or N sharing in an intercrop would increase the FSB and result in a positive effect on the chemical composition metrics considered. The chemical composition metrics considered include TDN, CP, NDF, and acid detergent fibre (ADF). When more N was available to the IWG from both the intercrop and synthetic application, it was hypothesized that the CP would increase, while the NDF and ADF were expected to decrease relative to the unfertilized treatment. Compared with the FORCON treatment it was hypothesized that the FSB of all IWG treatments would have a greater TDN and lower NDF and ADF, while the CP would be equal or greater than that of the FORCON treatment when more N was available to the IWG.

4.3 Materials and Methods

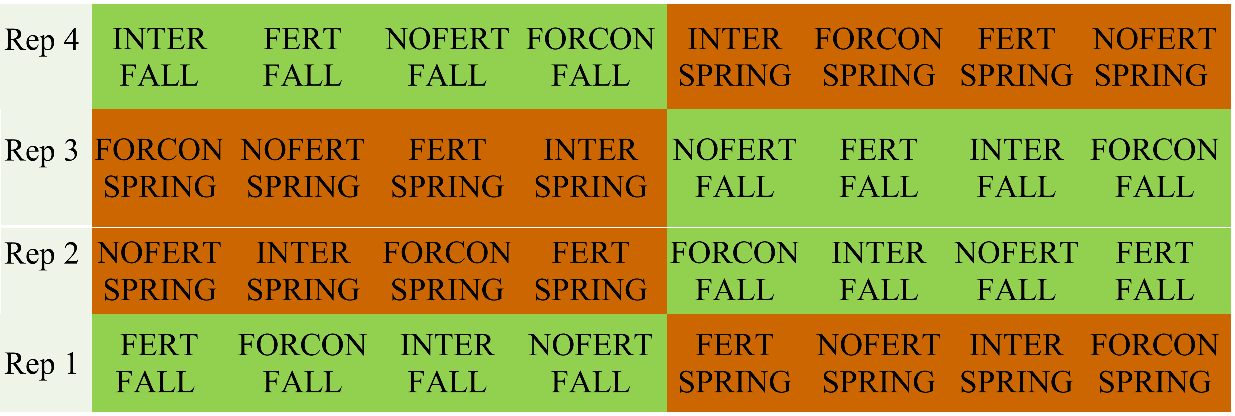
4.3.1 Experiment locations

This experiment was conducted at four locations in western Canada during the 2019-2021 growing seasons as per Chapter 3. Information regarding locations, soil textures and description, seeding dates, and plot sizes was outlined in Table 3.1. In 2019, small plot trials were established at Carman, Manitoba; Brandon, Manitoba; and Clavet, Saskatchewan. A large grazing site, with paddocks averaging 1.11 ha in size was established at Glenlea, Manitoba in 2020, and grazed by beef cattle in October and November 2021. However, in the spring of 2022 the field trial was lost due to was flooding in the region and therefore only one production year occurred. A 2.4 m high fence was erected around the small plots at Carman and Brandon with the exception of Clavet and the Glenlea pasture site to remove possible herbivory effects on treatments. Baseline soil properties from the soil tests performed prior to establishment can be found in Table 2.2 of the thesis published at the University of Manitoba by Muhandiram (2022).

4.3.2 Experimental design

The experiment was arranged in a randomized complete block design (RCBD) with four replicates. It was designed to test the effects of nitrogen in both synthetic and organic forms on grain yield and protein (reported in Chapter 3), and forage biomass yield and chemical composition characteristics of dual-purpose IWG systems. The experiment consisted of four main treatments; an unfertilized IWG monoculture (NOFERT), an IWG monoculture that was fertilized with 50 kg of N ha^{-1} post grain harvest (FERT), an IWG-alsike clover intercrop that did not receive synthetic nitrogen (INTER), and a forage intercrop of alfalfa (*Medicago sativa L.*) *cv.* Algonquin, tall fescue (*Schedonorus arundinaceus* Schreb.) *cv.* Courtney and cicer milkvetch (*Astragalus cicer* L.) *cv.* Oxley II (FORCON) to serve as an industry standard for comparing forage biomass yield and chemical composition of the IWG based treatments. At Carman and Brandon, the treatment structure was a split-plot (illustrated in Figure 4.1) with treatments doubled to account for stockpile forage sampling in the fall or subsequent spring to determine the effect of overwintering on the forage biomass yield and chemical composition of the material.

The plots/pastures were seeded at the same row spacing and seeding rates at all sites. The IWG monoculture treatment was seeded at 30 cm row spacing, while the intercrop treatment had alsike clover and IWG seeded in alternate rows at 15 cm row spacing (i.e. IWG rows every 30 cm, alsike clover every 30cm). The IWG was seeded at a rate of 6 kg ha^{-1} in all plots including INTER, with the alsike clover seeded at 1 kg ha^{-1} in the intercropped plots. The FORCON treatment was seeded at a rate of 4.5 kg ha^{-1} tall fescue, 2 kg ha^{-1} alfalfa, and 3 kg ha^{-1} cicer milkvetch. Unlike INTER, each species was bulk seeded within the same row at 30 cm row spacing. The FERT treatment received 50 kg N ha^{-1} of broadcasted urea post-grain harvest before September each season, the fertility regime used in the selection nursery (Cattani, 2017). Experiments were conducted under dryland conditions, and each site varied by plot size as outlined in Table 3.1due to differences in seeding equipment. All sites were soil tested, and fertilizer was applied to meet nutrient requirements for perennial grass establishment in Manitoba (Manitoba Agriculture, 2007).



Rep 4	INTER FALL	FERT FALL	NOFERT FALL	FORCON FALL	INTER SPRING	FORCON SPRING	FERT SPRING	NOFERT SPRING
Rep 3	FORCON SPRING	NOFERT SPRING	FERT SPRING	INTER SPRING	NOFERT FALL	FERT FALL	INTER FALL	FORCON FALL
Rep 2	NOFERT SPRING	INTER SPRING	FORCON SPRING	FERT SPRING	FORCON FALL	INTER FALL	NOFERT FALL	FERT FALL
Rep 1	FERT FALL	FORCON FALL	INTER FALL	NOFERT FALL	FERT SPRING	NOFERT SPRING	INTER SPRING	FORCON SPRING

Figure 4.1. Field map at the Ian N. Morisson Research Farm demonstrating the split plot structure for timing of forage stockpiled biomass sampling that was conducted at both Carman and Brandon sites.

4.3.3 Data collection

4.3.3.1 FORCON summer harvest

In mid-June, when the alfalfa reached approximately 10% bloom, two or more 0.25 m^2 areas of standing forage were sampled to ensure adequate biomass yield for chemical composition analysis randomly from the FORCON treatment at a cutting height of 4 cm above the surface using a 0.5 m x 0.5 m quadrat similar to methods by Ren et al. (2021).

After quadrat samples were collected, the remaining biomass was removed from the plot using an Alfalfa-Omega plot master forage harvester (R-Tech Industries Homewood, MB, Canada) at Carman and Brandon to cut a height of about 10 cm (2020). In contrast, at Clavet a Wintersteiger harvester (Model unknown, Wintersteiger Seedmech, Ried im Innkreis, Austria) was used and cut to the same height. The cutting height was increased to 15 cm at Carman and Brandon in 2021 to limit stress and plant die-off due to the moisture limitations. At Glenlea, the remaining biomass was cut to a height of approximately 15 cm with a Case IH disc bine (DC 162, Case International, Grand Island, Nebraska, USA), baled, and removed from the plot areas.

4.3.3.2 Fall stockpiled biomass yield (FSB), and total aboveground shoot biomass yield (TBIOM)

In mid-October to coincide with typical turnout time for fall grazing of stockpiled regrowth used by Dickson (2022), three randomly selected 0.25 m^2 quadrats were harvested in the plots at Brandon and Carman to a height of 4 cm above the soil surface. At Clavet, 1 m^2 of sample was harvested at random in each of the plots. At Glenlea, five randomly selected 0.25 m^2 quadrats were sampled throughout the plots to a height of 4 cm above the soil surface. After quadrat samples were collected, the remaining biomass was removed from the small plots using the forage harvester (Alfalfa-Omega plot master, R-Tech Industries Homewood, MB, Canada). Fall stockpiled biomass samples at Glenlea were collected in 2021 prior to initiation of the grazing experiment which was conducted on the FSB. Total aboveground shoot biomass yield (TBIOM) was determined by summing the shoot biomasses from each sampling harvest (FORCON summer harvest, biomass at grain harvest yield (BIOM), and FSB). For the NOFERT, the FERT, and the INTER treatments, this consisted of the shoot material from FSB added to the grain and shoot material from the BIOM, the methods and results of BIOM were described in Chapter 3. For the FORCON treatment, the TBIOM was the sum of the FORCON summer harvest measurement and all the aboveground material included in the FSB.

4.3.3.3 Processing and chemical composition analysis of forage samples

Immediately after sampling (FORCON summer harvest and fall stockpiled biomass yield), samples were weighed and then frozen until processing. Samples were then dried at 55°C for 72 hrs and then weighed to determine the shoot dry matter. The DM of the samples was averaged and converted to a DM yield per hectare. Dried samples were then ground using a Wiley Mill (Model #4, Thomas Scientific Swedesboro, NJ, USA) equipped with a 1 mm screen and submitted to Central Testing Laboratory Ltd. in Winnipeg, Manitoba, for wet chemistry analysis of the CP concentration, NDF, and ADF and determination of factors to calculate TDN. The procedures outlined by the Association of Official Analytical Chemists (AOAC) were used to determine the energy analysis of the samples (AOAC, 1995). The TDN of the samples was calculated using the formula described by Adams (1994). A YSI 2700 SELECT Biochemistry Analyser (YSI Incorporated Life Sciences, Yellow Springs, OH, USA) was used to quantify the starch fraction of the forage. A Leco FP528 (LECO Corporation, St. Joseph, MI) was used to quantify the CP concentration in accordance with AOAC 990.03 method (N x 6.25). Similar to the methods of Van Soest et al. (1991) the NDF and ADF concentrations were determined using a heat-stable α-amylase enzyme and sodium sulfate to digest in-vitro samples. The NDF and ADF concentrations were quantified using an ANKOM 200 automated fibre analyzer (ANKOM 36 Technology, Macedon, NY) as outlined by Komarek (1993). Finally, an ANKOM Extraction system (ANKOM Technology; Macedon, NY) at the University of Manitoba, Winnipeg, MB was used to determine fat concentration as per ANKOM technology Methods (NDF Method 13 and ADF Method 12).

4.3.4 Statistical analyses

The data were analyzed using SAS® OnDemand for Academics (SAS Institute Inc., Cary, NC, USA) using the GLIMMIX procedure. Before running the final model, the assumptions of heterogeneity of variances and conformation of the residuals to the normal distribution were tested. Heterogeneity of variances were determined by modelling variances for each level of key factors using the random residual/group = statement and comparing the AIC of the corrected and uncorrected models. The model with the lowest AIC was chosen. Residuals were generated in GLIMMIX and tested using the univariate procedure (PROC UNIVARIATE). The Shapiro-Wilk test and visual inspection of Q-Q plots were used to determine whether the distribution of the residuals was normal. In cases where residuals did not conform to the normal distribution, the following steps were conducted iteratively. Inspection of the residual plots were conducted to look at potential outliers and data were checked to ensure accuracy. Skewedness (between -1.0 and 1.0) and kurtosis (between -2.0 and +2.0) were also checked to determine if a transformation (e.g. for lognormal “solution d=lognormal” in the model statement) should be considered. If deemed necessary, a lognormal or a square root transformation was performed on the raw data and previously described steps were repeated to see if the transformation resulted in residuals that conform to a normal distribution. If that did not result in a normal distribution of the residuals, then Studentized residual tables were generated in GLIMMIX procedure to determine potential outliers and observations were removed if the values were outside +/- 3.4. When running the GLIMMIX procedure, treatments, locations and their interaction were analyzed as fixed effects, and the replicate factor was nested within location and considered as a random effect. A normal error distribution was used with the identity link function and the REML method was used to estimate variance components. The degrees of freedom were based on the Kenward Rodgers method, and the Tukey-Kramer LSD test was used to determine statistical significance ($p = 0.05$) among treatment means. Where data transformation was required, mean differences comparisons were made on the transformed data, however, data are reported as back-transformed means.

4.4 Results

4.4.1 Significance table for forage response variables

Forage biomass yield (both FSB and TBIOM) and the chemical composition metrics of the FSB showed significant treatment effects among 7 of the 12 different response variables (Table 4.1). Location had a significant effect on 6 of the 12 response variables: 5 of 6 in the first production year and only 1 of 6 in the second. A significant location x treatment interaction was detected in 9 of the 12 response variables. Total aboveground shoot biomass yield, which was composed of the BIOM yield (reported in Chapter 3) plus FSB, was the only observation that did not have significant treatment or location effects identified for both production years.

Table 4.1. P-values of the fixed effects of location (L) and treatment (T), and their interactions for the forage response variables in 2020 and 2021 for the response variables fall stockpiled biomass yield, total aboveground shoot biomass yield, total digestible nutrient of the fall stockpiled biomass, crude protein concentration of the fall stockpiled biomass, neutral detergent fibre of the fall stockpiled biomass, and acid detergent fibre of the fall stockpiled biomass.

Measurement	**L**	**T**	**L*T**
	First production year		
Fall Stockpiled Biomass Yield	**< 0.0001**	**< 0.0001**	**< 0.0001**
Total Aboveground Shoot Biomass Yield	0.5548	0.2073	0.5084
Total Digestible Nutrient of the Fall Stockpiled Biomass	**< 0.0001**	**< 0.0001**	**< 0.0001**
Crude Protein Concentration of the Fall Stockpiled Biomass	**< 0.0001**	0.1284	**< 0.0001**
Neutral Detergent Fibre of the Fall Stockpiled Biomass	**< 0.0001**	0.4706	**< 0.0001**
Acid Detergent Fibre of the Fall Stockpiled Biomass	**< 0.0001**	**< 0.0001**	**< 0.0001**
	Second production year		
Fall Stockpiled Biomass Yield	**0.0007**	**< 0.0001**	**0.0012**
Total Aboveground Shoot Biomass Yield	0.2457	0.3889	0.7094
Total Digestible Nutrient of the Fall Stockpiled Biomass	0.2229	**< 0.0001**	**0.0017**
Crude Protein Concentration of the Fall Stockpiled Biomass	0.3784	**< 0.0001**	**0.0005**
Neutral Detergent Fibre of the Fall Stockpiled Biomass	0.2672	**0.0001**	0.6627
Acid Detergent Fibre of the Fall Stockpiled Biomass	0.2216	**< 0.0001**	**0.0017**

Determined using Tukey-Kramer significance, bolded values indicate significance at $p < 0.05$

4.4.2 Fall stockpiled biomass yield (FSB) on a DM basis

In the first production year, the FSB in the FORCON treatment was greater or not significantly different than the greatest means reported at all locations (Table 4.2). At Glenlea the FSB did not differ significantly among treatments ranging from 2400 kg DM ha^{-1} in the INTER treatment to 3681 kg DM ha^{-1} in the FORCON treatment (Table 4.2). At Brandon, the FORCON treatment (4205 kg DM ha^{-1}) produced an FSB that was significantly greater than the FSB in all the IWG treatments which did not differ among each other (2413 kg DM ha^{-1} in the INTER treatment, 2506 kg DM ha^{-1} in the FERT treatment and 2649 kg DM ha^{-1} in the NOFERT treatment). At Carman, the FORCON treatment produced an FSB of 6535 kg DM ha^{-1}, significantly more than the FSB in the NOFERT treatment (537 kg DM ha^{-1}) and in the FERT treatment (448 kg DM ha^{-1}) which did not differ significantly from each other, while the FSB of the INTER treatment (248 kg DM ha^{-1}) was significantly lower than that in all other treatments. Based on the hypothesis, it was expected that the FERT and INTER treatments would produce FSBs that were similar to that of the FORCON treatment, or at least significantly greater than that of the NOFERT treatment. The lack of significant difference among the FSB of the NOFERT treatment and that in the FERT and INTER treatments in all site-years does not support the hypothesis. Post-harvest precipitation may have been a factor as it was low in 2020, with totals from August to October reported as 63% and 33% of the 30-year normal at Brandon and Carman respectively. While the post-harvest precipitation from August to October in the first production year at Glenlea (2021) was 76% of the 30-year normal.

Table 4.2. Fall stockpiled biomass yield (FSB) as influenced by treatment reported in two production years (analyzed using a lognormal transformation).

	Brandon	Carman	Glenlea	Brandon	Carman
		First production year FSB (kg DM ha^{-1})		Second production year FSB (kg DM ha^{-1})	
Treatment*					
NOFERT	2649 b[+]	537 b	2676 a	998 b	2556 b
FERT	2506 b	448 b	3353 a	2062 a	3827 a
INTER	2413 b	281 c	2400 a	906 b	2918 ab
FORCON	4205 a	6535 a	3681 a	2803 a	3145 ab

*Treatments were **NOFERT** = intermediate wheatgrass (IWG) monoculture control; **FERT** = IWG monoculture with 50 kg N ha^{-1} applied after grain harvest; **INTER =** intercrop of IWG and alsike clover; **FORCON** = intercrop of tall fescue, cicer milkvetch, and alfalfa

[+]Means followed by the same letter within treatment columns are not significantly different using Tukey-Kramer LSD at P = 0.05.

In the second production year, the FSB of the FERT treatment was the greatest and did not differ significantly from the FSB of the FORCON treatment at either location (Table 4.2). At Brandon, the FSB in the FORCON treatment (2803 kg DM ha^{-1}) and that in the FERT treatment (2062 kg DM ha^{-1}) did not differ significantly, while the FSB in the NOFERT treatment (998 kg DM ha^{-1}) and that in the INTER treatment (907 kg DM ha^{-1}) yielded significantly less. At Carman in the second production year, the FERT treatment (3827 kg DM ha^{-1}) produced an FSB that was significantly greater than that in the NOFERT treatment (2556 kg DM ha^{-1}), while the FSB in INTER treatment (2918 kg DM ha^{-1}) and the FORCON treatment (3145 kg DM ha^{-1}) did not differ significantly from the FSB in any other treatment. Unlike the first production year, the FERT treatment produced an FSB that was statistically similar to that of the FORCON treatment and significantly greater than the FSB of the NOFERT treatment at both locations. The distribution of the treatment means in the second production year supports the hypothesis that supplemental N can benefit FSB.

4.4.3 Total aboveground shoot biomass yield (TBIOM) on a DM basis

Total aboveground shoot biomass yield demonstrated no significant differences among locations or treatments (Table 4.3). Total aboveground shoot biomass yields ranged from 7959 kg DM ha^{-1} in the FORCON treatment to 12206 kg DM ha^{-1} in the FERT treatment in the first production year and from 5558 kg DM ha^{-1} in the FORCON treatment to 8723 kg DM ha^{-1} in the FERT treatment in the second production year. During both production years, the FERT treatment produced the greatest TBIOM value numerically, while the TBIOM of the IWG treatments were numerically greater than that in the FORCON treatment in each year, indicating that IWG can produce as much or more TBIOM as the FORCON treatment under a two-cut scenario. This two-cut scenario was used to determine the effects of biomass removal to establish an understanding of potential grain and forage biomass yield response if grazing were introduced. The FERT treatment improved the FSB of IWG resulting in an FSB similar to that in the FORCON treatment at both locations in the second production year and at Glenlea in the first production year (Table 4.2). However, the significant effect was not apparent in the TBIOM yield in the corresponding site-years. As previously described, the moisture limitations experienced at the locations likely influenced the yield potential (for both FSB and TBIOM) thus limiting any potential effect. The lack of treatment effect does not support the hypothesis that supplemental N would increase forage biomass yield.

Table 4.3. Location and treatment means of total aboveground shoot biomass yield (TBIOM) in two production years (analyzed using lognormal transformation).

	First Year	Second Year
Location	TBIOM Yield (kg DM ha^{-1})	
Carman	-	7424 a
Brandon	10799 a^{+}	6746 a
Glenlea	10283 a	-
Treatment*		
NOFERT	11605 a	6792a
FERT	12206 a	8723 a
INTER	10394 a	7267 a
FORCON	7959 a	5558 a

*Treatments were **NOFERT** = IWG monoculture; **FERT** = IWG monoculture with 50 kg N ha^{-1} applied after grain harvest; **INTER =** intercrop of intermediate wheatgrass and alsike clover; **FORCON** = forage control consisting of alfalfa, tall fescue and cicer milkvetch intercrop $^{+}$Means followed by the same letter within location or treatment sections are not significantly different using Tukey-Kramer LSD at P = 0.05.

4.4.4 Crude protein, total digestible nutrient, acid detergent fibre, and neutral detergent fibre reported on a DM basis of the FSB at Brandon, Carman, and Glenlea in the first production year

The CP concentration of the FSB was significantly different among treatments at all locations in the first production year (Table 4.4). At Brandon, the FORCON treatment produced a CP concentration (11.50% DM) that was significantly greater than that in the NOFERT, FERT, and INTER treatments which ranged from 7.99% DM in the NOFERT treatment to 9.23% DM in the FERT. At Carman, the opposite was true; the CP concentration ranged from 9.96% DM in the FORCON treatment to 20.17% DM in the NOFERT treatment which did not differ significantly from the CP concentration of the other IWG treatments. The CP concentration of the FORCON treatment at Glenlea was significantly greater than that in the NOFERT treatment (16.27% DM and 11.40% DM respectively), while the CP concentrations of the FERT and INTER treatments did not differ from either. It was hypothesized that additional N from synthetic application and nitrogen sharing from biological nitrogen fixation would significantly increase the CP of the IWG fall stockpiled biomass relative to the NOFERT treatment, however this was not observed in the first production year at any of the locations.

Table 4.4. Chemical composition of the fall stockpiled biomass as influenced by treatment reported by location at Brandon, Carman, and Glenlea in the first production year.

	Crude Protein (% DM)**		
Treatment*	Brandon	Carman	Glenlea
NOFERT	7.99 b[+]	20.17 a	11.40 b
FERT	9.23 b	19.95 a	13.56 ab
INTER	8.77 b	18.90 a	13.99 ab
FORCON	11.50 a	9.96 b	16.27 a
	Total Digestible Nutrient (% DM)		
	Brandon	Carman	Glenlea
NOFERT	54.82 a	74.60 a	57.74 b
FERT	55.99 a	74.02 a	62.24 ab
INTER	55.03 a	71.88 a	60.41 ab
FORCON	47.03 b	63.54 b	63.28 a
	Neutral Detergent Fibre (% DM)		
	Brandon	Carman	Glenlea
NOFERT	63.88 a	42.86 b	58.50 a
FERT	63.02 a	44.32 b	55.33 ab
INTER	63.63 a	44.80 b	55.09 b
FORCON	63.85 a	58.84 a	43.49 c
	Acid Detergent Fibre (% DM)		
	Brandon	Carman	Glenlea
NOFERT	41.02 b	22.51 b	38.28 a
FERT	39.92 b	23.05 b	34.07 b
INTER	40.82 b	25.05 b	35.79 ab
FORCON	48.31 a	32.85 a	33.10 b

*Treatments were **NOFERT** = monoculture control; **FERT** = monoculture with 50 kg N ha^{-1} applied after grain harvest; **INTER =** intercrop of intermediate wheatgrass and alsike clover; **FORCON** = intercrop of tall fescue, cicer milkvetch, and alfalfa

**Analyzed using lognormal transformation

[+] Means followed by the same letter within treatment columns are not significantly different using Tukey-Kramer LSD at P = 0.05.

The FORCON treatment produced significantly lower TDN concentrations than all other treatments at both Brandon and Carman in the first production year (Table 4.4), while at Glenlea, the TDN of the NOFERT treatment was significantly lower than that in the FORCON. At Brandon, the TDN concentrations reported for the IWG treatments (54.82% DM to 55.99% DM) were all significantly higher than the FORCON treatment at 47.03% DM. Conversely, at Carman, the TDN ranged from 74.60% DM in the NOFERT treatment to a significantly lower concentration of 63.54% DM in the FORCON treatment. Similar to the CP concentration at Glenlea previously outlined, the TDN in the FORCON treatment (63.28% DM) was significantly higher than that in the NOFERT treatment (57.74% DM) and in the INTER treatment (60.41% DM) and in the FERT treatment (62.24% DM) which were statistically similar to all other treatments. The TDN concentration of NOFERT, FERT, and INTER treatments were expected to be higher than that in the FORCON which was the case at 2 of the 3 locations in the first production year.

The FORCON treatment produced NDF and ADF concentrations that were significantly greater than that in all other treatments or not significantly different than the greatest NDF and ADF means at Brandon and Carman in the first production year (Table 4.4). There were no significant differences in the NDF of the FSB in the first production year at Brandon. The concentrations ranged from 63.02% DM to 63.88% DM in the FERT and FORCON treatments respectively. However, at the other two locations, there were significant differences, with the FORCON treatment producing the greatest NDF concentration at Carman (58.84% DM), and the lowest concentration at Glenlea (43.49% DM). The NDF concentration of the NOFERT, FERT, and INTER treatments did not differ significantly at Carman (ranging from 42.86% DM to 44.80%

DM), while at Glenlea, the greatest concentration was reported in the NOFERT treatment (38.28% DM) followed by the that in the FERT treatment (55.33% DM) which did not differ from what was reported in either the NOFERT or INTER treatments. In terms of ADF, the FORCON treatment produced the greatest concentration at Brandon and Carman (48.31% DM and 32.85% DM respectively). The NOFERT, FERT, and INTER treatments did not differ significantly in ADF at either location with concentrations ranging from 39.92% DM to 41.02% DM at Brandon and 22.51% DM to 25.05 % DM at Carman. At Glenlea the lowest ADF concentration was reported for the FORCON treatment (33.10% DM) which was statistically similar to that of the FERT treatment (34.07% DM), the ADF concentration of the INTER treatment (35.79% DM) did not differ from what was reported in any other treatment, and the greatest concentration of 38.28% DM was reported in the NOFERT treatment. It was hypothesized that the NOFERT, FERT, and INTER treatments would produce significantly lower NDF and ADF concentrations than that in the FORCON treatment which was the case in 1 of 3 site-years (NDF) and 2 of 3 site-years (ADF). Supplemental N from synthetic application and intercropping was expected to decrease the NDF and ADF concentrations as well relative to the that in NOFERT treatment, however this only occurred for the NDF concentration of the INTER treatment at Glenlea, and the ADF concentration of the FERT treatment at Glenlea.

4.4.5 Crude protein, total digestible nutrient, and acid detergent fibre reported on a DM basis of the FSB at Brandon and Carman in the second production year

At Carman, the CP and TDN concentrations reported for the FERT treatment were significantly greater than that in the NOFERT treatment, and an ADF concentration that significantly lower than that in the NOFERT (Table 4.5). The CP concentration of the FERT treatment was 14.27% DM which was significantly greater than what was reported in all other treatments. The CP concentration of the NOFERT treatment (10.62% DM) and the FORCON treatment (10.20% DM) were similar, however the CP concentration of the NOFERT treatment was significantly greater than that in the INTER treatment (8.79% DM). The TDN of the FERT (67.19% DM) and the FORCON (66.89% DM) treatments was significantly greater than that of the NOFERT and the INTER treatments, with TDN at 58.80% DM and 58.68% DM respectively. Acid detergent fibre produced by the INTER treatment (37.40% DM) and the NOFERT treatment (37.29% DM) was significantly greater than that of the FERT treatment (29.44% DM) and the FORCON treatment (29.73% DM). The CP concentration of the FERT treatment supported the hypothesis that supplemental N would benefit it, however, the NOFERT treatment was not expected to produce a CP concentration greater than that of the INTER treatment. In terms of TDN, the FORCON was not expected to be statistically similar to what was reported in any of the IWG treatments. The supplemental N was expected to benefit the ADF concentration of the FERT treatment relative to that in the NOFERT, however, the significantly lower ADF in the FORCON treatment was not expected.

Table 4.5. Crude Protein, total digestible nutrient, and acid detergent fibre of the fall stockpiled biomass as influenced by treatment reported by location at Brandon and Carman for the second production year.

	Crude Protein (% DM)	
Treatment*	Brandon	Carman
NOFERT	8.89 c[+]	10.62 b
FERT	11.95 b	14.27 a
INTER	8.82 c	8.79 c
FORCON	15.80 a	10.20 bc
	Total Digestible Nutrient (% DM)**	
	Brandon	Carman
NOFERT	60.71 bc	58.80 b
FERT	64.65 a	67.19 a
INTER	60.56 c	58.68 b
FORCON	62.91 ab	66.89 a
	Acid Detergent Fibre (% DM)**	
	Brandon	Carman
NOFERT	35.50 ab	37.29 a
FERT	31.82 c	29.44 b
INTER	35.65 a	37.40 a
FORCON	33.44 bc	29.73 b

*Treatments were **NOFERT** = monoculture control; **FERT** = monoculture with 50 kg N ha^{-1} applied after grain harvest; **INTER =** intercrop of intermediate wheatgrass and alsike clover; **FORCON** = intercrop of tall fescue, cicer milkvetch, and alfalfa

[+]Means followed by the same letter within treatment columns are not significantly different using Tukey-Kramer LSD at P = 0.05.

**1 outlier removed from analysis

In the second production year at Brandon, the FORCON treatment produced a significantly greater CP than that of the FERT treatment, and TDN and ADF concentrations that did not differ significantly from that in the FERT treatment. The FERT treatment produced a CP concentration of 11.95% DM, which was significantly less than that of the FORCON treatment (15.80% DM), and greater than that of the NOFERT treatment at 8.89% and the INTER treatment at 8.82% DM (Table 4.5). Total digestible nutrient of the FERT treatment at 64.65% DM was significantly greater than that of the NOFERT treatment at 60.71% DM and the INTER treatment at 60.56% DM. The TDN of the FORCON treatment (62.91% DM) was statistically similar to what was reported in the FERT and the NOFERT treatments. The acid detergent fibre concentrations were similar for the treatment means with concentration in the INTER treatment (35.65% DM) and the NOFERT treatment (35.50% DM) similar, and the concentration in the FORCON treatment at 33.44% DM, which was statistically lower than that in the INTER treatment but similar to that of the FERT treatment at 31.82% DM. The CP concentration reported for the FERT treatment illustrates a potential benefit from the N application, however, the CP concentration of the FORCON was not expected to be significantly greater than that of all other treatments. Similarly, the TDN concentration observed in the FORCON treatment was not expected to be significantly greater than what was observed in any of the other treatments. Conversely, the ADF of the FORCON treatment was expected to be significantly greater than the concentration reported in all the other treatments, which was not the case.

4.4.6 Neutral detergent fibre of the FSB reported on a DM basis at both Carman and Brandon in the second production year

The treatment effect for NDF was not different between the two locations (Carman, 52.47% DM and Brandon, 51.55% DM) in the second production season (Table 4.9). All treatments were significantly different from one another with the INTER treatment having the greatest NDF at 56.17% DM, followed by that of the NOFERT treatment at 54.31% DM, with the concentration of the FERT treatment at 51.55% DM and that of the FORCON treatment at 46.01% DM. The FORCON treatment was expected to produce an NDF concentration that was significantly greater than what was reported in all the other treatments, while it was hypothesized that the FERT treatment would produce the lowest NDF of all the treatments. Given that the FERT treatment had the lowest NDF relative to that of all the other IWG treatments (NOFERT and INTER), there appears to be a potential benefit from the supplemental N that was applied.

Table 4.6. Location and treatment means of the neutral detergent fibre of the fall stockpile biomass in the second production year.

Location	Second Year (% DM)
Carman	52.47 a[+]
Brandon	51.55 a
Treatment*	
NOFERT	54.31 b
FERT	51.55 c
INTER	56.17 a
FORCON	46.01 d

[+]Means followed by the same letter within location or treatment columns are not significantly different using Tukey-Kramer LSD at P = 0.05.

*Treatments were **NOFERT** = monoculture control; **FERT** = monoculture with 50 kg N ha^{-1} applied after grain harvest; **INTER =** intercrop of intermediate wheatgrass and alsike clover; **FORCON** = intercrop of tall fescue, cicer milkvetch, and alfalfa

4.5 Discussion

4.5.1 Fall stockpile biomass yield

The decision to graze a forage crop depends on many factors, one of the main factors being the DM yield (McGeough et al., 2017). Forage quantity is generally dictated by the forage species or mixture being grown (Dickson, 2022) and the growth environment (Ren et al., 2021; MacTaggart et al., 2023). Based on the results of this experiment, the potential for dual-purpose use within a year, while not guaranteed, was enhanced by post-harvest fertilization of 50 kg ha^{-1}. Weather conditions will dictate the amount of biomass yield that accumulates during a stockpile period as drought conditions can limit plant development and ultimately yield (Staniak & Kocon, 2015). A forage biomass yield of 2000 kg DM ha^{-1} is a target yield for late season stockpile grazing (McGeough et al., 2018). The FSB of the FORCON treatment achieved this in all site-years, while the FERT treatment met the requirement in all but 1 site-year. The NOFERT and INTER treatments also reached 2000 kg DM ha^{-1} in 3 of the 5 site years. The stockpile duration in the

FORCON treatment was longer than that of the IWG treatments due to the earlier hay cut which based on the advanced maturity it was expected that the yield would be greater (Abd El Moneim et al., 1990). The FORCON summer harvest occurred in June, coinciding with 10% alfalfa flower bloom similar to research by Ren et al. (2020), which allowed the FORCON treatment time to stockpile for four months until October. The FSB of the FERT treatment matched that of the FORCON treatment at all three locations in 2021, which was the first production year at Glenlea and the second at Carman and Brandon. This indicates good potential for this treatment to be used for fall stockpile grazing in a dual-purpose system when adequate moisture post grain harvest is received. The lack of response of IWG in FSB to N rate reported at Carman and Brandon in 2020 (the first production year) is consistent with Dobbratz et al. (2023), which showed little response of IWG in early stands due to residual soil nitrogen. The nitrate N concentration reported for the experimental locations at 0-60 cm ranged from 53 mg kg^{-1} to 150 mg kg^{-1} which was well above the requirements for perennial forage establishment. The subsequent positive response to the FERT treatment in the second production year was similar to what was reported by Fernandez et al. (2020). Based on the results of this current experiment, supplemental N appears to have benefited the FSB thus supporting the hypothesis.

4.5.2 Total aboveground shoot biomass yield

The TBIOM was not significantly affected by location or treatment in either production year. Picasso et al. (2008) reported that IWG-dominated mixtures are not as productive as alfalfa-dominated mixtures when subjected to multiple forage harvests, however that trend was not observed in this current experiment. This can be considered a positive result in terms treatment effect, as the timing of the harvests appear to have benefited IWG with respect to TBIOM compared with that of the FORCON treatment. This experiment reported yields of IWG that were not significantly different than that in the FORCON treatment in both production years considered, therefore it appears that this two-cut system was beneficial to TBIOM of IWG. Additionally, Seed Manitoba (2014) shows that IWG in Manitoba averaged approximately 6,000 kg DM ha^{-1} in testing; all IWG treatments in this study surpassed this amount, and they were harvested later than a forage crop, and included seed. This indicates that the materials tested have potential for increased forage production in Manitoba and the use in stockpile grazing is feasible.

4.5.3 Crude protein concentration of the fall stockpile biomass

In addition to forage biomass yield, the chemical composition is another crucial consideration when it comes to forage utilization (McGeough et al., 2017). An increase in available nitrogen, from synthetic N application was expected to increase CP, as observed in other the forage grasses (Moyer & Sweeny, 2016; Ziki et al., 2019); however, in those other experiments the nitrogen was applied in spring. In the first production year, the IWG treatments did not differ in CP concentration at Carman or Brandon, however in the second production year the benefit was observed at both locations. In the first production year at Glenlea, the FERT and the INTER treatments produced FSB with significantly higher CP than that of the NOFERT treatment, indicating a benefit early in the perennial production cycle. It was expected that the INTER treatment would produce an increased CP over that of the NOFERT treatment (Favre et al., 2019; Pinto et al., 2022); however, this was not the case in the second production year at the remaining sites. The CP of a legume forage and grass-legume intercrops is generally expected to be higher than a grass monoculture (Hackmann et al., 2008); however, the results of this experiment suggest there may be situations where CP of IWG monocultures exceed that of legume and/or grass-legume intercrops. An early frost occurred at Carman in 2020 and as a result the CP of the FSB of the FORCON treatment was significantly less than the CP of the NOFERT, FERT, and INTER treatments. This was expected as leaf loss in legumes is an issue during stockpiling (Aasen et al., 2004) which can affect the chemical composition of the available forage (McGeough et al., 2017).

4.5.4 Total digestible nutrient of the fall stockpile biomass

Total digestible nutrient is another critical chemical composition metric to consider when evaluating forage for stockpile grazing. It was hypothesized that the TDN of the NOFERT, FERT, and INTER treatments would be greater than the TDN in the FSB of the FORCON treatment. The TDN concentrations reported at Brandon and Carman were greater for the IWG treatments in the first production year. This was expected as the advanced maturity of the FORCON treatment would be expected to increase concentrations of fibre (King et al., 2012). The TDN of the FERT treatment was significantly greater than that of the NOFERT treatment at Carman and Brandon in the second production year. A significant increase in TDN related to nitrogen fertilization is inconsistent with literature which reports no significant effect of nitrogen application in orchardgrass at elevated N rates compared with those in this experiment (Reynolds et al., 1969). These authors had N treatments split between two applications in early March and early June, totaling 112 kg N ha^{-1}, and 224 kg N ha^{-1}. Conversely, when rates similar to the current experiment were used (0 – 100 kg N ha^{-1} at 20 kg N ha^{-1} increments), there was a decrease in TDN associated with increasing the rate of nitrogen applied in forage oats (*Avena sativa* L.) by approximately 0.4% DM for every 10 kg N ha^{-1} (Coblentz et al., 2017). It is worth noting that in the experiment by Coblentz et al. (2017), the oats were harvested after elongation had begun, prior to the 3-node stage; therefore, the crop was more mature than the regrowth considered in the current study. Based on the literature, this relationship between N fertility and TDN is complex, and the consideration of other chemical composition metrics may provide further insight into the factors associated with TDN concentration.

4.5.5 Neutral detergent and acid detergent fibre of the fall stockpile biomass

The NDF and ADF concentrations were expected to be lower in the FERT and INTER treatments relative to that of the NOFERT treatment. The supplemental fertility had little significant effect in the first production year as the NDF and ADF of the NOFERT, FERT and INTER treatments were not significantly different at Carman and Brandon, while at Glenlea the NDF of the INTER treatment was significantly less than that of the NOFERT treatment, and the ADF of the FERT treatment was significantly less than that of the NOFERT treatment. In the second production year the NDF and ADF concentrations of the FERT treatment were significantly less than those of the NOFERT treatment at both Carman and Brandon. The addition of N at the rates in this experiment would be expected to have little effect on NDF and ADF, based on the findings of Ertekin et al. (2022) which showed virtually identical values when comparing the NOFERT treatment with the 50 kg N ha^{-1} rate in an experiment testing Italian ryegrass. These authors reported treatments were applied as split applications preseeding and post-harvest, ranging from 0 kg N ha^{-1} to 200 kg N ha^{-1} increasing incrementally by 50kg N ha^{-1}; NDF and ADF were only significantly decreased when the rate exceeded 150 kg N ha^{-1} (Ertekin et al., 2022). The annual forage was harvested after months of stockpiling, therefore the plant material was likely more mature than that of the regrowth considered in this experiment. When testing five different grass species (perennial ryegrass (*Lolium perenne* L.), Italian ryegrass, tall fescue, cocksfoot (*Dactylis glomerata* L.), timothy (*Phleum pratense* L.), King et al. (2012) reported no significant effect on NDF and inconsistent increases in ADF (among grass species) comparing 0 kg N ha^{-1} with 125 kg N ha^{-1} and harvesting the biomass every two weeks which would be a similar stage to the IWG in this experiment. Favre et al. (2019) reported significantly lower NDF of IWG intercropped with red clover compared with an IWG monoculture, but no significant difference in ADF concentrations were observed. It is worth noting that in the research by Favre et al. (2019), both treatments were fertilized in April, whereas the IWG monoculture received a second application in May at the start of stem elongation. It is likely that the extensive die-off of the alsike clover, as reported in the botanical composition analysis (Cattani unpublished data), limited the potential for the INTER treatment to produce a significant effect in this experiment as there was little material in the FSB samples. Therefore, it appears that N must be available at a higher rate than what was applied in this experiment to observe a significant reduction in fibre concentrations (Ertekin et al., 2022).

It was hypothesized that the NDF and ADF of the FORCON treatment would be greater than what was reported in the NOFERT, FERT and INTER treatments. This was not consistently observed among site-years in this experiment. The FSB of the FORCON treatment produced an NDF concentration that was significantly greater than what was reported in one or more of the IWG containing treatments in 1 of 5 site-years, and an ADF concentration that was significantly greater than that of one or more of the IWG treatments in 3 of the 5 site years. This was not expected as the advanced maturity of the crops in the FORCON treatment was expected to increase the NDF and ADF concentrations similar to the results reported by Abd El Moneim et al. (1990). The NDF concentration was also expected to increase as a result of leaf drop which generally leads to increases in NDF (Peng 2017). The frost reported at Carman in 2020 appears to have been sufficient to cause a significant increase in NDF of the FSB of the FORCON treatment, similar to the differences in CP concentration outlined previously. However, in the other site-years, the legumes may have retained their leaves for a longer period resulting in lower overall NDF and ADF concentrations.

4.5.6 Implications for beef production

Forage production is dependent upon growth environment, both climatically and nutritionally. The FORCON treatment, described by Dickson (2022 as the superior perennial forage intercrop for stockpile grazing in their experiment which was conducted by the University of Manitoba at Brandon, MB. The chemical composition was better than the other intercrops tested, however this did not mean that supplementation was not necessary for effective grazing. The average CP concentration was 10.29% DM, the TDN was 54.93 % DM and the NDF was 59.35% DM (Dickson, 2022) for their FORCON treatment in 2016. In this study, the FSB of the FERT treatment surpassed each of those values in 4 of the 5 site-years (2020 and 2021). However, variability of chemical composition parameters between sites and years is to be expected and therefore each year and location will be different. Therefore, the suitability for beef cattle will need to be assessed on a site basis. Favre et al. (2019) reported that the FSB of IWG had chemical compositions that were adequate for grazing of beef cattle during lactation, and heifers in Minnesota. Concentrations were reported on a DM basis and for the FSB of the IWG were 59%, 33.7%, and 11.9% for the NDF, ADF, and CP respectively, while for the spring stockpiled biomass sampling, the values were 45.6%, 24.9% and 22.5% (Favre et al., 2019). Spring regrowth was included in their spring stockpiled observations resulting in the high CP%. Concentrations for the FSB of the FERT treatment were greater than 11.9% in 4 of the 5 site-years for the CP, and lower than 54.93% in 3 of the 5 site-years for NDF, and lower than 33.7% in 3 of the five site-years for ADF. The TDN concentration required for gestating cows in the second trimester ranges from 55-60% DM with a minimum CP concentration of 7% DM (McGeough et al., 2017). The TDN and CP concentrations reported in the FERT treatment were above the minimum requirements in all site-years, therefore, based on the literature, the concentrations reported in this experiment were sufficient for grazing non finishing classes of beef cattle, with the potential need for supplementation depending on weather conditions.

4.6 Conclusion

For perennial grains to be a viable option, use of both the grain and forage biomass yield is required. These results reported on a DM basis indicate that IWG reached yields where a producer could utilize the regrowth in four of the five site years, especially when fertility was added post-grain harvest. Relative to the FORCON treatment, the CP concentration of FSB of the FERT treatment was equal to or significantly greater in 3 of 5 site-years, TDN of the FSB was greater than that of the FORCON in all site-years, and the NDF and ADF concentrations were significantly less than, or equal to that of the FORCON in all site-years. In 2 of the 5 site-years, the FSB of the FERT treatment produced a TDN concentration greater than and an NDF concentration less than that of the NOFERT treatment. The ADF of the FSB of the FERT treatment was significantly lower than that in the NOFERT treatment in 3 of the 5 site-years. Moisture limitations can reduce forage biomass yield potential within a growing season, but that is a reality for dryland cropping systems and an unavoidable risk in annual grain production as well. Our results indicate that post-grain harvest regrowth was an acceptable feed source and can increase the value of utilizing IWG as a perennial grain. The utilization of the fall regrowth following grain harvest in IWG for stockpile grazing shows promise, however precipitation post grain harvest will be an important determining factor to its success.

4.7 Transition to Chapter 5

The research in the current chapter illustrated the potential of IWG for the generation of adequate stockpiled forage biomass yield for grazing, with the addition of 50 kg N ha^{-1} after grain harvest. Fall stockpiled biomass yield was affected by post-grain harvest precipitation; however, fertility applications reduced the risk of inadequate regrowth. The chemical composition of IWG fall stockpiled biomass was adequate for grazing in the fall. The research in the current chapter focused on the addition of nitrogen in synthetic form or nitrogen in organic form as shared nitrogen supplied by a legume intercrop. As the perennial IWG crop develops, the N requirement could change throughout the growing season leading to differences in investment based on the timing of its availability. As a result, the next chapter outlines research focusing on the effects of the timing of similar synthetic nitrogen rates on grain yield and fall stockpiled biomass yield and chemical composition.

5 YIELD AND CHEMICAL COMPOSITION OF GRAIN AND POST GRAIN HARVEST FORAGE REGROWTH IN DUAL-PURPOSE INTERMEDIATE WHEATGRASS STANDS AS INFLUENCED BY TIMING OF FERTILITY APPLICATION

5.1 Abstract

Intermediate wheatgrass (IWG, *Thinopyrum intermedium* (Host) Barkworth & D.R. Dewey) is being developed globally as a perennial grain. The proposed dual-purpose system researched in this experiment will allow for the harvest of human-grade grain and high-quality forage in the same growing season. This experiment evaluated the effect of the timing of nitrogen (N) application on yield and chemical composition of IWG grain and forage regrowth in late fall/early winter. This experiment was conducted at Carman, Manitoba over a 5-yr period (2017-2021) and with data presented for the third and fourth year of grain production (2020, 2021). It consisted of four treatments arranged in a 4 x 4 Latin Square Design to account for unknown soil fertility gradients in the field. Experimental treatments were: an unfertilized IWG monoculture control (NOFERT); an IWG monoculture with 50 kg N ha^{-1} post grain harvest (FALL); an IWG monoculture with 50 kg N ha^{-1} in the subsequent spring (SPRING); an IWG monoculture with 35 kg N ha^{-1} post grain harvest and 15 kg N ha^{-1} in the subsequent spring (SPLIT). This experiment evaluated grain yield, inflorescence density, floret and spikelet number, thousand seed weight (TSW), grain protein content, biomass at grain harvest yield (BIOM), harvest index, fall stockpile biomass yield (FSB) and chemical composition as well as the total aboveground shoot biomass yield (TBIOM) which was calculated as the sum of biomass samplings throughout the season. Over the two seasons, the spikelet number of the SPRING treatment was significantly lower with 17.7 spikelets inflorescence $^{-1}$ compared with all other treatments, which ranged from 18.4 – 18.7 spikelets inflorescence^{-1}. Significant treatment differences in BIOM

yield were reported (p = 0.0366), with the greatest BIOM reported on a dry matter (DM) basis in the NOFERT treatment at 7372 kg DM ha^{-1}, which was significantly greater than the BIOM in the SPRING treatment by more than 2000 kg DM ha^{-1}, but did not differ significantly from the BIOM of the FALL or SPLIT treatments. The TBIOM showed significant treatment differences during the two production seasons, with the NOFERT treatment producing the greatest TBIOM; more than 3000 kg DM ha^{-1} greater than that of the SPRING treatment and 2000 kg DM ha^{-1} greater than that of the FALL treatment but did not differ significantly from the TBIOM of the SPLIT treatment (p = 0.0029). All other grain yield and forage chemical composition observations did not differ significantly among treatments over the two years of the study. Drought conditions occurred during the two growing seasons (50% and 71% of the 30-year normal for 2020 and 2021 respectively), which likely reduced the potential for some treatment differences.

5.2 Introduction

Perennial cropping systems can provide several ecosystem benefits that can positively influence the soil environment. One of the main benefits is the season-long groundcover, which can reduce soil erosion thereby limiting soil degradation (Crews et al., 2016). Dual-purpose perennial cropping systems provide the opportunity to harvest human-grade grain and stockpiled regrowth following the grain harvest (Cattani & Asselin, 2018). Agronomic research on intermediate wheatgrass (IWG, *Thinopyrum intermedium* (Host) Barkworth & D.R. Dewey) has shown that similar to annual cereals, grain yield is limited by N availability (Jungers et al., 2017; Reilly et al., 2022). The addition of synthetic N has been reported to produce a positive rate response in both seed yield (Jungers et al., 2017; Fernandez et al., 2020), and vegetative biomass yield

(Fernandez et al., 2020). Jungers et al. (2017) reported that the N response in seed yield is not linear and when rates exceeded 100 kg N ha^{-1} seed yield decreases.

Research in France has reported that IWG will allocate excess N to biomass yield, while the actual N required for crop maintenance and survival are low (Fagnant et al., 2023). A moderate N rate of 60 kg N ha^{-1} yielded more grain than the unfertilized control and the high rate of 120 kg N ha^{-1} during the 2013 to 2015 growing seasons at two of three experiment sites managed by the University of Minnesota (Mulla et al., 2023). However, the forage biomass yield produced by the moderate treatment was nearly 8% lower than what was produced by the higher rate as predicted by the model. Determining the optimum N application rates and timing must balance crop biomass yield and grain yield.

A comprehensive understanding of reproductive induction requirements is critical for identifying the nutritional demands. Dual induction, which is the initiation process requiring exposure to vernalization conditions followed by spring temperature and daylight hours, is a requirement for the development of reproductive tillers in IWG (Cattani & Asselin, 2018; Duchene et al. 2021). The timing of the second inductive event (Heide, 1994) is thought to occur between the 13 and 14 hr of daylight in the spring. These daylengths are generally achieved between April 2nd and the 21st of April, which represent a range of mean growing degree days (GDD) of 60-128 as calculated with a base temperature of 0°C for 2010-2019 at (49.501523, 98.027554) Carman, Manitoba (D. Cattani, personal communication). Years vary greatly, and therefore, the spring timing of fertility may be influenced by the amount of GDD accumulated prior to induction in any given year. The presence of snow on the surface at amounts great enough to impede the interception of daylight can interfere with the ability of the plants to respond to specific growing conditions. Therefore, both the timing of acceptable conditions for development and the timing of fertility applications must be considered when interpreting results.

The germplasm of IWG developed for grain yield and has been evaluated for forage chemical composition and demonstrated concentrations acceptable for grazing animals with numerous nutritional needs, including dairy production (Favre et al., 2019). It is generally accepted that the regrowth stockpiled after grain harvest is highly nutritious because it is early vegetative material. Nutrients in early vegetative material are generally more digestible due to lower concentrations of fibre that increase as the plants mature (Abd El Moneim et al., 1990). It has also been reported that subsequent grain yields and forage biomass yield can benefit from harvesting the regrowth from the IWG crop (Pugliese et al., 2019). Given the potential nutritive value and the added yield benefit in the perennial production cycle if adequate post harvest precipitation occurs, there is merit in using the biomass yield to offset potential losses from reduced grain yield in the system.

5.2.1 Research objectives and Hypotheses:

The experiment outlined in this chapter focuses on the timing of N application in the dual-purpose cropping system to maximize grain yield, forage biomass yield and chemical composition characteristics. The objectives of the experiment were:

1. Evaluate the effect of increased available N from synthetic N application at specific times during the growing season on grain yield, grain protein, and fall stockpile biomass yield, and chemical composition of the fall stockpile biomass.

The experiment hypothesized that an increase in available N in the fall from synthetic application would result in the greatest increase of grain yield, grain protein content, and fall stockpile biomass yield (FSB), and would have a positive effect on chemical composition metrics. The chemical composition metrics considered include total digestible nutrient (TDN), crude protein concentration (CP), neutral detergent fibre (NDF), and acid detergent fibre (ADF). It was hypothesized that when more N was available to the IWG in the fall, the TDN and CP would increase; however, the NDF and ADF were expected to decrease relative to the unfertilized treatment.

5.3 Materials and Methods

5.3.1 Experiment location

The experiment consisted of a single location at the University of Manitoba's Ian N. Morrison Research Farm near Carman, Manitoba (49.501523, 98.027554). The experiment was established in 2017 under dryland conditions, and the soil was a loamy orthic black chernozem of the Denham series (MAFRI, 2010). Prior to the sampling years reported in this chapter (2020, 2021), the IWG was harvested for grain production annually. In 2018, total area grain yield was 1300 kg ha^{-1} and in 2019 the plot yield averaged (1190 ± 239.1 kg ha^{-1}). In 2018 and thereafter, the plots were fertilized according to their corresponding treatments.

Soil sampling was conducted in fall when conditions permitted. In the fall of 2019, the conditions did not allow for sampling resulting in the sampling being conducted in the spring of 2020. Soil samples were separated by treatment and collected from two depths (0-15 cm and 15-60 cm) using a manual probe, and submitted to Agvise Laboratories (Northwood, North Dakota, USA) to determine soil fertility levels as reported in Table 5.1.

Table 5.1. Soil nutrient status and properties for each experimental treatment prior to the 2020 and 2021 growing seasons.

Soil nutrient/property	N (0-15 cm)* N (15-60 cm) kg ha^{-1}	P ppm	K ppm	S kg ha^{-1}	Organic Matter (%)	Soil pH
Treatment				Sampled April 20, 2020		
NOFERT	5 9	55	644	186	4.8	7.9
FALL	8 9	68	711	44	5.7	7.8
SPRING	4 9	58	680	30	5.7	7.7
SPLIT	7 15	70	760	30	5.3	7.5
				Sampled October 22, 2020		
NOFERT	11 21	45	753	120	5.4	7.9
FALL	25 24	56	715	64	5.8	7.9
SPRING	13 12	59	709	40	5.8	7.6
SPLIT	26 18	50	718	74	5.9	7.6

*Soil nutrients were **N** = residual nitrates; **P** = Olsen test determined residual phosphorus; **K** = residual potassium; **S** = residual sulfur.

5.3.2 Experimental design

The experiment was arranged in a Latin square design, with plots that were approximately 95 m^2. The IWG seed used in the experiment was sourced from the University of Manitoba (Cattani, 2017). Unlike the small plots reported in the previous chapter, there was no perimeter fence around this site. The experiment consisted of four treatments; an unfertilized IWG monoculture (NOFERT) serving as the control; an IWG monoculture with 50 kg N ha^{-1} applied as broadcasted urea post grain harvest (FALL); an IWG monoculture with 50 kg N ha^{-1} applied as broadcasted urea in the spring (SPRING); and an IWG monoculture with 35 kg N ha^{-1} applied post grain harvest and 15 kg N ha^{-1} in the spring (SPLIT). Nitrogen was applied as broadcasted urea between grain harvest and September 1 in the FALL and the SPLIT treatments and on April 29 in 2020 and April 22 in 2021 in the SPRING treatment, and the remainder of the SPLIT treatment as determined by snow melt. All plots were seeded at 30 cm row spacings at a seeding rate of 6 kg ha^{-1}.

5.3.3 Data collection

5.3.3.1 Flowering counts: spikelet number, floret number, and inflorescence density

During anthesis, 20 random inflorescences were sampled throughout a plot. The inflorescences were laid out to dry and stored until spikelets and florets could be counted. Each inflorescence had the number of spikelets counted to determine spikelets inflorescence^{-1}. To determine floret count, the inflorescence was then divided into three segments; bottom, middle and top, and a central spikelet was chosen from each of the three segments to count florets, similar to methods outlined by Altendorf et al. (2021). Florets inflorescence^{-1} was then calculated by multiplying the average floret number spikelet^{-1} by the number of spikelets inflorescence^{-1}. Spikelets inflorescence^{-1} and florets inflorescence^{-1} were then averaged over 20 inflorescences. After anthesis, two randomly selected 1 m x 30 cm of row were counted within the plots to determine the inflorescence density. The two counts were averaged, and the area was calculated as 0.30 m^{2}. The average count was then divided by the area to determine the inflorescences m^{-2}.

5.3.3.2 Thousand seed weight (TSW)

In 2020, a representative grain subsample was taken from the plot yield and processed to bare seed. Hulls were removed by hand-threshing with rub-bars, using hand sieves and by density separation with a Hoffman Seed Blower (Model 67, Hoffman Manufacturing, Albany, OR, USA) until there was less than 5% hull visible. Once less than 5% of the hull was visible, the samples were considered bare seed. Samples were then passed through the seed counter (Model U, International Marketing and Design Corporation, San Antonio, TX, USA). The subsample was then weighed, and the weight and seed number were used to estimate thousand seed weight (TSW). In 2021, once the grain was ripe (hard dough stage, Berdahl and Frank, 1994), samples were taken from 50 randomly selected inflorescences within the plot; the cleaning and counting processes were the same as the previous season.

5.3.3.3 Grain protein content

The bare seed generated by the TSW process was milled using a Sample Mill (Cyclone, UDY Corporation, Fort Collins, CO, USA) through a 1 mm screen. Grain protein content was determined by measuring nitrogen in the seed using a Nitrogen/Protein Determinator which employs the Dumas combustion method (FP-528, LECO Corporation, St. Joseph, MI, USA). The determined N content was then converted to percent protein by using a multiplication factor of 5.75. The conversion factor of 5.75 was chosen instead of 6.25, because 6.25 tends to overestimate grain protein content as it does not factor non-protein nitrogen and the relative proportions of specific amino acids (Fujihara et al., 2008).

5.3.3.4 Grain yield

Grain yield was determined as the total plot yield, excluding the two outermost rows on either side of the plot, which served as a treatment buffer. The grain harvest was conducted by directly harvesting the plants using a Wintersteiger combine (Model unknown, Wintersteiger Seedmech, Ried im Innkreis, Austria). Harvested samples were then passed through a seed cleaner (M2BC, Clipper, Blount Ferrell-Ross, Bluffton, Indiana, USA) using the 6 ½ x ¾ inch screen and the #13 round sieve and then through the Laboratory Air-Screen Cleaner (LA-LS, Westrup, Slagelse, Denmark) using the 7/64 inch screen and the #13 round sieve to remove extraneous materials. They were subsequently weighed to determine the mass of grain harvested per unit area and expressed as kilogram per hectare.

5.3.3.5 Biomass at grain harvest yield (BIOM), and harvest index

At grain maturity four randomly selected 1 m rows (2020), or two randomly selected 1 m rows (2021) of IWG were harvested to determine plant biomass at grain harvest yield (BIOM). Plants were cut 4 cm above the soil surface. After cutting, heads were bagged to contain shattered seeds, secured with zip ties, and samples were bundled with zip ties and placed on drying beds for 3-5 d until and then dried in ovens at 60°C for 72 hrs and then weighed. Harvest index was determined by dividing the mass of grain per unit area (grain yield) by mass of plant material per unit area BIOM to determine the proportion of plant material that was grain.

5.3.3.6 Fall stockpile biomass yield (FSB)

In mid-October, four randomly chosen 0.25 m^2 areas were cut to a height of 4 cm above the surface to sample the plots. Immediately after sampling, samples were weighed fresh, and frozen until further processing could proceed. Materials were removed from the freezer, dried at 55°C for 72 hrs, and weighed to determine the percent DM. Total aboveground shoot biomass yield (TBIOM) was determined by adding the FSB and BIOM. After the quadrat samples were collected, the remaining biomass was removed from the plot using a forage harvester (Alfalfa-

Omega plot master, R-Tech Industries, Homewood, MB, Canada). Yield estimates were determined from the quadrat subsamples and expressed on a DM basis.

Dried samples were then ground using a Wiley Mill (Model #4, Thomas Scientific Swedesboro, NJ, USA) equipped with a 1 mm screen and submitted to Central Testing Laboratory Ltd. in Winnipeg, Manitoba, for wet chemistry analysis of the CP concentration, NDF, and ADF and determination of factors to calculate TDN. The procedures outlined by the Association of Official Analytical Chemists (AOAC) were used to determine the energy analysis of the samples (AOAC, 1995). The TDN of the samples was calculated using the formula described by Adams (1994). A YSI 2700 SELECT Biochemistry Analyser (YSI Incorporated Life Sciences, Yellow Springs, OH, USA) was used to quantify the starch fraction of the forage. A Leco FP528 (LECO Corporation, St. Joseph, MI) was used to quantify the CP concentration in accordance with AOAC 990.03 method (N x 6.25). Similar to the methods of Van Soest et al. (1991) the NDF and ADF concentrations were determined using a heat-stable α-amylase enzyme and sodium sulfate to digest in-vitro samples. The NDF and ADF concentrations were quantified using an ANKOM 200 automated fibre analyzer (ANKOM 36 Technology, Macedon, NY) as outlined by Komarek (1993). Finally, an ANKOM Extraction system (ANKOM Technology; Macedon, NY) at the University of Manitoba, Winnipeg, MB was used to determine fat concentration as per ANKOM technology Methods (NDF Method 13 and ADF Method 12).

5.3.4 Statistical analysis

The data were analyzed using SAS® OnDemand for Academics (SAS Institute Inc., Cary, NC, USA) using the GLIMMIX procedure. Before running the final model, the assumptions of heterogeneity of variances and conformation of the residuals to the normal distribution were tested. Heterogeneity of variances were determined by modelling variances for each level of key factors using the random statement and comparing the AIC of the corrected and uncorrected models. The model with the lowest AIC was chosen. When running the GLIMMIX procedure, location, treatments, year and their interaction were analyzed as fixed effects, and replicate within site was included as a random effect. Residuals were generated in GLIMMIX and tested using the univariate procedure (PROC UNIVARIATE). The Shapiro-Wilk test and visual inspection of Q-Q plots were used to determine whether the distribution of the residuals was normal. Skewedness (between -1.0 and 1.0) and kurtosis (between -2.0 and +2.0) were also checked to determine if a transformation should be considered. In cases where residuals did not conform to the normal distribution, the following steps were conducted iteratively. Inspection of the residual plots were conducted to look at potential outliers and data were checked to ensure accuracy. Skewedness (between -1.0 and 1.0) and kurtosis (between -2.0 and +2.0) were also checked to determine if a transformation (e.g. for lognormal "solution d=lognormal" in the model statement) should be considered. If deemed necessary, a lognormal or a square root analysis was performed in GLIMMIX and previously described steps were repeated to see if the transformation resulted in a better fit to the data. Inspection of the residual plots were conducted to look at potential outliers and data were checked to ensure accuracy. Studentized residual tables were generated to determine potential outliers and observations were removed if the values were outside +/- 4.0 and if a plot was adversely impacted by other identifiable factors. The best-fit model was selected and Tukey-Kramer LSD test was used to separate treatments. Where a transformation was required, mean comparisons were made on the transformed data, however, data are reported as back-transformed means.

5.4 Results and Discussion

5.4.1 Weather conditions at Carman, MB during the 2019 to 2021 growing seasons

Moisture limitations were a widespread problem throughout the Canadian Prairies from 2019 to 2021. As outlined in Table 5.2 the 30-yr normal for precipitation at Carman, MB is 531.3 mm. The moisture received in 2019 was the least limiting of the three years included in the table. In 2019 no data was collected, however the treatments were applied in the fall, and from October to December, the precipitation total was 87% of the 30 yr-normal, The following season was the most extreme, in 2020, Carman, MB received slightly above 50% of the average precipitation (267.8 mm) and in 2021 the total was 150 mm less than the 30-yr normal.

Table 5.2. Mean daily temperature and total monthly precipitation from 2019-2021 at Carman MB, and 30-year average (1989-2018).

	Mean daily temperature (°C)				**Total precipitation (mm)**			
Month	**2019**	**2020**	**2021**	**30 yr***	**2019**	**2020**	**2021**	**30 yr***
January	-17.1	-12.4	-9.3	-15.2	12.9	14.0	2.5	15.5
February	-20.6	-12.4	-17.0	-12.5	35.1	1.6	3.8	13.8
March	-7.0	-4.9	0.0	-5.3	1.4	2.6	2.6	21.4
April	4.8	1.6	3.4	4.1	17.8	24.7	9.4	28.9
May	9.6	10.8	10.8	11.5	36.9	27.8	27.2	78.5
June	17.3	18.3	19.3	17.1	37.9	70.2	102.9	98.0
July	19.5	20.3	21.2	19.3	57.7	52.9	17.2	70.4
August	18.1	18.4	18.2	18.6	61.7	24.3	78.0	68.6
September	12.6	12.3	15.7	13.5	150.7	10.8	16.5	51.4
October	2.9	2.1	8.4	5.6	54.1	17.2	79.6	39.0
November	-5.5	-3.2	-1.6	-4.0	16.6	4.2	23.8	23.5
December	-11.4	-6.9	-12.7	-11.7	2.7	17.5	17.6	22.3
Mean/Total	1.9	3.7	4.7	3.4	485.5	267.8	381.1	531.3

5.4.2 Significance of the fixed effects and their interaction

Of the 14 response variables recorded over the two production years included in this experiment, 11 did not demonstrate significant treatment differences when $p < 0.05$ (Table 5.3). Year of production was the main effect, accounting for differences in experimental means that resulted in significant differences in 12 of 14 response variables; however, no treatment-by-year interactions were demonstrated. The lack of significant differences in grain yield between years was not expected given the significant differences reported in the yield components, these trends illustrate the potential for yield component compensation as certain response variables would need to decrease while others increased to maintain a constant yield between years.

Table 5.3. Significance (p-value) of the fixed effects of year (Y) and treatment (T) and their interaction for the response variables: grain yield, inflorescence density, floret number, spikelet number, thousand seed weight, biomass at grain harvest yield, harvest index, grain protein content, fall stockpiled biomass yield, crude protein of the fall stockpiled biomass, total digestible nutrient of the fall stockpiled biomass, neutral detergent fibre of the fall stockpiled biomass, acid detergent fibre of the fall stockpiled biomass, total aboveground shoot biomass yield.

Measurement	Year (Y)	Treatment (T)	Y*T
Grain yield	0.0958	0.2194	0.6747
Inflorescence density	**< 0.0001**	0.8588	0.9568
Floret number	**< 0.0001**	0.8927	0.5531
Spikelet number	**< 0.0001**	**0.0247**	0.8359
Thousand seed weight	**< 0.0001**	0.8356	0.5072
Biomass at grain harvest yield	**< 0.0001**	**0.0366**	0.9860
Harvest index	**< 0.0001**	0.6540	0.9018
Grain protein content	0.2001	0.1380	0.9144
Fall stockpiled biomass yield	**< 0.0001**	0.5107	0.6395
Crude protein of the fall stockpiled biomass	**< 0.0001**	0.5579	0.8322
Total digestible nutrient of the fall stockpiled biomass	**< 0.0001**	0.5673	0.7380
Neutral detergent fibre of the fall stockpiled biomass	**< 0.0001**	0.6469	0.4387
Acid detergent fibre of the fall stockpiled biomass	**< 0.0001**	0.6230	0.7741
Total aboveground shoot biomass yield	**0.0310**	**0.0029**	0.1967

Determined using Tukey-Kramer significance, bolded values indicate significance at $p < 0.05$

5.4.3 Grain yield

Grain yield did not differ among years (446 kg ha^{-1} and 385 kg ha^{-1}, in 2020 and 2021 respectively), or treatment. The SPLIT treatment yielded 454 kg ha^{-1} followed by the grain yield of the FALL treatment at 444 kg ha^{-1}, then that of the NOFERT treatment at 410 kg ha^{-1}, and grain yield of the SPRING treatment at 354 kg ha^{-1} (Table 5.4). The lack of treatment effect on grain yield was not consistent with other research (Jungers et al., 2017; Fernandez et al., 2020), however the age of the stand (third and fourth year of grain production) and successive year drought conditions (2020 at 50% and 2021 at 72% of the 30-yr average precipitation, Table 5.1) likely contributed to the lack of significant differences. The lack of treatment effect could be due to moisture limitations reducing the availability of N to the plant (Bista et al., 2018). At rates similar to those used in this experiment, grain yield has shown significant increases in years following the first production year (Jungers et al., 2017; Fernandez et al., 2020); however, the experiments were not conducted on stands in their third and fourth production years. Although not significant, the grain yield decreased numerically (23%) progressing into the fourth production year, demonstrating a pattern similar to that outlined in prevailing literature (Tautges et al., 2018; Lanker et al., 2019; Li et al., 2019).

Table 5.4. Grain yield of intermediate wheatgrass as influenced by year and treatment at Carman, MB.

	Year		**Treatment***			
Parameter	2020	2021	NOFERT	FALL	SPLIT	SPRING
Grain yield (kg ha^{-1})	446 a^{+}	385 a	410 a	444 a	454 a	354 a

$^{+}$Means followed by the same letter within year or treatment rows are not significantly different using Tukey-Kramer LSD at P = 0.05.

*Treatments were **NOFERT** = control; **FALL** = 50 kg N ha^{-1} applied post grain harvest; **SPLIT** = 35 kg N ha^{-1} applied post grain harvest and 15 kg N ha^{-1} in the spring; **SPRING** = 50 kg N ha^{-1} in the applied in the spring.

5.4.4 Inflorescence density, spikelet number, and floret number

There were no significant treatment effects in either of the production, however, there was a significant increase in inflorescence density between the third and fourth production years (Table 5.5). In 2020, inflorescence density was 332.1 inflorescences m^{-2}, while 624.6 inflorescences m^{-2} were reported in 2021. Treatments ranged from 436.0 inflorescences m^{-2} in the SPRING treatment to 506.0 inflorescences m^{-2} in the SPLIT treatment. Inflorescence density has been shown to increase with increasing N rate in annual wheat (*Triticum aestivum* L.) cultivars (Otteson et al., 2007); however, the N rates used in that experiment were 3-6x greater than those used in this research. When lower incremental rates of N (0-90 kg ha^{-1}) were used in annual wheat, Pimentel et al. (2019) reported inconsistent N rate effects on inflorescence density that were cultivar specific; therefore, the effect could be related to the high N rate, as well as genetic background. Regardless of the treatment effect, inflorescence density in 2021 reached >400 inflorescences m^{-2}, which is described as adequate to maintain long-term grain yield potential in IWG perennial grain systems in European conditions (Fagnant et al., 2024), and may be an acceptable benchmark for Canadian production based on the results reported in this experiment. This inflorescence density in the fourth production year could indicate the potential for sustained grain yield as the stand ages.

Table 5.5. Inflorescence density, spikelet number, and floret number of intermediate wheatgrass as influenced by year and treatment at Carman, MB.

	Year		**Treatment**$^{+}$			
Parameter^{+}	2020	2021	NOFERT	FALL	SPLIT	SPRING
Inflorescence density (m^{-2})	332.1 b^{+}	624.6 a	479.8 a	491.8 a	506.0 a	436.0 a
Spikelet number (inflorescence^{-1})	18.9 a	17.7 b	18.7 a	18.7 a	18.4 a	17.7 b
Floret number (inflorescence^{-1})	148.1 a	111.4 b	130.6 a	127.9 a	130.1 a	130.4 a

$^{+}$Means followed by the same letter within year or treatment rows are not significantly different using Tukey-Kramer LSD at P = 0.05.

*Treatments were **NOFERT** = control; **FALL** = 50 kg N ha^{-1} applied each after grain harvest; **SPLIT** = 35 kg N ha^{-1} applied post grain harvest and 15 kg N ha^{-1} in the spring; **SPRING** = 50 kg N ha^{-1} in the applied in the spring.

Both spikelets inflorescence^{-1} and florets inflorescence^{-1} decreased significantly progressing into the fourth production year (Table 5.5). In terms f treatment, the spikelets inflorescence^{-}were significantly lower (p = 0.02) in the SPRING treatment (17.7 inflorescence^{-1}) compared with the that of the other three treatments including the NOFERT and the FALL treatments having 18.7 inflorescence^{-1} and the SPLIT treatment having 18.4 inflorescences^{-1} (Table 5.5). Mean florets inflorescences^{-1} decreased significantly in 2021 (111.4 florets inflorescence^{-1}) versus 148.1 florets inflorescence^{-1} recorded in 2020. Florets inflorescence^{-1} ranged from 127.9 in the FALL treatment to 130.6 in the NOFERT treatment across years. Both spikelet number and floret number have been reported to experience a positive rate response to nitrogen in annual wheat as reported by Ewert & Honermeier (1999) who demonstrated this with spikelet number with rates much higher than this experiment (200 kg N ha^{-1}), while lower rates of 120 kg N ha^{-1} resulted in significant increases in floret number (Zhang et al., 2023). The high inflorescence density in 2021 may have led to lower spikelet number and floret number values due to yield-component compensation, similar to what Dewey and Lu, (1959) described. This is a critical biological process in grain production, which facilitates consistent yield by compensating for reductions in other yields determining factors. Therefore, the effect of yield component compensation may have been more apparent in 2021 as it was a dry year compared with the 30-yr average (Table 5.2), and 215.5 mm of the year's 381.1 mm was received at or after grain harvest (August through December). As a result of the conditions, the increase in inflorescence density may have caused a reduction in the other seed yield components.

5.4.5 Thousand seed weight (TSW), grain protein content

There were no significant treatment effects on the TSW in either production year (Table 5.6). Thousand seed weight experienced a trend similar to the previously described spikelet number and floret number results with a significant decrease in 2021 (4.27 g TSW) compared with what was reported in 2020 (7.57 g TSW). This decreasing trend was likely due to the previously described drought conditions, as moisture limitations can reduce seed size (Cairns et al., 2021). The lack of treatment effects on TSW was consistent with other findings using N rates similar this experiment. When considering perennial ryegrass for seed production, it was reported that rates lower than 200 kg N ha^{-1} did not significantly affect TSW (Cookson et al., 2000); however, this was not a field experiment. Alternatively, in annual wheat production, rates similar to those in this experiment, ranging up to 200 kg N ha^{-1}, have resulted in significant increases in thousand-kernel weight (Hussain et al., 2006). This may not be experienced in perennial grain seed production due to the investment in vegetative development associated with N rate (Fagnant et al., 2023). It is possible that supplemental nitrogen after reproductive induction would be more beneficial for further development of what was induced rather than initiating additional tillers to compete with the reproductive effort.

Table 5.6. Thousand seed weight (TSW), and grain protein content of intermediate wheatgrass in the as influence by year and treatment at Carman, MB.

	Year		**Treatment***			
Parameter	2020	2021	NOFERT	FALL	SPLIT	SPRING
TSW (g)	7.57 a+	4.24 b	5.99 a	5.80 a	5.94 a	5.87 a
Grain protein content (%)	18.93 a	19.38 a	19.44 a	18.66 a	19.70 a	18.83 a

+Means followed by the same letter within year or treatment rows are not significantly different using Tukey-Kramer LSD at P = 0.05.

*Treatments were **NOFERT** = control; **FALL** = 50 kg N ha^{-1} applied each after grain harvest; **SPLIT** = 35 kg N ha^{-1} applied post grain harvest and 15 kg N ha^{-1} in the spring; **SPRING** = 50 kg N ha^{-1} in the applied in the spring.

Grain protein content was not affected by year or treatment (Table 5.6). The means between years were 18.93% and 19.38%, in 2020 and 2021, respectively, and the treatment means ranged from 18.66% in the FALL treatment to 19.70% in the SPLIT treatment. Research has reported significant increases in grain protein content in winter wheat associated with increases in N fertility, but the rates used in that experiment were 170 kg N ha^{-1} and 340 kg N ha^{-1} (Saint Pierre et al., 2008). In IWG production, N applied at those rates would be expected to have several adverse effects on grain yield due to the inherent investment of N in biomass yield (Jungers et al., 2017; Fagnant et al., 2023). Therefore, agronomic N application rates for grain yield are unlikely to affect grain protein content.

5.4.6 Biomass at grain harvest yield (BIOM), harvest index

The BIOM yield presented different treatment means (p = 0.0366), with a 50% decline experienced in the fourth production year (Table 5.7). Biomass at grain harvest yield in 2020 was 9127 kg DM ha^{-1} versus 4672 kg ha^{-1} in 2021. The NOFERT treatment had the largest BIOM yield at 7372 kg DM ha^{-1}. Biomass at grain harvest yield reported in the NOFERT treatment was significantly greater than that in the SPRING treatment at 5348 kg DM ha^{-1}, while the BIOM in the FALL and the SPLIT treatments were not significantly different than that of the other treatments at 6420 kg DM ha^{-1} (FALL) and 7066 kg DM ha^{-1} (SPLIT). Frahm et al. (2018) also reported no significant differences in BIOM yield at similar nitrogen fertility levels, although the paper did not specify whether moisture limitations were present during the study period. However, in an experiment in which fertilizer was applied to the developing crop before the initiation of stem elongation, BIOM yield increased significantly compared with the unfertilized control (Fernandez et al., 2020). This effect may have been masked in this current experiment by the drought conditions previously outlined, due to the relationship between soil moisture and nutrient availability, or an overall reduction in forage biomass yield (Staniak & Kocon, 2015). Another factor to consider is that this experiment was conducted near a river, resulting in deer grazing, bedding, and defecation, which were observed throughout the two growing seasons. Deer may have consumed variable amounts of forage from the plots throughout the season, and the random deposition of nutrients could have affected the results.

Table 5.7. Biomass at grain harvest yield (BIOM) and harvest index of intermediate wheatgrass as influenced by year and treatment at Carman, MB.

	Year		**Treatment***			
Parameter	2020	2021	NOFERT	FALL	SPLIT	SPRING
BIOM** (kg DM ha^{-1})	9128 a^{+}	4672 b	7372 a	6420 ab	7066 ab	5438 b
Harvest Index (%)**	4.71 b	10.50 a	6.20 a	7.85 a	7.31 a	6.90 a

$^{+}$Means followed by the same letter within year or treatment rows are not significantly different using Tukey-Kramer LSD at P = 0.05.

*Treatments were **NOFERT** = control; **FALL** = 50 kg N ha^{-1} applied each after grain harvest; **SPLIT** = 35 kg N ha^{-1} applied post grain harvest and 15 kg N ha^{-1} in the spring; **SPRING** = 50 kg N ha^{-1} in the applied in the spring.

** Analyzed using lognormal transformation

As indicated in Table 5.7, the harvest index significantly increased more than twofold from 2020 (4.71%) to 2021 (10.5%). Treatment averages ranged from 6.20% in the NOFERT treatment to 7.85% (FALL) and were not significantly different. This relationship between BIOM yield and harvest index, as demonstrated by the year effect, was consistent with annual species which tend to experience an inverse relationship between biomass yield and harvest index (Egli, 2011). The relationship may be consistent with annual cereal grain harvest index, however, the harvest index that can be achieved in annual cereal grain production is much greater, and in winter wheat for instance, the potential is projected to reach values of 62% (Wang et al., 2020). Although the TSW decreased as previously described (Table 5.6), the decrease in BIOM yield appears to have been significant enough that the overall change resulted in greater seed mass per unit plant mass, as demonstrated by the increased harvest index. The effect on harvest index was consistent with the literature, as research has reported that, regardless of the nitrogen rate, harvest index was not significantly affected, similar to what was observed in this experiment (Frahm et al., 2018; Zimbric et al., 2021).

5.4.7 Fall stockpile biomass yield (FSB) and chemical composition

The chemical composition characteristics of FSB showed significant year differences; however, no significant treatment differences during either production year were observed (Table 5.8). Fall stockpile biomass yield had an extensive range, with year means of 219 kg DM ha^{-1} in 2020 and 2893 kg DM ha^{-1} in 2021. Treatment differences were not significant and ranged from 1340 kg DM ha^{-1} in the SPRING treatment to 1779 kg DM ha^{-1} in the SPLIT treatment. In the fourth production year, FSB increased more than tenfold, likely due to the precipitation received after grain harvest. It was expected that FSB would increase with nitrogen application, similar to what was reported by Fernandez et al. (2020), however that was not observed in this experiment which could be a result of suppressed forage biomass yield from moisture limitations (Staniak & Kocon, 2015) or limited mass flow of nutrients to the plant roots as nutrient availability and uptake rely on soil moisture (Bista et al., 2018).

Table 5.8. Chemical compositions as influenced by year and treatment of the fall stockpiled biomass yield (FSB) at Carman, MB.

	Year		**Treatment***			
Parameter[+]	2020	2021	NOFERT	FALL	SPLIT	SPRING
FSB** (kg DM ha^{-1})	219.23 b[+]	2893.49 a	1505.47 a	1600.80 a	1779.47 a	1339.69 a
Total Digestible Nutrient (% DM)	75.75 a	67.48 b	71.07 a	71.70 a	72.09 a	71.61 a
Crude Protein (% DM)	22.55 a	17.02 b	19.23 a	19.48 a	20.91 a	19.52 a
Acid Detergent Fibre (% DM)	21.40 b	29.17 a	25.77 a	25.22 a	24.85 a	25.30 a
Neutral Detergent Fibre (% DM)	41.42 b	48.26 a	44.89 a	44.42 a	44.80 a	45.26 a

[+]Means followed by the same letter within year or treatment rows are not significantly different using Tukey-Kramer LSD at P = 0.05.

*Treatments were **NOFERT** = control; **FALL** = 50 kg N ha^{-1} applied each after grain harvest; **SPLIT** = 35 kg N ha^{-1} applied post grain harvest and 15 kg N ha^{-1} in the spring; **SPRING** = 50 kg N ha^{-1} in the applied in the spring.

**Analyzed using a simplified metric without randomization

The TDN (75.75% DM in 2020 vs. 67.48% DM in 2021) and CP (22.55% DM in 2020 vs. 17.02% DM in 2021) both were lower in 2021 than in 2020 (Table 5.8). Significant differences were demonstrated among years in NDF and ADF, with NDF concentrations of 41.42% DM in 2020 and 48.21% DM in 2021, and ADF concentrations of 21.40% DM in 2020 and 29.17% DM in 2021. Treatments did not differ statistically in any of the chemical composition metrics, with TDN ranging from 71.07% DM in the NOFERT treatment to 72.09% DM in the SPLIT treatment, CP ranging from 19.23% DM (NOFERT treatment) to 20.91% DM (SPLIT treatment). Neutral detergent fibre ranged from 44.42% DM in the FALL treatment and 45.26% DM in the SPRING treatment, while ADF ranged from 24.85% DM in the SPLIT treatment to 25.77% DM in the NOFERT treatment.

The lack of significant differences in TDN was consistent with research in orchardgrass (Reynolds et al., 1969). Similarly, NDF and ADF were not affected by nitrogen application in Italian ryegrass at rates of 50 kg N ha^{-1} (Ertekin et al., 2022), although the experiment was harvested at later stages of crop development. When sampled during earlier development, King et al. (2012) reported no significant N treatment effect on NDF and inconsistent increases in ADF among the five species tested. Conversely, CP of the regrowth was expected to increase with nitrogen application, as it has been shown to be significantly higher in fertility in several studies with other species, regardless of crop stage, including increases of up to 6% (Sauvé et al., 2010; Antunes et al., 2021; Erketin et al., 2022). The moisture limitations experienced in this study influenced crop development which affected yield and likely contributed to lack of differences in chemical composition metrics.

5.4.8 Total aboveground shoot biomass yield (TBIOM)

The TBIOM was about 30% lower in the fourth production year compared with the third production year and while similar to BIOM yield, the decrease in TBIOM was less pronounced (Table 5.9) with absolute values of 10666 kg DM ha^{-1} in 2020 and 7694 kg DM ha^{-1} in 2021. During both production years, the treatments produced a wide range of TBIOM , resulting in significant differences ($p = 0.0029$). Treatments ranged from 10687 kg DM ha^{-1} in the NOFERT treatment, which was significantly greater than that of the FALL treatment (8580 kg DM ha^{-1}) and the SPRING treatment at 7502 kg DM ha^{-1}, and the SPLIT treatment at 9950 kg DM ha^{-1}, which was statistically similar to all other treatments. Due to the combined samplings used to determine the value (FSB and BIOM), TBIOM was expected to show significant differences as the combined observations were expected to. An experiment by Fernandez et al. (2020) in biomass yield of IWG stands has shown significant increases with nitrogen application. This was contrary to what was demonstrated in the TBIOM of this experiment, where excessive wildlife herbivory, previously described, may have influenced the results.

Table 5.9. Total aboveground shoot biomass yield (TBIOM) of intermediate wheatgrass as influenced by year and treatment reported on a DM basis at Carman, MB.

	Year		**Treatment***			
Parameter	2020	2021	NOFERT	FALL	SPLIT	SPRING
TBIOM** (kg DM ha^{-1})	10666 a^{+}	7694 b	10687 a	8580 b	9950 ab	7502 b

$^{+}$Means followed by the same letter within year or treatment rows are not significantly different using Tukey-Kramer LSD at P = 0.05.

*Treatments were **NOFERT** = control; **FALL** = 50 kg N ha^{-1} applied each after grain harvest; **SPLIT** = 35 kg N ha^{-1} applied post grain harvest and 15 kg N ha^{-1} in the spring; **SPRING** = 50 kg N ha^{-1} in the applied in the spring.

**Two outliers were removed when analyzing the data

5.5 Conclusion

The hypothesis that applying supplemental N in the fall would increase IWG grain yield and forage biomass yield and enhance chemical composition was not supported by the majority of response variables reported over the two years of study. In instances where treatment significantly affected the means (spikelet number, BIOM, and TBIOM), the NOFERT treatment was greater than at least one of the supplemental fertility treatments. This was contrary to the hypothesis, as the application of nitrogen should have provided additional nutrition for the developing crop and resulted in increased yield and enhanced chemical composition of the forage. Based on the moisture conditions, the most limiting resource was water, which likely prevented any nitrogen-related treatment effects. As a result, further research is necessary to determine the effects of fertility timing on dual-purpose IWG production systems in western Canada.

6 SYNTHESIS OF RESEARCH

6.1 Significance of Research

Agricultural landscapes are in a compromised state, as intensive annual rotations leave them susceptible to destructive processes that can have long-term implications for productivity (Crews, 2017). By adding perennials to their rotations, grain producers may reap potential benefits such as decreases in soil erosion (Rashe et al., 2017; Tautges et al., 2018), soil carbon loss (de Oliveira et al., 2020), and nutrient leaching (Culman et al., 2013; Huddle et al., 2023; Mulla et al., 2023). Incorporating perennial grain crops into annual systems however, can entail economic losses due to reduced grain yields (Ryan et al., 2018; DeHaan et al., 2018). Fortunately, to account for that cost, the novel dual-purpose intermediate wheatgrass (IWG) perennial grain system studied here produces a human-grade grain, straw biomass, and may produce forage regrowth with grazing potential within the same season. By combining these products, a producer may earn more income from the stand over multiple seasons, helping to offset the economic loss compared with annual grain alternatives (Jungers et al., 2017). For livestock operations specifically, an additional option is to forego a grain crop and utilize the stand for feed (e.g. hay, silage) in years when there is limited feed supplies as was evident in 2021 in many parts of Manitoba. Increasing the value of IWG production systems is a step towards perennial grain intercrops (Crews & Cattani, 2018), which are expected to provide greater ecosystem benefits than perennial grain monocultures, with the added potential for higher economic return.

Research has shown that annual grain crops experience numerous benefits from the addition of nitrogen (Ewert & Honermeier, 1999; Hussain et al., 2006; Saint Pierre et al., 2008); therefore, it is important to understand the effect that nitrogen has on dual-purpose perennial grain systems to ensure efficiency and minimize potential nutrient losses. The two studies outlined in this thesis focused on the effects of additional nitrogen on grain yield and forage biomass yield and chemical composition in this system. The main objectives were to evaluate the effects of available nitrogen in synthetic and organic forms on the system (Chapter 3 and 4) and the effect that the timing of application may have on the system (Chapter 5).

6.2 Major Findings

In Chapter 3, the FERT treatment resulted in a grain yield that was nearly 200 kg ha^{-1} greater than NOFERT treatment in the third production year, an inflorescence density of 80 additional inflorescences m^{-2} compared with the NOFERT treatment in the third production year, and increased grain protein content in 1 site year. In Chapter 4, the FERT treatment produced a fall stockpiled biomass yield (FSB) in 3 of 5 site years that was similar to that of the FORCON treatment, a traditional grass/legume mix, with CP concentration similar or greater in 3 of 5 site years. In all instances, the TDN of the FERT treatment was greater than or equal to that of the FORCON treatment, and the NDF and ADF were significantly lower than those of the FORCON treatment. The TDN of the FSB was greater in the FERT treatment compared with the NOFERT treatment in 2 of 5 site-years and the NDF and ADF of the FERT treatment were lower in 2 of 5 site-years and 3 of 5 site years, respectively. These results indicate that the application of synthetic N in dual-purpose IWG systems has a positive effect on FSB and enhances the chemical composition metrics considered to concentrations that were more favourable than the industry standard FORCON treatment and unfertilized IWG stands thus increasing its economic value. These results indicate the potential for the use of IWG post-harvest regrowth for fall stockpile grazing, however the impact of the animals on subsequent grain production still needs to be investigated. Site parameters such as soil texture and its interaction with the timing of precipitation with respect to grazing will make this a decision made by the producer at the time of intended use. In Chapter 5, the SPRING treatment produced a significantly lower spikelet number than all other treatments over the two years of study. The BIOM was significantly lower than that of the NOFERT treatment, and a TBIOM that was significantly lower than that of the NOFERT treatment. It is important to consider the moisture limitations experienced throughout these studies which occurred in 6 of the 9 total site-years considered in this thesis. The most extreme being 50.4% of the 30-yr normal for precipitation received at Carman in the first production ranging to 93% of the 30-yr normal received at Brandon in the second production year.

The perennial nature of IWG significantly influences resource partitioning and nutrient allocation within the system. The inherent drive to invest in perennial structures diverts resources from grain yield to favor the long-term survival of the stand. Ultimately, this mechanism is beneficial for the species; however, it presents an issue when grain yield is the goal. The allocation of nutrients to vegetative development results in less nitrogen for grain production; as a result, the remaining N is distributed among competing developing structures (reproductive versus vegetative). Yield component compensation is an important concept in grain production, as it helps compensate for previously occurring developmental shortcomings in an attempt to maintain yield consistency. For example, a lower number of spikelets may result in fewer seeds being produced, by allocating more to the individual seeds, thus increasing the TSW and maintaining overall grain production on a mass basis in an individual inflorescence leading ot a more stable yield (Fagnant et al. (2023). These types of relationships were evident in the findings in Chapter 3, as demonstrated by the inverse relationship among the overall inflorescence density at all locations and floret number shift between the first and second production years, as well as harvest index and BIOM yield and TSW demonstrated these trade-offs as well. The TSW and BIOM yield decreased in the second production year, yet the harvest index increased. Chapter 5 illustrated the same relationships, in which significant increases in inflorescence density were coupled with significant decreases in floret number, spikelet number, and TSW, while maintaining an overall grain yield that was not significantly different from the previous growing season. These relationships demonstrate how complex resource allocation can be within the crop and the importance of considering the timing of supplemental nitrogen applications in a dual-purpose perennial system. Intermediate wheatgrass for perennial grain production can be successful, especially with additional fertility which can help maintain grain yield over time. However, grain yields are not, nor will they be equivalent to annual grains in the near future, if ever. Therefore, in order to attract producers, the utilization of the FSB could aid in the adoption of IWG grain production as it produces a feed that can be fed to beef cattle in mid-October in western Canada.

6.3 Recommendations

Based on the results of the experiments outlined in this thesis, there are limited recommendations for agronomic management of dual-purpose IWG systems in western Canada. Additional research is required to draw conclusions as the treatment effects were inconsistent among site years. The application of broadcast urea without incorporation as done in these experiments can result in losses due to volatilization, therefore a different form of nitrogen, or incorporating the urea could reduce losses (Del Moro et al., 2017). This could ensure more N is available to the plant in the synthetic treatments, however it would require some degree of disturbance which would need to be considered in the production system. Other recent research suggests that a split application of nitrogen involving an application at the vegetative regrowth stage in the fall followed by an application in early spring would initiate more tillers and focus nutrient allocation on reproductive development rather than biomass yield which in turn would increase the proportion of grain produced per unit nitrogen applied (Fagnant et al., 2023; Fagnant et al., 2024). Alternatively, a better way to supply nitrogen could be consistent maintenance levels throughout the season, rather than a heavy upfront application that is available for a short time and at a high concentration. Based on intercropping research, this may be achievable with a legume intercrop (Hayes et al., 2016); however, competition is an important consideration that needs to be addressed by using a companion crop that limits the negative effect (Tautges et al., 2018; Favre et al., 2019; Pinto et al., 2022). Alternative methods for integrating the legume into the system, such as frost-seeding (Law et al., 2021; Olugbenle et al., 2021), appear to be a better way to establish the stand and limit competition while employing the nitrogen benefit for the IWG. With respect to natural systems agriculture, this is the preferred way to supply nitrogen, as the nutritive value of the forage produced by the stand can also benefit from the addition of a legume (Pinto et al., 2022) thus adding additional value to the stockpiled forage for grazing.

6.4 Future Research

These experiments were designed to investigate the effects of nitrogen fertility on dual-purpose IWG cropping systems. Lack of moisture was a challenge for 7 of the 10 site years included in the experiments which may have limited the development of the crop, likely resulting in limited availability and use of the additional nitrogen supplied, except in Carman in 2021. As a result, the research presented significant differences among locations and years; however, it showed few significant treatment effects. The lack of treatment effects contradicts the literature on nitrogen application effects on IWG and annual cereal crops; therefore, there is potential to explore and better understand this relationship.

The timing of forage harvest in Chapter 4 presented issues for analysis and comparison. To conduct an unbiased comparison of the chemical composition of the FORCON and the IWG treatments, a similar stockpile window would be preferred. Based on this experiment, it is inaccurate to consider the IWG stockpile regrowth as similar or better than the FORCON treatment; however, the potential of using the post-grain harvest regrowth from stockpiling is demonstrated. Conclusions can only be based on a staggered stockpile window in the different treatments. The legume species in the FORCON treatment had reached the reproductive stage while the IWG treatments were at a vegetative stage, thereby favouring yield in the FORCON treatment and chemical composition in the IWG treatments (Abd El Moneim et al., 1990). The experiments demonstrated that the forage biomass yield and chemical compositions produced by the stockpiled IWG treatments are an important component that can increase the value of the system. This is crucial for providing a livestock feed option at a time of year when it may be limited, but the value compared with alternative forage sources needs further research.

It is challenging to draw comparisons between the effect of nitrogen on IWG compared with research in annual grain crops outlined in the literature, mainly because the amounts that are being studied in annual grain production are generally 2-4x those that are accepted in IWG production (Otteson et al., 2007; Nyiraneza et al., 2012). Reports have outlined a grain yield (and therefore economic) penalty when nitrogen applications exceed rates of 100 kg N ha^{-1} in IWG stands, which was expected to result from excessive biomass yield leading to lodging (Jungers et al., 2017). This excess biomass yield that is only available at grain harvest has a relatively poor chemical composition compared with the stockpiled biomass yield available in the spring and fall as reported by Favre et al. (2019) therefore the excess biomass yield is not of benefit at this point in the production system when grain yield is a goal. To account for the divergence of N from grain yield to biomass yield, the timing of application can result in periodic nutrient availability, which may be more beneficial than an upfront application that is invested in biomass yield prior to the establishment of reproductive structures in the crop. To determine the true potential of agronomic fertility management in the crop, a multilevel fertility study that considers a wide range of fertility rates, timing, and sources would be necessary (Fagnant et al. 2023).

To test the effect of nutritional requirements as the stand ages, the experiment would require a minimum of three years, and ideally five, to consider the latent effects of nitrogen sharing by intercrops as demonstrated by Reilly et al. (2022) and allow for extensive soil scavenging of the large root system in the control treatment. Due to limited treatment effects among the nitrogen added treatments of the INTER, the FERT, and the NOFERT treatments control in both experiments, it appears that the root system accessed adequate soil nutrients to maintain consistent yields. During the establishment season, all plots received the same base fertility to meet soil test recommendations, which was necessary for establishment of the perennial stand; however, as a result, the treatment effect may take longer to become apparent, similar to what was reported by Dobbratz et al. (2023). To account for this, it may be necessary to test nitrogen levels at greater depths to determine the concentrations deeper in the soil profile to account for root scavenging. The potential for preferential grazing in the FERT plots, as suggested by the results in Chapter 5, may indicate that nutrient levels in plant tissues are more pronounced, and tissue testing in late production years could be an important addition to determine whether the control is developing the expected nutrient deficiencies.

Given the economic value of the forage produced which can serve as a feed source for beef cattle production, the potential use of the stockpiled forage regrowth as a feed source remains a crucial consideration for evaluating the crop. Pugliese et al., (2019) reported that harvesting the regrowth is beneficial to grain and forage biomass yield as well. The total area would be significant to accommodate all the necessary treatments, given the range of fertility management outlined previously. Deer-exclusion fences, such as those used at the small plot locations in Experiment 1, are likely a necessity for fertility studies, as herbivory was evident. Due to the size and duration of the experiment, dryland research would be the most economical option, as the large area and cost of irrigation is expensive. This leaves the system susceptible to drought, which could have long term effects similar to those observed in these experiments. With further breeding advancement leading to greater grain yield potential, irrigation may become a viable option as research in Europe conducted in irrigated environments produced grain yield up to 2000 kg ha^{-1} (Olivier Duchene, personal communication). With the large area required for forage research come numerous limitations and additional costs for the experiment.

The value of having the flexibility and potential to produce a human-grade grain, high yielding straw biomass, and grazeable stockpile material in one season is critical. Combining these end uses could help livestock producers in years of drought and support the development of their systems to better utilize crop-livestock integration, which could extend among farms, thereby increasing ecosystem benefits for many operations. We are at the beginning of researching perennial grain systems, and this was an initial look at them in our region. Ultimately, this system can be managed to increase economic value, and several options remain to be explored in depth.

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APPENDIX

Appendix A. Additional Tables

Table A.1. Raw data collected from the Robel pole measurements during the first two samplings.

	May 13 & 14								June 3 & 4							
Paddock	Point 1				Point 2				Point 1				Point 2			
Side of pole	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1	0.5	0	0.5	0	0.5	0.5	0.5	0.5	0.5	2.5	2.5	3	1.5	1	2	1.5
1	0	0	1	0	0	0.5	0.5	1	2.5	2.5	3.5	3.5	3.5	2	2.5	2.5
1	1.5	0.5	0.5	0.5	0	0.5	0.5	0.5	2	3.5	2.5	2.5	2	2	2	2
1	1	1.5	1	0.5	0.5	0.5	1	0.5	2.5	3	2.5	2	2.5	4	3	3.5
1	0.5	0.5	0	0.5	1	0.5	0.5	1	2.5	2.5	2.5	2.5	3	2.5	3	3.5
2	1	1.5	0.5	1.5	0	1	1	0	1.5	2	2	3	3	3.5	2.5	2
2	0.5	0.5	1	0.5	0	0	1	1.5	1.5	0.5	1	2.5	2	3	3	2.5
2	0.5	0.5	0	0	0	0.5	0	0.5	1	2	2	2.5	1.5	2.5	0	0.5
2	0.5	0.5	0	0	0.5	1	0	0	1.5	3	2	1.5	2	1.5	1	2
2	0.5	0.5	0.5	0.5	1	0.5	0	0.5	0.5	1	0.5	1	1	1.5	2	1.5
3	0.5	0.5	0.5	0	0	0.5	0.5	0.5	1	2	2	1.5	1	1	0.5	1
3	0	0.5	0.5	0.5	0.5	0	0.5	0	0.5	1.5	2	1.5	0	1.5	1	1.5
3	0.5	0	0	0.5	1	0.5	1	0.5	2.5	2	2.5	3.5	2.5	0.5	1.5	0
3	0.5	0.5	0	0.5	0	0	1	1	1	2	2	2.5	1.5	2	2.5	2.5
3	0	0	0	0	0	0.5	0.5	1	1.5	1.5	1.5	2	0	0.5	1	2
4	0	0	0	0	0	0	0	0	0.5	2.5	1.5	0	0.5	1.5	2	2.5
4	0	0	0	0	0	0	0.5	0	1	1	0	1	1	1	0.5	1
4	0	0.5	0.5	0	0	0	0	0	0.5	0.5	1.5	0.5	0	1	0.5	0.5
4	0	0	0	0	0	0	0	0	0.5	0	0.5	0.5	0.5	1	0.5	0.5
4	0	0	0	0.5	0.5	0	0	0	0	0.5	2	1.5	0.5	0.5	0.5	0.5
5	0	0.5	0	0.5	0	0	0	0	0.5	1.5	1.5	1.5	1	1	1	1
5	0	1	0	0	0	0.5	0	0	1.5	1	1	1.5	1.5	1.5	2.5	1.5
5	0	0.5	0	0.5	0	0.5	0	0	0.5	2	1	0.5	0.5	0.5	0.5	1
5	0	0	0	0	0	0	0	0	1	1.5	2.5	2.5	2	2.5	0.5	3
5	0	1.5	0.5	1	0.5	0	0.5	0	2	1	2	2	1	1.5	2	2.5
6	0	0	0.5	0.5	0	0	0.5	0.5	2.5	1	0.5	1.5	1.5	1.5	1.5	2.5

6	0	0	0	0	1	1	0	0.5	0.5	2	2	2	2.5	2	1.5	2.5
6	0	0.5	0	0	0	0	0	0	1.5	2.5	2.5	2.5	2	2.5	1.5	2
6	0.5	0.5	0	0	0	0	0	0	1.5	1.5	2.5	1	1	0.5	1	1.5
6	0.5	0	0	0	0.5	0	0	0.5	1.5	1	0.5	1	0.5	1.5	2	1
7	0	0	0	0.5	0	0.5	0	0	1.5	0.5	1	1	1.5	2	1	1.5
7	0	0	0	0	0	0.5	0	0.5	0.5	1	1	1	1.5	1.5	2	1.5
7	0.5	0	0.5	0.5	0	0.5	0	0.5	1.5	2	2	2	1	1	2.5	1
7	0.5	0	0	0	0.5	0.5	0	0	0.5	1	1.5	1.5	0.5	1.5	1.5	1.5
7	0	0.5	0	0	0	0	1	0.5	0.5	1	2	2	1	1.5	1.5	2
8	1	0	0	0	0.5	0	0.5	0	2.5	2	2	3	2	2	2	2.5
8	0.5	0	0.5	0.5	1	0.5	0	0.5	2.5	2.5	2	2.5	2	1.5	2.5	2.5
8	0	0	0	0	0.5	0.5	0	0	1	1.5	1.5	3	2	3	2	2
8	0	0.5	0	0	0.5	0.5	0.5	0.5	1	1.5	1.5	2.5	2.5	2.5	2.5	2.5
8	0	0	0	0	0	0	0	0	2	2.5	2	1.5	2.5	3.5	1.5	1
9	0	0	0	0	0	0.5	0	0	1.5	1	1	1.5	0.5	1	1.5	1
9	0	0	0	0	0	0	0	0	1.5	1.5	0.5	1.5	1	1	1.5	1
9	0	0	0	0.5	0	0.5	0	0	1	1.5	1	1	1	1.5	1	2.5
9	0.5	0	0.5	0.5	0	0	0	0	1.5	1.5	2	2.5	0.5	0	0.5	1
9	0.5	0.5	0.5	0.5	0	0	0	0	1.5	3	3.5	1	2	2	2	1
10	0	0.5	0	0	0	0.5	0	0.5	1.5	1.5	2	1.5	1.5	1	1.5	2
10	0	0.5	0	0	0	0	0.5	0.5	0.5	1.5	0	0.5	0	1.5	1	1.5
10	0.5	0	0	0	0	0	0	0.5	1.5	1	0	1.5	1	2	1	1.5
10	0	0.5	0.5	0	0	0.5	0	0.5	1.5	2	3.5	2	2	2.5	2	1.5
10	0.5	0	0	0	0	0	0	0	0.5	1.5	1	1	1	1	0.5	0.5
11	0	0	0.5	0	0	0	0	0	0	2	0.5	0	2	1.5	1.5	1.5
11	0.5	0.5	0	0	0	0	0	0	1	2	2	3.5	2.5	2.5	2.5	2.5
11	0	0.5	0.5	1	0	0.5	0	0	1.5	2	2	2.5	0.5	4.5	2.5	1.5
11	0	0.5	0	0	0.5	0.5	0	0	0.5	1.5	2	2	0	0	1	0.5
11	0	0	0	0	0	0	0.5	0.5	1	2	1.5	1.5	2	2.5	2	2
12	0	0.5	0	0	0	0	0	0	2.5	1.5	1.5	1.5	0.5	1	0	0.5
12	0.5	0	0	0.5	0	0	0	0	0.5	1	1	1	2	2.5	1	1.5
12	0	0	0	0	0	0	0	0	1.5	1.5	0.5	1.5	2	1.5	1	0
12	0.5	0.5	0.5	0	0	0.5	0	0	2.5	2	1.5	1	0.5	2	1.5	2
12	0	0.5	0.5	0	0	0.5	0	0	2	2.5	2.5	2.5	2	3	2.5	2.5
13	0	0	0	1.5	1	1	1	1.5	3.5	3.5	2.5	2.5	1.5	2.5	2.5	3.5
13	1	0.5	1	0	0	1	0.5	1	1.5	2.5	1	2.5	0.5	2.5	1.5	2.5

13	0	1	0	1	2	1.5	1	1.5	2	1	1.5	1.5	1.5	2.5	1.5	2
13	0	0.5	1	0	0.5	0.5	0.5	0.5	3.5	3	3	2.5	3	2	1.5	2.5
13	0	0.5	0	0.5	0.5	0	0.5	0	1.5	3.5	3	3	2	3	2.5	2.5
14	0	0	0	0	0	0	0.5	0	0.5	1.5	1	1	0.5	1.5	0.5	0.5
14	0	0	0	0	0.5	0.5	0	0	1	1	0.5	1	1	1.5	1	1.5
14	0	0	0	0.5	0.5	0	0	0.5	1	1	1.5	1.5	1	1	1	1
14	0	0	0	0	0	0	0	0	1.5	1.5	1.5	1.5	1	0.5	0.5	1
14	0	0	0	0	0	0	0	0	1	2	1	1	1.5	1.5	1.5	1.5
15	0	0.5	0	0.5	0	0	0	0	0.5	0	0.5	0.5	0	0	0	1
15	0.5	0	0	0	0	0.5	0	0	3	2.5	2	3	1	1.5	1	3
15	0.5	0	0.5	0	0.5	0	0	0	1.5	1	2	2.5	1	0	0.5	0.5
15	0.5	0	0	0	0	0.5	0	0	2.5	2.5	3	3	1.5	3	2	1.5
15	0	0	0	0.5	0	0.5	0	0	2	1	2.5	3	1	2	1.5	1
16	0.5	0	0.5	0.5	0	0.5	0	0	2	1.5	1.5	2.5	0.5	0.5	1.5	2.5
16	0	0	0	0.5	0.5	0.5	0	0	1.5	2.5	1.5	1.5	2.5	2	2	1.5
16	0	0	0	0.5	0	0	0.5	0.5	2.5	2.5	2	2.5	0.5	2	2	3
16	0	0	0	0	0	0.5	0.5	0	2.5	2.5	2.5	2.5	0.5	1	1.5	2.5
16	0.5	0	0.5	0	0	0.5	0	0	3	2.5	2	2.5	2.5	2.5	3.5	3.5

Table A.2. Raw data collected from the Robel pole measurements during the last two samplings.

	June 24 & 25								July 15 & 16							
Paddock	Point 1				Point 2				Point 1				Point 2			
Side of pole	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1	3	4	4	4.5	6	6	6.5	5	5.5	8	8	8	5	6	6.5	8.5
1	6.5	6.5	7	6.5	4	6	6	7	8	6.5	7.5	8	8.5	7	8	7
1	6	7	7	7	6.5	5	5.5	6.5	8	8.5	8	11	11	11	8	9.5
1	6.5	5	6	7	5.5	7	5.5	6	6.5	9	11	9	7.5	8.5	8	6.5
1	5	5	5.5	7	6	5.5	4.5	4.5	9	7	8	8	7	9	8	8.5
2	6.5	6	6	6.5	5.5	7.5	7.5	8	4.5	7	8	8	8.5	9	7.5	8
2	3.5	3	2	3.5	6	5.5	6.5	6.5	5	6	4.5	5.5	6	7.5	7	6
2	1.5	3	2	2	4.5	4.5	7	4.5	4	8	8.5	6	2	2.5	3	2
2	4.5	8	6	8.5	7	7.5	7	8.5	11	13	12	12	9	8.5	8.5	7
2	6	5	3	4	1	1.5	3	4	4	4	4.5	3.5	2	5	3	6.5
3	0	0	0	0	0	0	0	0	2	1.5	0.5	2	0.5	2	2.5	1
3	0	0	0	0	0	0	0	0	2	2	1	1.5	2	1	2	3

3	0	0	0	0	0	0	0	0	0	0.5	1	2	2	1	0.5	2
3	0	0	0	0	0.5	0	0	0	0.5	1	1	0.5	1.5	1.5	1.5	0
3	0	0	0	0	0	0	0	0	1.5	1	1.5	1	0.5	1	0.5	1
4	1.5	3	1.5	3	0.5	3.5	0	4.5	1	2	3	2	6	5	5	6
4	3	2	3	3	6	5	3	5.5	8	4	3	4.5	4	4.5	4	3.5
4	2.5	3	3	3	2	3	2	4	5	7	5	3	6	5	5	4
4	1	2	2	2.5	3.5	4	3	3.5	3	5	0.5	2.5	2	3	5	4
4	2	1	1.5	3	2.5	3	2.5	4	4	4	5.5	2.5	7	2.5	5	3.5
5	2.5	3	2.5	3	2	3	2.5	2	3	4.5	6.5	2	4.5	2	3.5	4
5	2.5	3	3.5	4	5	4.5	5.5	2	6	7	3.5	2.5	6.5	8.5	2	0.5
5	3	4.5	6	2.5	2	6	2	4	1	6	4	2	3	2.5	2.5	4
5	4	5	4	5	7	5.5	4	6	2.5	7	6.5	5	10	7	6	5.5
5	7	6	4	5	6	6	6	6.5	6	6	5.5	4.5	4	6.5	4	6
6	0	0	0	0	0	0	0	0	0	0.5	1.5	0	0	0.5	0	0
6	0	0	0	0	0	0	0	0	1.5	0.5	0.5	2	1	1.5	1	1.5
6	0	0	0	0	0	0	0	0	2	1.5	2.5	2	1	0	1.5	0.5
6	0	0	0	0	0	0	0	0	2	1.5	2	0.5	2	1	1	0.5
6	0	0	0.5	0	0	0	0	0	1.5	2	1.5	1.5	1	0.5	0.5	1
7	2.5	3	2.5	3	3	3	2	2.5	0.5	1	2.5	2.5	2	5	0.5	2
7	2.5	2	3	2	3	2.5	1.5	2	3	4	3.5	3.5	1	2	2	2.5
7	5	5	6	4	3	4	3.5	5	2.5	6	4.5	4.5	2.5	4.5	4.5	5
7	3	5	3.5	3	6	6	6	5	3	5	6	7.5	7	8	7.5	4
7	3	5	4	4	3	5	5	5	5.5	6	6.5	5	4	7	7	8.5
8	5	5	6	6.5	7	7.5	7	8	8	7.5	8.5	8	4	9	6.5	6
8	3	5	7	5	3.5	5	5.5	6	6	6	5.5	8.5	7	9.5	7	9
8	5	5.5	6.5	5.5	3.5	6	6	6	4	4	5.5	3	6.5	7	6	7
8	4.5	7	5	4	6	5	6.5	7.5	9	5.5	5.5	6.5	3.5	5.5	7	6
8	7	4	6	6	4	5	7	5.5	4	6	4	6	1.5	9	8	7
9	3.5	3.5	3.5	2.5	1	2.5	3	2.5	4.5	3.5	3	6	2.5	3.5	2	2
9	2.5	2.5	2.5	3	3	3	4	3	2.5	2.5	3	1.5	0.5	3	4	2.5
9	2.5	5	3	3	1.5	2	3.5	4	4	4	3	3	2	1	2	1.5
9	2.5	3	3	3.5	2	3	4	3	4.5	3	6	2	2	5	4	3
9	4	6.5	4	3	6	6	5.5	3	5	6	4.5	5	4	3	3.5	5.5
10	3.5	2.5	4	4	2.5	2.5	2	3.5	6	3.5	3.5	8	4	4	3	5
10	1	4	5	4	3	2.5	2.5	3	6	5	4	6	3.5	6	5	4.5
10	2.5	4.5	1	5.5	2	3	2.5	2.5	2	2	2.5	2	1.5	7	5	6

10	6.5	4.5	5	4	4.5	4.5	2	4.5	6	6	6.5	6	7.5	4.5	7	7.5
10	3	4	3	4.5	3	2	3.5	2	1.5	1	2	2	3	4	5	4
11	0.5	2.5	2.5	2.5	3	4	2.5	2.5	2	5	5	5	2	3.5	2	2
11	3	3	3	7	4	5	5.5	4.5	4	4.5	4.5	5.5	10	6	8	4.5
11	4.5	3	4.5	6	4	4.5	5.5	5	7	6	6.5	7.5	5.5	6.5	7.5	8
11	1	0.5	2	5.5	2	1	2	1.5	3	2.5	3	2.5	2.5	3	2	4
11	0.5	6.5	4	4.5	5.5	5	4.5	4.5	7.5	8	8	6.5	5.5	6	6.5	6.5
12	0	0	0	0	0	0	0	0	2	0.5	0	2	1.5	1	1.5	0.5
12	0	0	0	0	0	0	0	0	2	2	1	1.5	0.5	1.5	1.5	2
12	0	0	0	0	0	0	0	0	2	2	2	1	2	2.5	0	0.5
12	0	0	0	0	0	0	0	0	0.5	0	0.5	0	1.5	2	2	2
12	0	0	0	0	0	0	0	0	1	0.5	0.5	1.5	1.5	1.5	1.5	2
13	6	4.5	5.5	7.5	4.5	6.5	8.5	7	7	11	9.5	9	7	7.5	8	8
13	7.5	7.5	7.5	6	8	7.5	7.5	6.5	10	9	8.5	9.5	8	12	9.5	8.5
13	4	8.5	6.5	6.5	7.5	8	6.5	8	7	10	9.5	9.5	6	7	6	7.5
13	6.5	7	5	5.5	7.5	8.5	7.5	7.5	10	7	8	10	8	12	7	9
13	4.5	7	8	7	7.5	7.5	7	7.5	7.5	8.5	12	9.5	7.5	8	8	9
14	3	3	3.5	3.5	2.5	2	2.5	3	2	3	2	3	2	2	2	2
14	3.5	3.5	4.5	3.5	6	6	5	4	3	4	4	5	2.5	3	2.5	4.5
14	3	2	3	4	1.5	3	3	3	3	5.5	4.5	2	3	5	3	5
14	3.5	4	3.5	3.5	2.5	5	2	2.5	3	2	3	3	3	3	3	3.5
14	3	3.5	3	3.5	2.5	3	3.5	3	1	3	5.5	2.5	3	3.5	2.5	2
15	3	4	5.5	5	4	2	3	3	8.5	8	7	6.5	0	2	3.5	3
15	6	4.5	4	5.5	4.5	5.5	4.5	4.5	2	2	10	10	4.5	3	5	7
15	3.5	4	4	5.5	2.5	5	5.5	4	6.5	9.5	9	7	7	8.5	7	6.5
15	6	4.5	6	5.5	5.5	5	4	5	4	4.5	9	7.5	7.5	9.5	2	7
15	2	5	5	5	3.5	5	3.5	3.5	4	5	6	7	9	9	6	9.5
16	0	0	0	0	0	0	0	0	0.5	0.5	1.5	2	1.5	1.5	1	2
16	0	0	0	0	0	0	0	0	0.5	0.5	0.5	0.5	3.5	1	1	0.5
16	0	0	0	0	0	0	0	0	1	2	2	1.5	0	1	2.5	1.5
16	0	0	0	0	0	0	0.5	0	1	1	1.5	1.5	0.5	1	0.5	1
16	0	0	0	0	0	0	0	0	1.5	1.5	1.5	0.5	1.5	3	1	0.5

Table A.3. Raw data collected from the Weins pole measurements including litter depth (L), dead plants (D), broadleaf grasses (B), narrow leaf grasses (N), forbs (F), and maximum height of contact observed (H) at the first sampling on May 13 & 14.

Paddock	Point 1						Point 2						Point 3						Point 4					
Measurement	L (mm)	D	B	N	F	H (cm)	L (mm)	D	B	N	F	H (cm)	L (mm)	D	B	N	F	H (cm)	L (mm)	D	B	N	F	H (cm)
1	51	1	0	0	0	5.5	53	3	2	1	0	19	31	4	0	2	0	11	48	3	1	2	0	10
1	71	3	0	0	0	7	0	0	0	2	0	10	29	1	0	0	0	2	14	1	1	1	0	6
1	74	8	0	0	0	11	45	4	3	2	1	21	28	2	3	3	0	8	42	5	1	23	0	5
1	47	8	0	0	0	14	44	3	0	2	0	6	73	3	0	3	0	9	120	7	3	0	0	11
1	68	2	0	0	0	4.5	12	0	0	0	0	0	59	4	0	2	0	12	28	2	0	1	0	8
2	121	6	0	4	0	13	17	0	0	3	0	3	34	3	0	5	0	6	9	0	0	1	0	11
2	17	2	0	2	0	2.5	41	3	1	1	0	4	28	0	0	0	0	0	34	0	1	0	0	4
2	0	0	0	0	0	0	39	3	0	4	0	9	36	1	1	0	0	5	28	2	2	1	0	12
2	44	3	0	0	0	7	53	3	2	1	0	7	24	3	2	3	0	15	13	1	2	2	0	12
2	51	2	0	3	0	11	28	1	0	0	0	2	21	4	0	3	0	3	47	1	1	0	0	3
3	45	1	0	0	2	7	68	5	0	1	0	7.5	53	1	0	0	0	4	62	3	0	0	0	3
3	11	0	0	1	5	8	22	0	0	0	0	0	15	1	0	0	0	6	36	0	0	1	0	5.5
3	0	0	0	0	2	4	18	0	0	0	0	0	39	1	0	1	4	10	36	1	0	0	0	3
3	42	1	0	0	0	5.2	11	0	1	0	0	4.2	34	1	0	0	0	1.3	24	2	0	1	1	9.5
3	17	1	0	0	1	7.5	41	0	0	0	0	0	34	0	0	0	0	0	4	0	0	1	0	1.5
4	19	0	0	1	0	2.5	34	0	4	1	0	5.5	36	1	2	1	0	9.5	54	3	0	0	0	2
4	32	0	0	0	0	2.5	26	0	1	0	0	4.5	34	0	2	2	0	11	26	0	0	2	0	3.5
4	24	0	0	0	0	0	51	1	0	2	0	2.5	43	0	1	4	0	6.5	26	1	0	1	0	3
4	34	0	0	2	0	6.5	22	0	0	0	1	4.5	29	1	1	0	0	4.5	41	0	0	0	0	0
4	24	1	0	0	3	9	48	2	0	0	0	4.5	31	1	0	0	0	3	12	0	0	0	0	0
5	62	3	0	0	0	11	33	0	4	2	0	6.5	49	0	0	0	0	0	34	0	1	0	0	1.5
5	44	1	0	0	0	7.5	28	0	0	0	0	0	16	0	0	0	0	0	29	1	0	0	0	2
5	27	1	0	0	0	5	41	1	1	1	0	3	37	0	3	0	2	7	43	0	0	0	0	0
5	14	1	0	1	0	9	17	3	0	0	0	20	6	2	0	1	0	7	26	0	0	0	0	0
5	28	0	0	0	0	0	62	4	0	1	0	6	79	1	2	2	0	4	51	3	4	1	0	16
6	42	0	0	0	1	4	18	0	0	0	0	0	54	2	0	0	0	5	13	0	0	0	0	0
6	28	1	0	0	4	27	28	1	0	0	0	22	34	0	0	0	0	0	22	0	0	0	0	0
6	48	0	0	0	2	6	46	0	0	0	0	0	46	0	0	0	0	0	22	1	1	0	4	8
6	0	1	0	0	0	3	8	0	0	0	0	0	74	0	0	0	0	0	41	2	0	0	0	3
6	37	0	0	0	0	0	38	0	0	0	1	2	48	1	0	0	0	2	24	0	0	0	3	11
7	44	0	0	1	0	6	38	0	0	0	0	0	23	0	0	1	0	3.5	16	0	0	0	3	3

7	61	0	0	0	3	3	25	0	0	0	2	2	57	0	0	2	0	6	31	0	0	0	0	0
7	43	0	0	0	0	2	52	0	0	5	0	116	6	1	0	0	0	3	55	0	0	1	0	7
7	36	0	0	1	0	5	32	0	6	4	0	14	26	0	1	2	0	4	9	0	0	0	0	0
7	13	0	0	0	0	0	22	0	0	1	0	4	44	0	0	0	0	6	19	1	4	1	0	14
8	31	0	0	2	0	11	40	1	1	1	0	13	19	1	0	2	0	9	22	0	0	0	0	0
8	47	0	0	1	0	12	6	0	1	2	0	12	28	0	0	0	0	0	43	0	2	1	0	13
8	6	0	0	0	0	0	24	0	0	1	0	6	57	1	3	1	0	15	24	0	0	1	0	4
8	18	0	0	0	0	5	34	0	2	2	0	16	49	0	2	1	0	23	13	1	3	0	0	10
8	11	0	0	0	0	0	21	0	1	0	0	4	56	0	0	4	0	14	17	0	0	0	0	0
9	23	1	0	0	2	3	54	0	0	0	0	0	46	1	0	0	0	0.5	37	1	0	0	0	3
9	32	1	0	0	0	3	0	2	0	0	0	6	41	3	0	0	0	5	42	2	0	1	0	13
9	57	0	0	0	0	0	26	0	0	0	0	0	31	0	0	2	0	11	17	0	0	0	0	0
9	32	1 1	0	0	0	1	24	1	0	1	1	8.5	22	1	0	1	0	4	23	0	0	0	0	0
9	44	0	0	0	4	7	22	1	0	0	1	7	46	3	0	0	0	6	56	1	0	0	0	1
10	22	0	0	0	0	0	24	1	1	0	0	12	9	0	0	0	0	0	11	0	0	0	0	0
10	21	1	0	0	0	4	13	1	0	0	0	0.5	53	3	0	0	0	11	11	2	0	0	0	7.5
10	27	1	0	0	0	7.5	55	1	0	0	0	2.5	22	2	0	0	2	4.5	13	0	0	0	4	7
10	22	0	0	1	0	3	26	1	1	3	0	7	53	0	2	6	0	18	57	0	0	1	0	7
10	33	0	0	0	0	9	17	0	2	1	0	4	23	1	1	3	0	13	66	0	2	2	1	5.5
11	11	2	0	1	0	4	27	2	1	1	0	9	18	1	1	2	0	7	28	0	0	0	0	0
11	36	5	0	5	0	13	31	2	0	1	0	4.5	13	3	0	5	0	3	24	0	2	1	1	7
11	22	6	0	0	0	7	32	1	0	0	0	4	12	0	0	0	0	0	24	0	1	0	0	3
11	62	0	0	0	0	18	18	0	0	0	0	0	9	0	0	0	0	0	12	0	0	0	0	0
11	5	3	0	0	0	11	22	0	0	0	0	0	31	0	0	1	0	7	52	1	0	0	0	3.5
12	28	2	0	0	2	8	21	0	0	0	0	0	8	1	0	2	0	11	32	0	0	0	2	3.5
12	34	0	0	0	0	0	39	0	0	0	0	0	37	0	0	0	0	0	22	0	0	0	0	0
12	11	5	0	0	0	9	6	1	0	0	3	8	7	3	0	0	0	2	2	2	0	0	0	1.5
12	24	2	0	2	1	12	26	0	0	0	0	0	27	0	0	0	0	0	9	3	0	0	0	8
12	19	1	0	0	0	2	13	2	0	1	0	11	19	1	0	0	0	3	6	0	0	0	0	0
13	29	0	0	0	0	0	25	0	2	1	0	45	21	0	0	0	0	0	46	2	0	1	0	56
13	72	0	0	0	0	0	43	0	3	3	0	16	21	0	0	0	0	0	14	0	1	0	0	8
13	52	0	0	0	0	0	33	4	1	0	0	9	36	2	0	0	0	5.5	16	0	0	0	0	0
13	42	0	0	1	0	9	52	0	1	3	0	12	32	0	0	0	0	0	40	1	0	0	0	3
13	40	3	0	0	0	7	35	1	1	0	0	6	35	0	0	0	0	0	24	0	0	1	0	5.5
14	62	0	0	0	0	9	22	1	1	1	0	8	46	0	1	1	0	5	44	0	0	0	3	3

14	28	1	0	0	3	7	27	1	4	1	0	13	21	0	2	1	0	10	46	0	0	0	2	4
14	40	0	0	0	2	2.5	27	0	0	0	0	0	48	0	0	0	0	0	44	1	0	0	0	4
14	17	0	0	0	0	0	43	0	0	0	0	0	38	0	0	0	0	0	44	0	0	0	1	1
14	46	0	0	3	0	4	84	1	2	2	0	7	36	3	1	0	0	4	49	2	0	0	2	2
15	32	0	0	0	2	4.5	62	0	0	0	0	0	50	1	0	0	0	3	51	1	0	0	0	2
15	25	0	0	0	0	0	0	2	0	0	0	2	12	2	1	2	0	9.5	31	1	0	0	0	2
15	16	1	0	1	0	5	44	1	3	0	0	18	41	0	4	3	0	14	16	0	0	1	1	4
15	32	2	0	0	0	2	24	0	0	0	0	0	29	1	0	2	0	5	2	0	0	0	0	0
15	39	1	0	2	0	8	0	0	0	3	0	2	51	0	0	0	0	0	14	0	0	0	0	0
16	13	0	0	0	0	0	26	0	0	0	0	0	39	1	0	0	0	4	18	0	0	0	7	6
16	56	1	0	1	0	1.5	24	0	0	0	1	7	31	0	0	0	0	0	9	2	0	0	2	10
16	48	0	0	0	1	2	48	0	0	0	2	1	16	0	0	0	0	0	27	1	0	0	0	4
16	51	2	0	0	0	6	28	0	0	0	0	0	26	0	0	0	0	0	38	0	0	0	1	4
16	11	0	0	0	3	10	24	1	0	0	0	4	23	0	0	0	1	2	14	0	0	0	3	5

Table A.4. Raw data collected from the Weins pole measurements including litter depth (LT), dead plants (D), broadleaf grasses (BLG), narrow leaf grasses (NLG), forbs (F), and maximum height of contact observed (MH) at the second sampling on June 4 & 5.

Paddock	Point 1						Point 2						Point 3						Point 4					
Measurement	L (mm)	D	B	N	F	H (cm)	L (mm)	D	B	N	F	H (cm)	L (mm)	D	B	N	F	H (cm)	L (mm)	D	B	N	F	H (cm)
1	15	3	4	0	0	25	17	1	1	0	0	22	13	4	3	0	0	24	35	3	3	0	0	23
1	17	2	4	0	0	26	10	4	6	0	0	30	18	2	6	0	0	36	12	0	2	0	0	26
1	18	0	4	0	0	7	28	4	3	1	0	27	48	4	3	0	0	37	50	2	1	0	0	7
1	40	4	2	0	0	37	51	1	2	0	0	33	45	0	1	1	0	25	41	3	5	0	0	39
1	20	6	3	0	0	33	47	2	4	0	0	42	40	1	3	2	0	30	43	0	3	0	0	41
2	9	1	1	1	0	26	32	5	4	0	0	32	23	2	5	0	0	32	21	1	3	2	0	33
2	30	4	4	1	0	40	38	2	3	0	0	27	29	1	3	0	0	24	51	2	3	0	0	30
2	28	0	2	0	0	15	24	3	3	0	0	18	21	2	0	0	0	4	27	0	3	0	0	26
2	34	2	3	0	0	32	38	1	5	0	0	37	39	3	2	0	0	35	31	2	1	0	0	28
2	6	2	2	0	0	18	11	1	2	0	0	18	11	1	1	0	0	28	19	3	3	0	0	32
3	27	1	0	1	0	18	0	4	0	3	2	24	7	2	0	2	3	21	31	2	0	2	4	33
3	17	1	1	0	6	38	18	2	0	0	3	23	20	1	0	1	3	32	24	1	0	0	2	27
3	0	1	0	0	3	34	12	1	0	5	0	27	13	1	0	0	3	29	8	0	0	0	5	25
3	20	2	0	0	4	31	18	2	0	1	0	15	17	1	2	0	0	15	10	1	0	0	5	28
3	14	1	0	3	1	29	20	2	0	0	0	2	18	0	2	4	0	25	21	0	0	1	2	18
4	9	1	2	0	0	25	19	3	0	0	4	16	27	1	6	1	0	32	31	1	1	0	0	16
4	19	1	2	0	0	24	17	1	5	0	0	37	20	1	4	0	0	31	25	1	2	0	0	24
4	28	0	6	0	0	26	31	0	4	1	0	27	25	1	4	1	0	24	18	1	0	0	0	2
4	18	2	0	0	0	6	17	1	1	0	2	21	17	2	1	0	1	17	18	1	2	0	0	15
4	19	2	1	0	2	17	9	1	3	0	1	21	14	0	4	0	0	19	20	1	4	0	0	34
5	15	0	4	0	0	16	18	0	0	0	1	5	25	0	0	0	2	9	20	0	2	0	0	28
5	52	0	3	0	0	23	30	0	3	0	0	21	29	0	4	0	0	21	18	0	5	0	0	26
5	20	0	0	0	1	6	10	0	3	0	0	30	20	0	3	0	1	19	28	0	2	0	0	15
5	13	0	0	0	0	0	33	0	3	0	0	21	21	0	1	0	0	13	24	0	3	0	0	15
5	25	0	6	0	0	25	25	0	3	0	0	22	21	0	0	0	2	10	13	0	0	0	1	9
6	25	0	2	0	1	20	27	0	0	0	5	30	34	0	3	0	0	12	15	0	0	0	2	8
6	18	0	0	1	3	29	20	0	2	0	2	19	24	0	0	0	1	23	35	0	0	0	3	23
6	30	0	0	0	3	27	34	0	0	0	3	26	14	0	0	2	1	24	30	0	0	0	5	27
6	70	0	0	0	0	0	40	0	0	2	2	16	38	0	3	0	2	24	25	1	0	0	1	7
6	40	0	0	0	1	14	23	0	0	0	7	22	10	0	0	0	0	0	5	0	1	0	5	20
7	35	0	2	0	1	14	10	0	0	0	2	11	29	2	0	0	0	2	65	0	0	0	3	22
7	15	0	2	0	0	18	20	0	4	0	0	32	18	0	0	0	1	19	31	0	0	0	4	13
7	20	3	0	0	0	3	20	0	1	0	0	21	30	0	0	0	2	9	49	0	4	0	0	26
7	25	0	0	0	2	7	50	0	2	0	0	4	35	0	2	0	0	32	41	0	7	0	0	28
7	25	0	1	0	2	9	42	2	1	0	0	23	51	0	4	0	0	25	30	0	3	0	0	19
8	31	0	8	0	0	41	21	0	2	0	0	4	23	0	4	0	0	22	22	0	0	0	0	0
8	25	0	3	0	0	26	30	0	5	0	0	30	14	0	6	0	0	20	21	0	4	0	0	29
8	21	0	3	0	0	10	30	0	5	0	0	32	31	0	2	0	0	27	37	0	0	0	0	0
8	40	0	6	0	0	38	48	1	8	0	0	31	45	0	3	0	0	17	39	0	6	0	0	43

8	35	3	4	0	0	11	20	0	5	0	0	33	0	0	0	0	1	1	29	0	0	0	0	0
9	18	0	0	2	0	29	48	0	0	0	1	1	15	0	0	0	5	11	52	2	2	0	0	30
9	21	2	2	0	0	9	37	1	3	0	0	20	21	0	0	0	4	12	50	0	0	0	4	16
9	37	0	0	3	0	27	25	0	0	0	4	7	27	0	0	0	3	8	30	0	0	2	0	19
9	27	0	0	3	0	34	30	0	0	0	1	3	12	0	0	6	0	26	30	0	0	0	0	0
9	29	0	1	2	1	27	35	0	0	1	0	22	10	0	0	0	0	8	17	0	1	2	0	23
10	60	0	3	0	0	17	31	0	2	1	0	37	28	0	0	0	0	0	41	0	2	1	0	14
10	31	1	2	0	0	22	11	0	0	0	0	0	4	0	0	0	1	2	27	2	0	0	0	4
10	35	0	0	0	0	0	0	0	3	0	1	18	25	1	0	0	2	12	29	0	0	0	0	0
10	17	3	9	0	0	49	25	0	1	0	0	30	0	0	2	0	0	17	38	0	6	0	0	37
10	15	2	0	0	3	11	46	1	5	0	1	17	47	0	0	0	1	4	11	2	3	0	0	24
11	12	0	0	0	1	2	45	0	1	1	0	15	31	0	2	0	0	20	41	0	1	1	1	25
11	52	1	8	1	0	41	18	1	3	2	0	8	23	0	1	2	0	24	46	0	3	1	0	42
11	20	0	2	1	0	8	10	0	0	6	2	31	12	0	2	1	0	8	34	0	0	0	0	0
11	18	0	0	0	0	0	33	2	0	0	2	13	48	1	1	2	0	30	35	0	0	0	1	10
11	34	0	2	1	3	26	23	0	5	2	0	21	25	0	3	2	0	41	32	0	0	0	0	0
12	13	0	0	0	0	0	20	0	0	3	6	25	27	0	0	0	6	8	33	0	0	0	5	19
12	29	0	0	0	2	12	17	0	0	0	0	0	18	0	0	3	0	22	21	0	0	1	5	19
12	25	0	0	4	5	29	35	1	0	6	0	17	0	0	0	2	0	11	9	1	0	0	0	2
12	43	0	0	0	0	0	28	0	0	0	3	5	55	2	0	5	0	25	19	1	0	5	1	24
12	0	0	0	0	1	1	25	2	0	2	8	31	37	0	0	1	4	29	0	0	0	0	2	4
13	21	0	2	0	0	34	34	0	3	0	0	20	36	0	5	1	1	28	45	1	5	0	0	24
13	17	0	3	0	0	26	45	0	1	0	0	18	33	0	5	0	0	40	33	1	3	0	0	23
13	23	0	2	0	0	20	28	0	1	0	0	17	33	0	0	0	0	0	35	0	1	0	0	19
13	20	0	3	0	0	33	33	0	4	0	0	32	24	0	3	0	0	28	26	0	2	0	0	20
13	43	0	5	0	0	30	37	1	4	0	0	29	47	0	1	0	0	29	35	0	3	0	0	20
14	39	0	0	0	2	14	30	1	0	0	0	9	46	0	0	0	5	14	38	0	0	0	2	9
14	42	0	0	0	2	14	39	0	0	1	0	6	49	2	4	0	0	30	35	0	1	0	2	22
14	70	0	0	0	0	23	40	1	0	0	0	5	50	0	0	0	1	7	45	0	0	0	1	18
14	60	2	0	0	1	8	38	1	1	0	0	34	28	0	2	0	0	17	34	1	0	0	0	2
14	48	0	0	0	1	8	28	0	3	0	0	28	40	0	1	0	3	8	27	0	4	0	0	32
15	45	0	2	0	1	21	40	0	2	0	0	16	25	0	0	0	2	11	30	0	0	0	2	13
15	10	0	3	0	0	32	21	0	4	0	0	22	40	2	4	0	0	34	27	0	1	0	0	32
15	25	0	2	0	0	15	18	0	2	0	1	16	34	0	4	0	0	28	27	0	3	0	0	38
15	20	0	4	1	0	17	40	0	5	0	0	24	21	0	2	0	0	15	35	0	4	0	0	18
15	45	0	2	0	1	10	15	1	2	0	0	30	25	0	1	0	0	13	20	0	4	1	1	28
16	30	0	0	0	3	6	15	0	0	0	7	26	25	0	0	0	0	0	20	0	0	0	5	18
16	0	0	0	0	0	0	31	1	1	0	1	18	19	0	5	0	0	29	29	0	0	0	5	23
16	20	2	1	0	5	24	0	0	0	0	8	28	20	0	0	0	6	27	0	0	0	0	2	21
16	31	2	0	0	3	21	30	1	0	1	6	22	21	1	0	0	0	4	18	1	3	0	5	37
16	30	0	0	0	0	0	0	0	0	0	3	24	28	2	0	2	1	30	25	4	0	2	3	22

Table A.5. Raw data collected from the Weins pole measurements including litter depth (LT), dead plants (D), broadleaf grasses (BLG), narrow leaf grasses (NLG), forbs (F), and maximum height of contact observed (MH) at the third sampling on June 24 & 25.

Paddock	Point 1						Point 2						Point 3						Point 4					

Measurement	L (mm)	D	B	N	F	H (cm)	L (mm)	D	B	N	F	H (cm)	L (mm)	D	B	N	F	H (cm)	L (mm)	D	B	N	F	H (cm)
1	19	3	6	0	0	75	28	1	8	0	0	45	41	1	8	0	0	61	19	3	5	0	0	78
1	24	3	13	0	0	70	35	3	6	0	0	91	35	3	6	0	0	80	30	4	10	0	0	84
1	35	1	8	0	0	77	28	2	10	0	0	75	25	2	10	0	0	82	30	2	9	0	0	56
1	35	2	4	1	0	72	40	3	8	0	0	75	38	3	8	0	0	80	45	4	5	2	0	46
1	41	0	3	0	1	90	33	6	8	0	0	78	30	6	8	0	0	58	29	3	6	0	0	82
2	45	4	8	1	0	90	27	1	7	0	0	75	28	1	7	0	0	71	20	1	5	1	0	72
2	31	0	3	0	0	78	40	1	4	1	0	84	20	1	4	1	0	82	35	3	6	0	0	68
2	30	2	3	1	0	80	28	0	4	0	3	78	21	0	4	0	3	60	18	1	4	0	0	81
2	15	0	3	0	0	80	21	3	13	0	0	67	28	3	13	0	0	79	18	2	8	0	0	71
2	5	0	2	0	0	61	7	0	2	0	1	60	0	0	2	0	1	71	0	0	4	0	2	76
3	0	0	0	1	1	13	5	0	0	3	0	0	0	0	0	3	0	13	0	0	0	3	1	11
3	0	0	0	1	1	24	7	0	0	0	0	0	4	0	0	0	0	0	6	0	0	0	0	2
3	39	1	0	0	2	9	30	0	0	0	0	9	35	0	0	0	0	0	24	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	9	20	0	0	0	0	0	8	2	0	2	2	14
3	6	0	0	0	0	0	20	0	0	0	0	25	8	0	0	0	1	18	0	0	0	0	0	0
4	19	3	1	0	1	35	18	0	0	0	1	37	20	0	0	0	0	0	21	0	5	0	0	78
4	15	1	6	0	0	75	21	3	7	0	0	75	21	3	7	0	0	74	15	1	10	0	0	75
4	30	4	10	0	0	80	31	0	6	0	0	71	20	0	6	0	0	63	0	0	4	0	0	84
4	18	2	4	1	0	75	23	0	2	0	3	80	21	0	2	0	3	73	25	0	3	0	2	40
4	16	3	4	0	0	70	21	0	3	0	2	71	20	0	3	0	2	41	15	0	5	0	3	64
5	9	0	1	0	5	27	12	0	1	0	0	21	24	0	2	0	6	35	19	1	8	0	1	80
5	20	1	5	0	0	73	28	1	3	0	0	65	23	0	1	0	2	75	20	2	8	0	0	77
5	22	3	6	0	2	83	25	0	6	0	0	47	18	1	0	0	5	62	24	0	2	0	4	71
5	35	1	4	0	0	47	28	0	2	0	2	42	18	4	0	0	0	80	24	0	2	0	1	33
5	19	0	6	0	0	81	27	4	6	0	0	75	30	1	8	0	1	74	24	1	1	1	1	77
6	21	2	0	3	0	10	19	1	0	0	0	6	0	0	0	0	1	9	22	0	0	0	0	0
6	20	2	0	0	2	8	0	0	0	0	0	0	12	0	0	0	0	0	10	1	0	2	1	9
6	5	0	0	0	0	0	17	2	0	1	3	7	15	1	0	1	0	14	0	0	0	0	0	0
6	25	1	0	0	1	4	31	0	0	0	0	0	0	0	0	0	0	0	21	1	2	0	1	8
6	6	0	0	0	0	0	0	0	1	0	0	6	8	1	1	0	0	12	4	0	0	0	1	2
7	14	0	0	0	7	36	40	1	1	0	5	33	7	0	1	0	2	32	10	0	0	0	3	29
7	28	0	3	0	5	36	25	2	3	0	4	56	24	1	2	0	7	80	30	0	1	0	6	35
7	25	1	2	0	0	19	19	0	2	0	5	76	36	0	4	1	3	78	32	0	1	0	0	71
7	30	0	1	0	2	91	38	0	3	0	4	34	32	0	0	0	2	47	18	0	5	0	3	60
7	21	0	7	0	0	66	24	0	0	0	5	36	34	3	4	0	0	80	14	3	0	0	3	38
8	10	0	8	1	0	75	25	3	5	0	0	76	12	0	10	0	0	87	25	2	14	0	0	77
8	16	4	0	0	0	76	45	4	0	0	0	19	33	6	9	0	0	88	38	2	8	1	0	78
8	10	2	8	0	0	75	45	1	4	0	0	43	8	0	2	0	0	70	35	4	5	1	0	57
8	10	0	4	0	0	67	30	1	4	0	0	75	41	1	14	0	0	90	21	1	7	0	0	81
8	25	8	14	0	0	74	32	0	0	0	4	24	28	5	14	0	0	57	41	9	12	0	0	74

9	13	0	0	0	2	17	4	0	2	0	3	74	6	0	0	0	12	10	6	0	0	0	10	36
9	7	0	0	0	9	40	61	0	0	0	0	0	23	0	2	0	0	52	4	0	0	0	3	25
9	8	0	0	0	8	36	9	0	4	0	2	70	2	0	5	0	2	42	2	0	0	0	3	37
9	8	0	7	0	0	68	18	0	1	0	2	77	18	0	8	0	0	35	7	0	0	0	3	21
9	11	0	3	0	5	47	24	0	4	0	1	49	33	2	1	0	3	32	3	0	0	0	2	5
10	22	0	0	0	2	3	6	0	6	0	4	82	28	0	7	0	3	44	35	0	0	0	0	0
10	62	0	11	0	0	42	17	0	3	0	1	67	7	0	0	0	8	32	4	0	2	0	9	71
10	7	0	2	0	4	49	11	0	3	0	5	63	44	0	2	0	2	30	22	0	0	0	3	23
10	21	0	3	0	0	57	16	0	5	0	1	61	22	0	5	0	0	74	46	0	8	0	0	74
10	16	0	4	0	0	35	3	0	0	0	0	0	12	0	1	0	6	74	44	0	10	0	3	74
11	12	0	4	0	2	74	7	0	1	0	0	64	23	0	3	0	2	73	4	0	0	0	3	16
11	14	0	1	0	1	53	3	0	7	0	3	54	4	0	2	0	1	55	6	0	0	0	0	0
11	2	0	5	0	0	82	2	0	3	0	0	58	23	0	2	0	0	61	6	0	5	0	4	85
11	39	5	24	0	0	74	8	0	3	0	1	53	4	0	0	0	1	20	16	0	0	0	4	13
11	17	0	7	0	0	74	20	0	4	0	3	77	26	0	1	0	0	5	33	0	3	0	0	15
12	4	0	0	0	0	0	7	0	0	0	0	0	9	0	0	0	0	0	8	0	0	0	0	0
12	13	0	0	0	0	0	6	0	0	0	0	0	4	0	0	0	0	0	12	0	0	0	1	4
12	2	0	1	0	0	11	4	1	1	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0
12	26	0	0	0	0	0	24	0	2	0	0	8	9	0	0	0	0	0	26	0	2	0	0	14
12	13	0	0	0	0	0	17	0	1	0	0	8	7	0	0	0	2	5	7	0	0	0	2	3
13	11	0	1	0	0	51	18	0	6	0	0	52	24	0	4	0	0	39	18	0	1	0	1	50
13	31	0	0	3	0	78	26	0	0	2	0	3	9	0	0	9	0	79	7	0	3	0	0	75
13	32	0	6	0	0	62	27	0	12	0	0	87	4	0	6	0	0	72	7	0	0	0	0	0
13	39	0	4	0	0	82	18	0	1	0	0	10	11	0	2	0	0	66	14	0	7	0	0	75
13	41	0	3	0	0	78	14	0	5	0	0	72	31	0	3	0	1	39	37	0	19	0	0	88
14	19	0	2	0	4	26	16	0	2	0	3	41	22	0	4	0	1	45	7	0	0	0	1	20
14	14	0	1	0	2	18	0	0	11	0	2	79	48	0	2	0	3	29	2	1	6	0	0	45
14	14	0	0	0	1	13	23	0	1	0	3	18	12	0	2	0	2	47	11	0	2	0	5	51
14	9	0	1	0	2	28	9	0	2	0	2	33	8	0	0	0	3	29	7	0	0	0	2	36
14	13	0	3	0	4	58	9	0	6	0	1	76	42	0	3	0	1	44	22	0	2	0	2	37
15	28	0	0	0	3	8	44	0	2	0	2	46	2	0	0	0	3	23	2	0	1	0	6	39
15	62	0	12	0	0	79	12	0	9	0	0	73	0	0	2	0	1	57	2	0	0	0	2	26
15	12	0	3	0	0	83	19	0	4	0	16	80	2	0	5	0	0	61	26	0	8	0	0	67
15	9	0	0	0	0	0	11	0	3	0	2	75	20	0	1	0	0	42	8	0	4	0	0	41
15	29	0	1	0	1	54	3	0	2	0	0	49	6	0	6	0	0	42	63	0	3	0	0	55
16	19	0	0	0	0	0	20	1	0	0	1	4	25	0	0	0	1	1	15	0	0	1	0	2
16	5	0	0	0	0	0	5	0	0	0	0	0	5	0	0	0	0	0	10	0	0	0	0	0
16	14	0	0	3	1	12	13	0	0	0	0	0	42	0	0	0	1	3	11	0	0	0	1	4
16	12	2	0	0	0	3	39	0	0	0	0	0	17	0	0	0	4	7	0	0	0	0	1	0
16	24	0	0	1	1	4	7	0	0	1	0	11	8	0	0	0	0	0	37	0	0	0	0	0

Table A.6. Raw data collected from the Weins pole measurements including litter dept (LT), dead plants (D), broadleaf grasses (BLG), narrow leaf grasses (NLG), forbs (F), and maximum height of contact observed (MH) at the fourth sampling on July 15 & 16.

Paddock	Point 1						Point 2						Point 3						Point 4					
Measurement	L (mm)	D	B	N	F	H (cm)	L (mm)	D	B	N	F	H (cm)	L (mm)	D	B	N	F	H (cm)	L (mm)	D	B	N	F	H (cm)
1	12	8	7	0	0	78	21	3	6	0	0	75	17	5	7	0	0	78	66	5	6	0	0	76
1	22	1	2	0	0	86	26	5	6	0	0	87	18	3	6	0	0	80	22	6	13	0	0	69
1	4	0	3	0	0	81	14	4	6	0	0	72	7	6	7	0	0	70	6	0	7	0	0	70
1	22	5	2	0	0	78	8	3	11	0	0	88	18	3	5	0	0	90	85	10	16	0	0	76
1	4	3	5	0	0	50	7	7	11	0	0	73	8	2	8	0	0	93	12	1	9	0	0	76
2	12	3	6	0	0	78	36	4	11	0	0	76	16	4	5	0	0	75	24	4	7	0	0	74
2	12	4	2	0	0	78	21	6	10	0	0	74	7	6	7	0	0	86	6	7	5	0	0	87
2	3	1	3	0	0	86	3	3	1	0	0	37	6	4	6	0	0	77	7	0	4	0	2	66
2	26	9	17	0	0	86	8	6	11	0	0	93	6	6	12	0	0	78	1	4	6	0	0	72
2	12	0	1	0	3	88	22	3	5	0	2	79	11	2	4	0	0	77	2	1	3	0	0	68
3	4	1	0	3	2	21	3	0	0	1	0	10	3	0	0	1	6	40	6	0	0	1	3	24
3	6	0	0	0	1	20	3	0	0	1	3	32	7	0	0	2	1	32	8	2	0	8	3	44
3	4	1	0	1	3	31	8	0	0	3	1	24	3	1	0	1	4	41	12	1	0	1	2	42
3	11	1	0	1	3	20	8	0	0	2	1	29	8	0	0	1	8	38	2	0	0	1	3	38
3	7	1	0	4	1	32	8	0	0	1	0	23	4	0	0	1	4	31	78	1	0	1	3	24
4	11	3	4	0	0	75	8	0	4	0	1	74	4	5	0	0	3	71	17	4	8	0	0	81
4	2	1	5	0	0	85	22	5	6	0	0	74	4	6	0	0	0	86	0	2	8	0	0	78
4	14	1	4	0	0	78	2	0	4	0	0	75	12	14	0	0	0	83	16	4	7	0	0	78
4	24	0	1	0	3	67	26	1	3	0	2	65	14	5	0	0	3	84	8	3	5	0	3	81
4	14	1	2	0	1	78	3	1	1	0	2	91	22	4	0	0	0	79	8	5	7	0	1	89
5	3	3	12	0	1	77	29	1	2	0	1	49	3	3	8	0	1	76	8	1	0	0	2	25
5	8	1	13	0	0	82	18	5	10	0	0	76	6	1	2	0	1	79	4	3	8	0	0	85
5	22	1	11	0	3	72	4	1	3	0	5	79	16	2	13	0	3	78	26	5	11	0	1	89
5	22	2	12	0	2	84	8	12	7	0	0	88	4	3	9	0	1	79	9	1	3	0	0	77
5	7	3	6	0	0	88	24	4	14	0	0	82	16	2	10	0	0	92	22	1	6	0	0	86
6	6	1	0	1	2	21	9	0	0	0	1	12	16	2	0	6	0	19	8	0	0	0	4	32
6	4	2	0	1	1	24	6	0	0	1	3	20	2	0	0	0	1	13	9	1	0	0	5	38
6	12	0	0	2	6	29	8	1	0	2	9	38	8	0	0	2	1	26	11	0	0	0	1	32
6	0	0	0	0	3	31	22	0	0	3	6	36	11	0	0	0	1	21	23	0	0	1	0	16

6	2	0	0	0	4	39	16	0	0	6	0	17	3	0	0	0	0	0	9	1	0	1	5	35
7	26	4	5	0	6	84	28	1	0	0	2	35	24	5	2	0	2	61	24	3	1	0	4	47
7	7	0	0	0	3	50	12	1	1	0	1	39	8	0	0	0	2	31	28	2	4	0	3	72
7	12	4	4	0	2	58	9	3	5	0	2	74	12	3	6	0	3	80	22	6	5	0	0	89
7	4	1	8	0	4	79	11	0	3	0	1	74	6	3	7	0	4	86	18	1	3	0	3	76
7	66	5	4	0	0	41	13	4	11	0	1	68	16	1	1	0	1	46	11	0	3	0	1	45
8	4	4	10	0	0	89	13	4	11	0	0	94	18	6	7	0	0	84	11	3	5	0	0	90
8	17	7	6	0	0	73	16	1	4	0	0	52	6	6	6	0	0	80	26	5	6	0	0	89
8	3	0	7	0	0	74	26	3	1	0	0	58	4	2	4	0	0	73	6	2	4	0	0	80
8	12	4	2	0	0	79	11	5	6	0	0	78	42	1	6	0	0	80	31	9	13	0	0	78
8	8	1	0	0	0	28	7	0	0	0	1	13	21	1	1	0	0	79	12	5	8	0	2	72
9	22	2	0	0	3	76	7	0	0	0	0	0	9	0	0	0	2	14	14	1	1	0	3	35
9	18	2	3	0	1	74	12	4	0	0	3	31	26	1	4	0	2	75	18	1	7	0	2	88
9	22	0	2	0	4	77	9	0	4	0	3	81	26	3	6	0	1	78	46	0	6	0	2	77
9	8	2	1	0	2	91	34	8	12	0	1	92	17	2	9	0	4	91	18	0	5	0	2	44
9	24	0	0	0	3	27	18	0	3	0	2	65	41	0	0	0	1	17	8	3	4	0	4	78
10	12	0	1	0	0	92	5	0	5	0	4	82	2	3	6	0	1	79	48	0	1	0	0	90
10	24	0	0	0	3	55	4	1	0	0	4	58	55	1	2	0	0	49	31	1	3	0	1	70
10	14	1	1	0	6	54	36	0	0	0	1	22	26	0	0	0	1	2	22	1	1	0	4	53
10	19	1	8	0	0	83	38	2	7	0	0	75	26	0	0	0	0	0	3	4	4	0	0	76
10	12	1	2	0	4	78	46	3	6	0	1	82	12	2	7	0	2	74	42	3	4	0	2	77
11	2	0	1	0	4	68	6	1	3	0	2	75	2	2	2	0	3	62	4	1	2	0	3	54
11	14	1	2	0	1	63	7	1	8	0	1	77	3	5	10	0	0	78	34	3	4	0	0	82
11	12	2	1	0	0	77	4	6	5	0	0	76	11	0	0	0	0	0	26	1	0	0	1	14
11	13	1	1	0	1	33	17	2	4	0	2	67	14	0	0	0	1	14	33	1	4	0	0	76
11	12	0	1	0	0	92	5	0	5	0	4	82	2	3	6	0	1	79	48	0	1	0	0	90
12	9	0	0	0	4	37	12	0	0	1	1	26	3	0	0	1	3	33	4	0	0	2	1	37
12	28	0	0	1	4	31	3	0	0	0	0	0	13	0	0	0	3	44	3	1	0	0	3	33
12	0	1	0	0	6	56	0	0	0	0	2	20	2	0	0	0	0	0	0	0	0	0	3	34
12	6	0	0	0	1	28	4	0	0	1	0	13	4	0	0	2	1	15	26	0	0	1	2	31
12	2	0	0	1	0	20	3	1	0	4	3	54	7	1	0	3	4	39	6	1	0	1	3	23
13	16	3	6	4	0	79	4	3	3	0	0	64	18	9	8	1	0	80	18	5	4	0	0	80
13	1	2	10	0	0	90	24	6	4	0	1	80	18	8	10	0	1	93	17	0	3	0	2	70
13	6	0	4	0	0	80	3	3	5	0	0	88	23	6	9	0	0	80	2	4	3	0	1	92
13	9	4	10	1	0	92	6	2	9	0	0	76	14	8	9	0	0	96	16	20	9	1	0	82
13	14	15	11	0	0	80	11	2	6	0	0	76	19	1	9	0	0	91	12	5	6	0	0	84
14	14	2	2	0	3	83	18	1	7	0	4	81	21	3	5	0	4	68	8	3	5	0	4	69
14	18	2	2	0	7	80	9	0	4	0	5	60	16	4	7	0	2	79	16	2	7	0	4	87
14	26	0	4	0	6	54	6	2	8	0	5	75	8	0	1	0	4	32	11	0	2	0	4	71
14	1	0	3	0	5	65	21	2	3	0	4	67	13	1	2	0	5	56	21	3	3	0	4	65
14	14	0	1	0	6	70	13	3	1	0	8	85	12	3	5	0	1	88	19	1	4	0	2	36
15	9	0	0	0	5	29	6	1	0	0	4	17	11	1	1	0	7	70	18	3	7	0	0	74
15	4	1	4	0	0	69	28	6	4	0	0	56	12	2	1	0	0	67	11	8	12	0	0	88

15	3	5	10	0	1	89	4	5	9	0	3	79	2	0	8	0	0	86	21	4	5	0	0	90
15	19	5	5	0	0	82	28	3	4	0	0	76	16	5	6	0	1	81	11	0	6	0	0	86
15	12	3	5	0	0	77	8	0	2	0	0	73	12	4	5	0	2	66	12	5	8	0	1	86
16	7	3	0	0	6	33	17	1	0	0	4	28	6	2	0	0	3	41	11	2	0	0	5	39
16	5	0	0	2	1	9	11	1	0	0	3	26	7	2	0	0	3	29	4	0	0	0	4	27
16	7	0	0	0	3	37	4	0	0	0	1	23	9	0	0	1	1	22	11	1	0	0	12	33
16	4	0	0	1	4	40	12	0	0	2	5	38	16	0	0	0	4	45	0	0	0	0	0	0
16	14	0	0	0	2	31	4	1	0	2	5	40	6	1	0	0	7	40	6	0	0	3	6	30

Table A.7. Raw data collected from the bare ground estimates at all the samplings.

Paddock	May 13 & 14		June 4 & 5		June 24 & 25		July 15 & 16	
Quadrat	1	2	1	2	1	2	1	2
1	2	40	3	5	0	40	4	0
1	0	30	40	2	50	0	3	5
1	45	5	2	35	10	2	3	8
1	0	0	2	0	0	0	0	0
1	0	50	4	8	0	2	2	0
1	4	25	7	0	0	0	0	6
2	6	0	2	3	0	2	2	0
2	4	10	6	40	30	5	3	14
2	4	2	30	2	10	2	3	5
2	15	58	30	50	20	2	2	5
3	60	10	5	25	55	45	3	7
3	20	30	75	35	30	10	3	4
3	60	55	0	45	40	70	4	3
3	40	30	6	5	55	50	5	5
3	35	30	45	45	60	50	12	8
4	4	5	10	1	35	2	3	7
4	2	23	2	3	10	3	5	7
4	4	0	3	2	30	50	2	3
4	6	4	1	4	2	0	5	3
4	4	35	2	2	0	4	4	2
5	2	3	15	10	0	0	8	0
5	0	0	1	20	2	10	13	3
5	0	1	0	2	2	2	2	2
5	5	6	10	20	5	2	8	5
5	1	10	5	2	2	5	0	1
6	5	5	10	20	40	25	1	2
6	4	8	30	5	40	30	0	11
6	4	6	0	1	25	20	5	6
6	4	5	15	20	4	50	9	3
6	3	0	15	10	40	30	6	8
7	7	25	0	10	0	0	0	3
7	4	5	5	15	0	0	3	0
7	5	5	30	25	5	2	2	0
7	2	3	10	5	2	20	4	3
7	4	5	5	15	2	0	3	1

8	6	10	5	5	2	5	2	0
8	0	1	5	1	0	2	1	0
8	18	4	25	1	40	5	0	4
8	3	0	1	1	2	0	2	3
8	65	7	10	60	8	40	5	5
9	0	4	3	1	0	0	0	0
9	4	2	7	9	2	0	4	3
9	2	17	2	6	4	0	1	3
9	4	30	8	10	3	3	5	4
9	35	4	3	7	7	11	3	2
10	10	25	2	7	2	2	2	0
10	15	10	30	1	14	0	0	3
10	0	2	2	2	2	0	3	0
10	2	0	0	4	0	5	5	0
10	5	10	7	10	3	6	1	1
11	2	3	20	4	3	5	4	2
11	2	0	3	0	0	7	2	4
11	30	20	5	6	11	55	13	1
11	35	5	20	0	6	4	6	2
11	5	0	0	1	4	0	3	0
12	60	8	12	7	14	8	6	9
12	3	0	2	5	4	12	11	23
12	80	85	41	65	95	73	25	10
12	15	20	6	5	5	3	5	2
12	50	20	3	2	12	26	10	2
13	1	0	10	0	2	2	1	1
13	3	3	0	2	0	0	0	3
13	5	4	12	4	7	0	1	1
13	1	0	0	0	0	1	0	0
13	2	0	2	5	0	3	0	0
14	1	2	7	0	0	0	0	0
14	0	5	8	2	0	0	3	1
14	0	1	0	0	0	0	0	0
14	3	0	5	10	0	0	0	0
14	0	0	2	2	0	0	1	0
15	0	2	2	5	4	2	0	1
15	0	10	2	8	0	12	5	7
15	4	50	2	2	3	5	0	0
15	40	15	2	10	8	11	6	11
15	10	50	4	5	15	0	4	2
16	10	4	10	1	5	0	1	5
16	75	10	6	2	5	10	14	7
16	5	7	4	2	30	7	0	0
16	0	6	2	0	27	40	2	5
16	8	10	1	3	14	7	1	1

Table A.8. Yield and chemical composition of the spring stockpiled biomass (SSB) as influenced by treatment reported as a proportion of DM of the intermediate wheatgrass treatments for one production year at Brandon, MB.

Treatment[+]	SSB* (kg DM ha^{-1})	CP (% DM)	TDN (% DM)	NDF (% DM)	ADF (% DM)
NOFERT	2192.6 a	8.30 a	54.67 a	63.08 a	41.15 a
FERT	2035.9 a	9.48 a	55.75 a	60.98 a	40.15 a
INTER	1852.2 a	9.72 a	55.08 a	61.92 a	40.77 a

[+] Treatments were **NOFERT** = monoculture control; **FERT** = monoculture with 50 kg N ha^{-1} applied after grain harvest; **INTER =** intercrop of intermediate wheatgrass and alsike clover

*Means followed by the same letter within treatment sections are not significantly different using Tukey-Kramer LSD at P = 0.05.