Alfalfa establishment with annual companion crops including Sudangrass

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Abstract

When establishing alfalfa (*Medicago sativa L.*) stands there are two primary options to minimize weed encroachment: the use of herbicides or the use of annual companion crops. Companion crops will minimize weed development during the establishment year, provide more harvestable forage biomass, and reduce risks of erosion. In Quebec, small-grain cereals are traditionally used as companion crops but other species such as Sudangrass and ryegrass are now also available. However, such species haven't been evaluated locally as companion crops for the establishment of alfalfa. This project had for objective to determine the effects of establishing alfalfa with various companion crop species on forage yield and quality, and alfalfa establishment and persistence, with a focus on newly available species. Sudangrass hybrids appear to be promising as companion crop for alfalfa establishment since it has a greater yield potential than traditionally used species and adapts well to drought conditions which are increasingly prevalent in southern Quebec. Results indicated that the use of a Sudangrass companion crop has a potential superior to that of oat and ryegrass to improve total seasonal forage yields during alfalfa establishment. In addition, Sudangrass was less competitive to alfalfa than oat or ryegrass and was among the most productive companion crop, resulting in high alfalfa and companion crop yields. On the other hand, Sudangrass weed suppression potential appeared to be lower then that of oat or ryegrass when weed pressure was high. In post-seeding years, the negative effect of the companion crops on yields was inconsistent. Alfalfa established with Sudangrass produced a forage of a similar average seasonal quality than the oat treatment but lower than ryegrass and solo-seeded alfalfa. Finally, of all companion crop treatments evaluated, Sudangrass was less

aggressive to alfalfa stands with no impact over alfalfa stands density found in subsequent years.

Résumé

Il y a plusieurs options afin de limiter la présence de mauvaises herbes lors de l'établissement des luzernières; les deux principales étant l'utilisation d'herbicides ou l'utilisation des plantes de compagnonnage. L'emploi de plantes de compagnonnage a l'avantage de non seulement contrôler les mauvaises herbes, mais aussi de produire une plus grande biomasse et de réduire les risques d'érosion lors de l'année d'implantation. Les céréales telles que l'avoine sont fréquemment utilisées, mais d'autres espèces moins traditionnelles peuvent aussi être employées. Toutefois, ces nouvelles options ont souvent été peu évaluées. L'herbe de Soudan est une plante annuelle qui pourrait être utilisée comme plante de compagnonnage pour l'établissement de luzernière au Québec. C'est une espèce pour laquelle de nouveaux hybrides adaptés aux conditions québécoises ont récemment été développés. L'herbe de Soudan a l'avantage d'être très tolérante aux conditions climatiques plus sèches associées aux changements climatiques, d'avoir de très bons rendements et une valeur nutritive forte intéressante pour l'alimentation des ruminants. Cependant, son potentiel comme plante de compagnonnage pour l'implantation de la luzerne n'a pas encore été évalué sous les conditions québécoises. Donc, ce projet vise à comparer les effets (rendements, qualité, survie à l'hiver et établissement) d'ensemencer la luzerne avec l'herbe de Soudan à d'autres options plutôt traditionnelles (céréales et raygrass). Les résultats indiquent que l'utilisation de l'herbe du Soudan comme plante de compagnonnage à la luzerne présente un potentiel de rendement supérieur à l'avoine et au raygrass, augmentant les rendements totaux durant l'année d'établissement. De plus, l'herbe du Soudan fut moins compétitive face à la luzerne et fut parmi les options les plus productives produisant

simultanément de plus hauts rendements de luzerne et de plante de compagnonnage. Toutefois, l'herbe du Soudan semble avoir un moins grand potentiel de suppression des mauvaises herbes comparativement aux autres plantes de compagnonnage évaluées. L'impact de l'utilisation des plantes de compagnonnage sur les rendements de luzerne dans l'année suivant l'établissement fut variable. La luzerne établie avec l'herbe du Soudan produit un fourrage de qualité saisonnière similaire à l'avoine, mais inférieure au raygrass. Finalement, l'herbe du Soudan fut moins agressive que les autres plantes de compagnonnage évaluées, permettant l'établissement adéquat de la luzerne ainsi qu'un impact négligeable sur le nombre de tiges dans l'année suivant l'établissement.

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Contribution of authors

This thesis is written in the form of a traditional thesis according to the “Guidelines Concerning Thesis Preparation” of McGill University. My role was to design experiments, conduct the majority of the experimental procedures and develop the text of the thesis. Dr. Philippe Seguin provided help in the design of experiments, supervision and technical assistance throughout this study. He contributed significantly to the edition and correction of various drafts of the thesis. Dr. Shyam Bushansingh Baurhoo also provided help on experimental strategies, supervision and funding throughout this project. He also contributed to the edition of various sections of this thesis.

List of Abbreviations

ADF	Acid Detergent Fiber
CP	Crude Protein
DM	Dry matter
K	Potassium
N	Nitrogen
NDF	Neutral Detergent Fiber
P	Phosphorus

Chapter 1 Introduction

1.1 General Introduction

Forages are collectively the main crop in Quebec, being grown on approximately 1.14 million ha (CQPF, 2016). Their importance is at the base of Quebec's dairy industry, which has more than 5,000 dairy farms with $2.2 billion in receipts for 2016. Perennial forage crops can be established using different methods; in mixtures of perennial species, seeded alone with the use of herbicides or with an annual companion crop.

In the Northeast of North America, livestock producers often prefer systems where both perennial grasses and legumes are grown in mixtures (Dhont et al., 2004; Sturludóttir et al., 2014; Cornell University, 2016). In contrast, in the Midwest, the standard practice was to mix grasses with alfalfa, but then solo-seeded alfalfa became more common (Peterson, 2006; Sheaffer et al., 2014). The trend observed in the Midwest can also be seen in Quebec recently; producers are still seeding simple mixtures of perennial grasses and legumes, but there is an increasing tendency for seeding alfalfa with annual species. However, this still remains marginal (Allard et al., 1998; Seguin, 2015; Bélanger et al., 2017).

When establishing alfalfa fields there are two major options to minimize weed encroachment: the use of herbicides or of annual companion crops. A companion crop is usually an annual species that is seeded together with perennial legumes such as alfalfa. The use of an annual companion crop is advantageous during the slow establishment of alfalfa. For example, companion crops usually increase forage yields and help control weeds during the establishment year. Traditionally, the use of small grain cereals has been common but new options such as Sudangrass hybrids (*Sorghum X drummondii*

Nees ex. Steud) and annual ryegrass (*Lolium* L.) are now available. There is, however, limited information regarding the use of Sudangrass as companion crop in alfalfa establishment. Therefore, the goal of the present study is to evaluate the potential of different companion crops for the establishment of alfalfa.

1.2 Objectives and Hypotheses

1.2.1 ***Hypotheses***

When compared with small grain cereals or ryegrass, the use of Sudangrass in alfalfa establishment will increase forage yields and forage quality, and help to improve alfalfa establishment and winter survival.

1.2.2 ***General objective***

Evaluate the potential of different annual companion crops for alfalfa establishment.

1.2.3 ***Specific objectives***

1. Compare the effects of establishing alfalfa with annual companion crop species (i.e., Sudangrass and ryegrass) compared to the use of small-grain cereals and pure stands on:

    i) forage yields

    ii) forage quality

    iii) alfalfa winter survival and establishment

Chapter 2 Literature Review

2.1 Importance of Forage Crops

The dairy industry in the province of Quebec generates 37% of the country's dairy revenues and 28% of the province's total revenues generated from agriculture (MAPAQ, 2014). This industry being the principal user of forage crops, it is not surprising that forage fields are a very important part of Quebec's landscape, covering the largest proportion of agricultural land (CQPF, 2016). Most of harvested forages are used for animal production and serve as base feed for the dairy and beef cattle, ovine and horse sectors (CQPF, 2016). Based on animal's nutritional needs and performance, few specific forage types have been favored throughout the years and are now used on most acreage of forage fields. In Quebec, the most commonly used species are alfalfa (*Medicago sativa L.*), timothy (*Phleum pratense* L.), red clover (*Trifolium pratense* L.), white clover (*Trifolium repens* L.), tall fescue (*Schedonorus arundinaceus* Schreb.), orchardgrass (*Dactylis glomerata* L.), smooth bromegrass (*Bromus inermis* L.) and meadow bromegrass (*Bromus riparius* Rehm.). These forages are well adapted to Quebec's soil and climatic conditions, and provide various advantages both in terms of field and animal production compared to other species. Seeded in pure stands or in mixtures, these legumes and grasses species can be used for silage, hay, and/or pasture production. In term of importance, alfalfa has certainly become locally the most widely used legume by the livestock industry.

2.2 Importance of Alfalfa

2.2.1 Uses

Alfalfa has become the most popular forage crop species not only in Quebec and Canada, but also in many parts of the world. Overtime, forage breeders have developed specific cultivars of alfalfa that adapt well in every province of Canada. Because of its high protein content, it provides an ideal base diet for ruminant livestock. Alfalfa can be grown for baled hay, silage and alfalfa pellets production, and some cultivars are also adapted to grazing (AAFC, 2016). This popular legume is also favored in crop rotations and for soil conservation as it prevents erosion.

2.2.2 General description and management

After establishment, alfalfa stands usually persist for 3 to 5 years in Quebec. However, proper alfalfa establishment is critical for its persistence and survival through harsh winter conditions. Understanding alfalfa growth habit will also influence how the crop is managed. Throughout the season and depending on its physiological stage, alfalfa yield and nutritive values (especially protein and fiber concentrations) will vary (CRAAQ, 2005). In southern Quebec, depending on environmental conditions and location, optimal forage yield and quality are obtained when alfalfa is harvest at late vegetative to flowering stages (Brink et al., 1989; Min, 2016; Bélanger et al., 2017). The second cut follows approximately 30 days later or when the targeted stage is reached again (CRAAQ, 2005). It is commonly accepted that short intervals between cuts may lead to a better forage quality, but at the expense of forage yields and stand persistence (Belanger et al., 1992; Dhont et al., 2004). In contrast, if the stands are allowed to grow for longer intervals (i.e., at early flowering stage), alfalfa yields and persistence could be improved. On average, 3 to 4 cuts per year are usually performed in southern Quebec in post-seeding years.

Like several other deep-rooted plants, alfalfa performs better in well-drained soils. Due to its sensitivity to soil moisture levels and specifically within the rhizosphere, drainage is one of the most critical features to manage when it comes to winter survival. Hardiness of the stands will also vary with the age of the plants (Undersander et al., 1991). As alfalfa ages, its capacity to overwinter decreases and disease incidence increases (CRAAQ, 2005). Due to its capacity to initiate a symbiotic relationship with nitrogen fixing bacteria, lower nitrogen fertilization will be required. However, proper phosphorus and potassium fertilization is required (Verhallen et al., 2012).

2.3 Forage Establishment

Alfalfa may be used in various cropping systems for multiple purposes by producers. Simmons et al. (1992) studied how alfalfa is established in the Midwest, what are the popular practices and perceptions of the producers. In their survey of local forage production, they identified that among 351 respondents, 298 (85%) answered that they were establishing alfalfa with the use of annual companion crops. Out of the latter, 87% of them were using oat (*Avena sativa* L.), 22% spring barley (*Hordeum vulgare* L.) and 8% spring wheat (*Triticum aestivum* L.). While the use of companion crops is still widespread, other approaches are also common. In a more recent study, Hoy et al. (2002) compared seven alfalfa establishment methods including the use of herbicides, companion crops and mulch, a residue from fall-seeded oat. The authors observed that forage yields and quality were not significantly different between treatments, underlying that establishment methods should be adapted accordingly to the site and producer needs.

2.3.1 Alfalfa mixtures with perennial grasses

Over the years, several studies have been conducted, underlying the advantages and disadvantages of seeding alfalfa in mixtures with other forage species such as perennial grasses. Often, legumes in mixture with grasses provide better yields and a greater protein content throughout the season (Berdahl et al., 2001). This is mainly due to the fact that legumes establish a symbiotic relationship with N-fixing bacteria. Through this association, legumes obtain enough atmospheric N to fulfill their own N needs. In addition, they may provide part of grasses N requirements. To obtain an estimation of how much N is fixed by alfalfa, Burity et al. (1989), performed trials in Ottawa where mixtures of grasses and alfalfa were sown and found that approximately 93 kg N/ha/yr was fixed during the establishment year. This number increased to 258 kg N/ha/yr for the second year and decreased slightly during the third year. Out of the total N fixed, grasses received 5% of the total N fixed during the year of establishment to 8% of the total N fixed during the third year (which represented slightly under 50% of their total N requirements) (Burity et al., 1989). It was also reported that one of the advantage of seeding binary grass-alfalfa mixtures is that over time in post-seeding years, yields are stable with mixtures whereas solo-seeded alfalfa yields are often declining (Berdahl et al., 2001). However, not all grass species can grow in mixture with alfalfa, interfering with the legume in some cases preventing from obtaining a well-balanced and persistent mixture.

2.3.2 Solo-seeded alfalfa

Alfalfa establishment with the objective of obtaining pure alfalfa fields in post-establishment years can be done using various methods such as herbicide applications, or using an annual companion crop during the establishment year. Solo-seeded alfalfa may be preferred by those who intend to sell their crop or to obtain a more uniform and constant forage quality.

2.3.2.1 Herbicides

The use of herbicides for the establishment of alfalfa has been extensively studied in the past decades so many options are currently available. In addition, glyphosate tolerant alfalfa has recently been released and is now available to North American producers, including those of Quebec. During the seeding year, the first harvest is usually affected by weeds to a greater extent than subsequent ones (Wilson et al., 2009).

Alfalfa establishment is often greatly improved by weed control and management using herbicides, as they can quickly and effectively control a range of weeds at specific critical time periods. Indeed, the presence of weeds will impact alfalfa establishment and subsequent yields if they are present during the first three weeks after seeding (Genest, 1969). This is due to weeds' great ability to compete with the main crop (Schreiber, 1967).

Because the range of herbicide treatments available is greater when only alfalfa is present compared to grass-legume mixtures, the use of herbicides is a more viable option when pure stands of alfalfa are seeded. Among the options available, pre-plant incorporated herbicides can be used. In alfalfa, this would serve mainly to control annual grasses and some broad-leaves. Post-emergence herbicides can also be applied during the establishment year and subsequent production years of pure alfalfa stands, after alfalfa and weeds have emerged. This timing of application is often preferred since the proper herbicide can be selected after weeds are identified. However, the stages of the alfalfa and weeds are critical for maximum efficiency on the weeds and low toxicity on alfalfa (Becker, 2015; OMAFRA, 2017).

In an experiment contrasting establishment strategies of solo-seeded alfalfa, Wilson et al. (2009) compared the use of glyphosate with glyphosate-tolerant alfalfa, a combination of herbicides on conventional alfalfa, and a non-treated conventional alfalfa. For the first harvest, lower total forage yields were obtained with both herbicide treatments. However, more than half of the yields obtained with the untreated (no herbicide) control was made up of weeds. Consequently, the overall forage quality was better for the two herbicide treatments compared to the non-treated control.

One concern arising from the use of herbicides is the cost associated with their use. Indeed, it is well-known that herbicides are costly as well as they require precision in their application timing and dosage. This concept is emphasised by a study of the critical period for weed control in alfalfa (Dillehay et al., 2011). According to the latter, the variability of the results obtained leads to a hedging problem: the decision of using herbicides should be based on the potential return from weed control versus the cost of the treatment (Dillehay et al., 2011). Moreover, systems where less or no herbicides are used are gaining in popularity, emphasizing the importance for new options, thus reducing the impact of such products over the environment (Sheaffer et al., 2014).

2.3.2.2 Use of annual companion crops for alfalfa establishment

Like mixtures of alfalfa with perennial grasses, the use of annual companion crops will most likely have an impact on alfalfa establishment and subsequent growth. An ideal companion crop should be minimally competitive to alfalfa and allow it to optimally establish and survive into the post-seeding year. Weed control during the establishment year, more harvestable above biomass, and reduced risks of erosion are all reasons why annual companion crops are used during alfalfa establishment (Klebesadel et al., 1959). Previous studies have evaluated the use of many annual species as companion crop for alfalfa establishment including oat (*Avena sativa* L.), barley (*Hordeum vulgare* L.), Sudangrass, buckwheat (*Fagopyrum esculentum* Moench), soybean (*Glycine max* L.), spring vetch (*Vicia sativa* L.) and other non-traditional species (Briggs et al., 1953; Basaran et al., 2014; Sheaffer et al., 2014; Sowiński, 2014).

Overall, past studies have shown that forage yields and persistence of alfalfa vary according to the companion crop species used. Indeed, competition can arise between species grown together, and this phenomenon must be lessened in order to benefit from their use. The use of a companion crop for establishing alfalfa provides many advantages that seem to overall satisfy the producers both in terms of yields and profitability compared to solo-seeded alfalfa combined with the use of herbicides (Simmons et al., 1992). There are, however, still risks associated with the use of a companion crop during alfalfa establishment such as competition for light, moisture, nutrients and space between the two crops.

2.3.2.3 Competition between alfalfa and other species

When alfalfa is seeded in mixture with perennial grasses or with a companion crop, these plants share resources (e.g., light, water, nutrients and space). If shortage in any of these resources occurs, the needs of both species may not be appropriately met and therefore competition arises. It is common to observe that overtime, one species will dominate the other due to a lower requirements and/or greater competitiveness. This is why it is difficult to maintain a good grass-legume balance on the long-term in mixtures (Davies, 2001). When alfalfa is seeded with a grass species, the other species enters in competition for several resources such as nutrients, light and soil moisture (Klebesadel et al., 1959). In a modern context where climate change may limit and deplete resources, the allocation of resources in the field becomes even more important.

2.3.2.4 Effects of moisture and temperature on competition

Many plant physiological processes such as photosynthesis and evapotranspiration are related to temperature. However, the impacts of temperature on such functions vary among competing grass and legume species. In an alfalfa-grass association, it is possible to observe how soil temperature as well as ambient temperature affects germination and subsequent growth. For example, grasses such as ryegrass are known to grow better under cold conditions in contrast to legumes (Davies, 2001). On the other hand, when compared to ryegrass, white clover undergoes reduced growth rate as the temperature decreases (Mitchell et al., 1962). It is assumed that the photosynthetic rates of legumes and grasses are different at lower temperatures. According to Woledge et al., 1982, the main competition factor between species is related to differences in the surface area of leaves. The authors have shown that the surface area of ryegrass leaves increased at a higher rate under lower temperatures when compared to legumes (i.e., white clover) (Woledge et al., 1982).

Soil moisture has also been found to be a major factor in alfalfa-grass establishment. It is well-known that alfalfa germination is directly impacted by water level in the soil. For instance, soil moisture is negatively correlated with alfalfa seedling emergence. The greater the soil-moisture tension becomes, the lower is the emergence rate (Triplett et al., 1960). Germination success of grasses can also be impaired by moisture stress. An Increase in water stress delays or reduces germination rate. Nonetheless, for certain grass species, if temperature is adequate, moisture stress is by-passed and germination occurs at a normal rate (McGinnies, 1960).

If moisture is critical for germination, it is also very important for the establishment and growth of plants. Even though some species require great amount of moisture for germination, it does not mean that these same species are not drought tolerant during the growing season (McGinnies, 1960). For example, timothy is known to be highly productive under moist conditions (i.e., during spring season) but will produce lower yields under dry conditions compared with fescues or ryegrass (Efetha et al., 2009). Drought tolerance of alfalfa is, however, known to be fairly good during the growing season even if germination requires higher soil moisture.

2.3.2.5 Effects of light on alfalfa competition with other species

Light is also a factor that will affect alfalfa and grasses seeded simultaneously. As the above ground biomass increases, the canopy closes and captures light. It is commonly accepted that fertilization and temperature have an impact on canopy development (Tow et al., 2001). During canopy development, nutrients and temperature will impact the share of light received since they are the primary factors involved in the capacity to expand leaf area. When the canopy closes, the share of radiation no longer relies on these two. Thus, under lower N availability or temperature, the species (most likely grass) which is able to grow larger leaf area has the potential to capture greater amount of light at the expense of the other species (legumes) (Tow et al., 2001). So, establishment and development of legumes is more affected by the lack of radiation due to the competing species growing in mixture than nutrients and soil moisture (Genest, 1969). In the long run, the composition of the forage field will vary, as affected by shade.

2.4 Choice of a Companion Crop

When choosing companion crop species that will lead to successful alfalfa establishment, several factors must be considered including growth habits and competitiveness as explained above (Genest, 1969). A survey was conducted in Minnesota to identify factors that influenced forage producers in their selection of a companion crop species for the establishment of alfalfa (Simmons et al., 1992). The first consideration of producers was soil conservation potential. Forages, grain and/or straw yield potential was ranked as important but not evenly among respondents. Weed control was also mentioned but not ranked as being as important as the other two factors (Simmons et al., 1992). Since the publication of that study a larger emphasis has been placed in the industry on forage quality. Forage quality is now a consideration for several producers as it is accepted that it is directly related to the animal performances (Ball et al., 2001).

Therefore, there is an existing need for new alternatives that will reflect the modern priorities of forage producers, in systems where forage yield and quality are both considered.

2.4.1 Small grain cereals used as companion crops for alfalfa establishment

The use of small grain cereals as companion crop for the establishment of alfalfa has traditionally been the common practice in several areas of North America for two main reasons: their ability to effectively supress weed growth and to increase the harvestable forage yield when harvested as a forage in the establishment year (Johnston et al., 1998). Not only forage yield is increased but the quality of the harvested forage is usually greater due to lower proportions of weeds. Lodging, height of the stands and aggressiveness are all characteristics to be considered when choosing a small-grain as companion crop for the establishment of alfalfa. This will determine the success of alfalfa establishment and subsequent yields throughout the season (Collister et al., 1952; Simmons et al., 1995; Sheaffer et al., 2014). Several small-grain species are available such as wheat, barley and triticale (*Triticosecale rimpaui* C.). They all have the potential to produce great forage quality and interestingly, cereal species have similar nutritional qualities when harvested at the same stage (Johnston et al., 1998). Another characteristic that small grain cereals can provide is that they have a wider establishment period compared to other potential companion crops.

Of small-grain species used as companion crop, oat has often been one of the most commonly used. To determine the advantages of seeding alfalfa with a small-grain companion crop, alfalfa yields were evaluated when established with an oat companion crop (three seeding rates) versus an untreated solo-seeded alfalfa (Lanini et al., 1991). Seasonal forage yields were higher with the companion crop treatments in the establishment year. However, Lanini et al. (1991) reported that the oat companion crop harvested as a forage only increased forage yields for the first harvest of the establishment year. While the presence of an oat companion crop was also reported to reduce alfalfa yields in the establishment year, yields are also reduced by weed pressure when no companion crop or herbicide are used. In the latter study, the oat companion crop was found to control weeds up to 75%, which was also reported to be equivalent to most herbicide treatments at that time (Lanini et al., 1991). Nowadays, herbicide treatments in conventional alfalfa stands are still not guaranteed to control weeds completely, depending on species present. The development of a glyphosate-resistant (Roundup ready or RR) alfalfa improves the ease of weed control during alfalfa establishment, the use of glyphosate being reported to control up to 97% of weeds in RR alfalfa stands (Bradley et al., 2010; Heap, 2014). However, Sheaffer et al. (2007) demonstrated that in the seeding year, alfalfa yields and forage quality parameters were not different between conventional alfalfa seeded with an oat companion crop harvested for forage and a glyphosate-tolerant alfalfa established using glyphosate.

Even if it was demonstrated that oat reduces weed encroachment during the year of establishment of alfalfa, using it at high seeding rate also has the potential to reduce alfalfa yields during that same year and the following year of production (Lanini et al., 1991).

2.4.2 Other species used as companion crop for alfalfa establishment

Previous studies have demonstrated the growing interest of using less traditional species as companion crops for alfalfa establishment (Jefferson et al., 2005; Onal-Asci et al., 2010; Ćupina et al., 2011). Similarly to small-grains, other species used must provide interesting forage yields, forage quality and reduce weed presence. Other species such as ryegrass and festulolium (*Lolium spp.*) can be superior to small-grain species in terms of quality while producing interesting forage yields (Wiersma et al., 1999). The use of field pea was also reported as an interesting option for alfalfa establishment (Ćupina et al., 2011). A recent study also compared alfalfa establishment using small-grain cereals, field pea (*Pisum sativum* L.), annual flax (*Linum usitatissimum L.),* a rapid cycling brassica (*Brassica rapa* L.), and ryegrass with a control of alfalfa without the use of a companion crop (Sheaffer et al., 2014). Of all the forage companion crops evaluated, ryegrass resulted in the highest forage yield. However, the effects of the companion crops on alfalfa yields were inconsistent (Sheaffer et al., 2014).

While many studies report the beneficial effects of companion crops on total forage yields and weed control, some also underline the great variability between species, regions, climatic conditions and their effects on subsequent yields (Tan et al., 2004; Jefferson et al., 2005; Sheaffer et al., 2014).

Amongst other species that are available to producers, sorghum (*Sorghum bicolor* L.) and millet (*Panicum miliaceum* L.) are two species that have received considerable attention in the past few years. According to previous trials, these species produce acceptable quality forage with high yields (OMAFRA, 2009). More recently, other crops also became available, awakening interest of producers, including Sudangrass hybrids. Genetically different from forage sorghum and Sorghum-Sudan hybrids previously evaluated, Sudangrass hybrids, resulting from a cross between two Sudangrass parents, are leafier, highly productive and forage quality is high (Undersander, 2003; Wright et al., 2012; Poehlman, 2013). On the other hand, Sorghum-Sudan hybrids are issued from crosses between two forage-types sorghums and sudangrass of intermediate yield potential (Undersander et al., 1990).

There is a growing interest in the use of Sudangrass hybrids as companion crops because this tropical grass has proven its ability to adapt to Quebec's climatic conditions, producing important forage yields especially under dry and warm conditions (Wright et al., 2012). Also, the success of its establishment in all soil types is good. From a nutrition standpoint, a crude protein content greater than for corn and low lignin concentration make Sudangrass highly nutritive. However, the protein content will be reduced as the plants mature and the fibre content will increase. In addition, the level of prussic acid is negligible, meaning it is safe for cow's health, a problem associated with other tropical grass species used locally including sorghum (Dangi, 2012; Wright et al., 2012). One of its advantages is that it can be harvested multiple times (3+ cuts) per growing season, in contrast to sorghum and small-grain cereals which will usually be present only for the first cut. Also, it is known that Sudangrass will grow quickly after each cut and yields can reach over 7 T/ha dry matter with crude protein of 14-15% (AERC, 2007). Oat, in contrast, will yield around 4 T/ha with crude protein over 16%DM at the boot stage (optimal harvest stage). In order for oat to have yields as high as Sudangrass, a trade-off in crude protein has to be made, with around 10%DM for 6-7T/ha, generally reached at the milk stage (Johnston et al., 1998). Finally, Sudangrass hybrids prefer warmer soils (over 12˚C), so the seeding date often must be delayed to approximately the third week of May in southern Quebec, which makes its seeding date less flexible and late compared to small-grain cereals (AERC, 2007).

While Sudangrass appears to have interesting characteristics, its use as a companion crop for the establishment of alfalfa has not yet been evaluated in Quebec and should be compared to other options available locally.

2.5 Nutritive Value of Forages

When evaluating forage crop species, it is essential to assess their nutritional quality. As ruminant livestock consume forages throughout their lives and more importantly to support their production (i.e., milk, meat, etc.), it is more accurate to consider forage production and utilization as a practical system where these two parameters are inseparable (Raymond, 1969). However, a lot of variation exists among the available species of forage crops.

2.5.1 Nutritional assessment

In order to assess nutritional quality, many factors must be taken into consideration. Indeed, environmental parameters in addition to agronomic decisions (i.e., drought, harvest time, etc.) will subsequently affect forage composition (Van Saun, 2006). Overall, there are many advantages in producing high quality forage such as reduced requirements for costly feed supplements. Once harvested, specific parameters must be measured and will be subsequently used to determine the overall quality of the forage.

First, the dry matter (DM) content of forages must be measured. This fraction includes all the components minus the water content. Plant species and forages vary greatly in the amount of water contained in tissues (Van Saun, 2006). The relevance of having this value arises from the fact that on a DM basis, different forages can be compared. Indeed, if forages were to be compared on a fresh basis, species containing more water would be found to be the least nutritive since the contents would be diluted.

The second very important parameter that must be measured is the fiber content of forages. In order to characterise fiber or more specifically total cell wall content in feed, neutral detergent fiber (NDF) followed by acid detergent fiber (ADF) and lignin are used as primary measurements developed by Van Soest (Van Soest, 1967). NDF measures the proportion of fiber that is insoluble in a neutral detergent, ADF fraction is insoluble in an acid solution and finally lignin would be the very last fraction left after digestion of cellulose and hemicellulose (Raymond, 1969). These fiber values are a great indicator of overall forage digestibility and quality for ruminants. Indeed, there is a negative correlation between the ADF concentration of forages and fibre digestibility by the animal, and a negative correlation between the NDF concentration and feed intake (Bagg, 2004). Based on these observations, target values for NDF and ADF are given in order to assess the overall quality of forages. In general, targeted values for NDF are less than 40% for alfalfa and less than 50% for grass species. The lowest the NDF value, the greatest amount the cow can consume. For ADF, the target values are less than 30%. The highest the value, the least it is digestible, even for ruminants (Belisle, 2016; Wood et al., 2018).

Lastly, among many other parameters, crude protein is commonly used as a measure of feed quality. Indeed, a higher forage quality if often related to a higher crude protein content (Van Saun, 2006).

Chapter 3 Materials and Methods

3.1 Experimental Site and Treatment Description

An experiment was established to assess the potential of a Canadian Sudangrass hybrid as a companion crop for the establishment of alfalfa compared to other companion crop species including small-grain cereals and annual ryegrass. The different treatments were compared by assessing alfalfa establishment, forage yields, forage quality, and alfalfa winter survival.

The experiment was conducted in total of four environments over two consecutive years (i.e., the establishment and post-establishment years) in Sainte-Anne-de-Bellevue, QC (45° 26' N, 73° 55' W) with seeding in May 2014, May and June 2016, and May 2017. Treatments evaluated included binary mixtures of alfalfa (cv. Solstice in 2014 and 2016 and Acapella in 2017) sown at 13 kg ha^{-1} on a pure stand basis with Sudangrass (cv. CFSH30) sown at 15 or 20 kg ha^{-1}, annual ryegrass (cv. Fox) at 20 kg ha^{-1}, oat (cv. Triple Crown) at 90 kg ha^{-1}, or wheat (cv. Nass) at 160 kg ha^{-1}. A pure alfalfa control established without companion crop (13 kg ha^{-1}) was also included resulting in a total of 6 treatments. Seeds of all species were provided by Belisle Solution Nutrition Inc. (Saint-Mathias-sur-Richelieu, QC, Canada). All plots (6 × 1.5 m) consisting of 7 rows spaced 18 cm apart were seeded at a target depth of 2 cm using an experimental seeder (Fabro ltd, Swift Current, SK, Canada). Each treatment was assigned to a randomized complete block design with 4 replications.

In each environment, fertilization prior seeding was based on results from a soil analysis following local recommendations for alfalfa establishment (CRAAQ, 2010). In 2014, plots were seeded on 9 June on a Chateauguay Clay-loam that was in canola the previous year. In 2016, plots were established at two different dates (i.e., 18 May and 13 June) in a Macdonald Clay-loam soil that was in fallow the previous year. Finally, in 2017, plots were seeded on 20 May in a mix of Chateauguay Clay-loam and St-Bernard loam that was seeded with soybean the previous year.

During the establishment year in 2014 and 2016, no pesticides were applied. However, on the 4 July 2017 Basagran Forté [(mix of bentazone (0,84-1,08 kg ha^{-1}) and an oil concentrate (1-2 L/ha)] was applied at a rate of 2 L/ha (OMAFRA, 2017) to partially control severe weed pressure from broadleaf weeds [i.e., predominantly lamb's quarters (*Chenopodium album*)]. Twice during the growing season (2 July and 20 July, 2017), Matador 120 (Lambda-cyhalothrine 120g/L) was applied at a rate of 83 mL/ha to control a severe infestation of potato leafhopper (*Empoasca fabae*), the occurrence of which is rarely problematic in Quebec (Agri Reseau, 2010).

All plots were harvested when alfalfa reached the budding stage, resulting in two to three harvests in the establishment year depending on the environment and four in the post-seeding year. For the wheat companion crop, treatment plots were harvested in the establishment year for grains when wheat reached physiological maturity, no alfalfa harvest being done.

3.2 Field Data Collection

For each harvest, a 4×0.6m (3 rows) area was harvested using an experimental flail mower (Swift Machine & Welding ltd, Swift Curent, SK, Canada) with yields being recorded. A 500g subsample was then collected and dried in a forced-air oven at 55°C for 48 h to determine forage yields on a dry matter basis. Samples were subsequently grinded to pass through a 1 mm screen using a Wiley mill.

For the experiments seeded in 2016 and 2017, the yield contribution of alfalfa, the companion crop, and weeds was determined at each harvest of the establishment year by sampling a 0.35 m^2 representative area in each plot. Plants were then separated by species (alfalfa, companion crops, and weeds) to determine the botanical composition of each plot. Components were dried in a forced-air oven at 55°C for 48 h to determine yield contribution of each component on a dry matter basis.

Alfalfa stem density was determined by counting number of stems in a 0,09 m^2 area in the fall of the establishment year and spring of the post-establishment year to assess the impact of treatments on alfalfa winter survival (Palmer et al., 1972).

3.3 Chemical Analyses

All samples were analyzed in the laboratory to determine their CP, NDF and ADF concentrations. Crude protein (N × 6.25) was analyzed using a Leco Nitrogen Analyzer (TruSpec Nitrogen Determinator System; Leco Corp., St. Joseph, MI). The NDF concentration was analyzed using heat stable α-amylase and sodium sulfite as per Van Soest et al. (1991). The ADF concentration was determined using method 973.18 of the Association of Official Analytical Chemists (AOAC, 1990). The NDF and ADF procedures were done with an Ankom200 Fiber Analyzer (Ankom Technology, Macedon, NY) using F57 filter bags.

3.4 Statistical Analysis

Data were analyzed separately for each environment and year using the GLM procedure of SAS (SAS Institute, 2014). Differences between treatments means were determined using the LSD test, and statistical significance was declared at $P < 0.05$ level.

Chapter 4 Results and discussion

4.1 Environmental Conditions

In South-West Quebec, the average temperature recorded between 1971 and 2000 during the summer (April to October included) is 14 ºC with average precipitations accumulated of 589 mm (152 mm in April and May).

In 2014 and 2017, the average temperature from April to October in Sainte-Anne-de-Bellevue was 15 ºC. On average for both years, there was a total of 656 mm of precipitations from April throughout October, with 234 mm from April to May only.

In 2016, the average temperature from April to October was 15 ºC. That year, only 466 mm were accumulated from April to the end of October, with only 111 mm accumulated in April and May combined. Weather conditions of spring 2016 were influenced by the effects of El Niño which translated into a much warmer winter (5ºC higher than the average during winter 2015-2016) and warmer spring (Environment Canada, 2016). Figures 4.7 to 4.10 illustrate average daily temperatures and precipitations for each summer during which data were recorded.

In both 2014-2015 and 2016-2017 winters, episodes of thaw occurred with temperatures below 0ºC and a snow cover of 0 mm. However, in 2016-2017, this thaw-frost episode occurred much later in the season (around the 120th day of winter) whereas in 2014-2015, no thaw-frost episode was recorded after the 64th day of winter. This situation might explain some of the differences in subsequent seasonal yields and winter survival, as explained below (Figure 4.11 and figure 4.12).

4.2 Yields

4.2.1 Year of establishment

4.2.1.1 Total forage yield

Differences in total forage yields were observed between the different companion crop treatments in all environments (Table 4.1). In three out of four environments (i.e., 2014 and both 2016 seeding dates) using Sudangrass as a companion crop resulted in the highest total forage yields during the year of alfalfa establishment. Compared to alfalfa establishment without a companion crop, the use of a Sudangrass companion crop increased total seasonal forage yield by 41 to 211% (with an average of 133%) across environments. The benefit of using a Sudangrass companion crop for the establishment of alfalfa was greater when seeding was done in June (i.e., in 2014 and 2016). When seeding was done in May (i.e., in 2016 and 2017), total seasonal forage yield was not different between solo-seeded alfalfa and alfalfa seeded with Sudangrass depending on its seeding rate (i.e., 15 kg ha^{-1} and 20 kg ha^{-1}).

The use of an oat companion crop increased total seasonal yield compared to alfalfa established without a companion crop in two out of four environments (i.e., 2014 and 2017). When using oat, the greatest increase in yield (by 68%) occurred in 2017 when compared to alfalfa established without a companion crop.

In contrast, the use of ryegrass as a companion crop for the establishment of alfalfa had no impact on total seasonal forage yield in all environments compared to alfalfa established without a companion crop.

In 2017, plots were subjected to heavy rainfall combined with cool temperatures after seeding. Furthermore, because of these conditions, it was possible to harvest three times with a May seeding in 2016, but only two in 2017. Noland et al. (2017) recognized that Sudangrass may produce high forage yields, but that poor Sudangrass establishment in cool and humid conditions was a concern. Such conditions may negatively impact Sudangrass establishment and growth, a situation which was reported in a study of the effect of planting date on Sudangrass hybrids (Remick et al., 2016). Indeed, it was reported that an early seeding coupled with non-favorable conditions (cold and humid) could lead to slow Sudangrass germination and poor seedling vigour. A recent study highlighted the importance of delaying seeding dates for Sudangrass in the Northern regions of China (Zhang et al., 2017). It was shown that under those conditions, amongst four warm-season grasses, Sudangrass had the highest yield potential when seeding date was delayed (Zhang et al., 2017). In various regions, including Southwestern Quebec, it is often possible to seed warm season grasses in May as conditions are optimal (MDDELCC et al., 2013). However, based on previous studies and on our observations for the current project, it may be risky to seed Sudangrass in May because of unforeseeable harsh weather conditions (cold and rainy).

A large difference was observed between total seasonal forage yields of most treatments seeded in May 2016 and May 2017, with much lower yields being obtained in 2017 (average of 4214 vs. 3242 kg ha^{-1}, respectively). This was in part explained by an outbreak of potato leafhopper (*Empoasca fabae*) in 2017. Such infestation has the potential to reduce alfalfa yields up to 50% as a result of poor regrowth and alfalfa vigour (Bagg, 2012).

When comparing the Sudangrass and oat companion crop treatments, differences between treatments were observed in three out of four environments. In two of these environments (i.e., 2014 and June 2016 seeding) a Sudangrass companion crop resulted in greater total seasonal forage yield than oat, while the reverse was observed in one environment (i.e., 2017). This may in part be associated with the environmental conditions that prevailed at the time of seeding in these specific environments as described above.

In this experiment, the use of ryegrass as a companion crop for alfalfa establishment had the lowest forage yields and is therefore the least promising companion crop treatment when compared to other treatments evaluated. Sulc et al. (1993a) in Wisconsin evaluated the use of ryegrass as a companion crop for alfalfa establishment at different seeding rates compared to using oat. Lower total seasonal forage yields were reported for ryegrass treatments for most seeding rates in comparison with an oat companion crop seeded at a rate of 54 kg ha^{-1}. In this study, seeding ryegrass at higher seeding rates (i.e., 18 to 24 kg ha^{-1}), which is comparable to the rate used in our present experiment, significantly reduced alfalfa yields and total forage yields during the year of establishment when compared to lower seeding rates (Sulc et al., 1993a). Another study also conducted in Wisconsin reported inconsistent results when comparing the use of ryegrass (6 kg ha^{-1}) and oat (48 kg ha^{-1}) as companion crops for alfalfa establishment (Wiersma et al., 1999). In two out of four environments, ryegrass produced superior total seasonal forage yields to an oat companion crop, both options producing superior yields in comparison to an alfalfa control established without the use of a companion crop (Wiersma et al., 1999). Therefore, seeding rates of both ryegrass and oat are critical factors influencing total seasonal forage yields; higher rates may have a detrimental effect similar to the present study.

As discussed above, most companion crop contributed to total seasonal forage yields among the different environments. However, the timing of the contribution coming from the different options was found to be different for each companion crop. Indeed, yields varied from the first harvest to the subsequent harvests following different trends, depending on the companion crop (Table 4.2). Although ryegrass was reported to produce lower annual yields, its contribution to total yields was measured to increase from the first to the second harvest, increasing total seasonal forage yields in 2014 and 2016. On the other hand, total seasonal forage yields of the oat treatment, which were superior to ryegrass, were found to decrease from the first harvest to the next with a decreasing contribution of oat to the total in 2014, 2016 and 2017. The difference between both treatments is that ryegrass was present in mixture with alfalfa for all cuts whereas oat was mostly present in the first cut with limited contribution in subsequent harvests (Figure 4.5). In 2016, Sudangrass was different from other companion crop treatments, contributing steadily and allowing an equal contribution of grass to each harvest and steady yields from the first harvest to the subsequent harvests. In 2017, the poor establishment of Sudangrass and alfalfa did not allow those trends to be reflected, except for the oat companion crop treatment.

4.2.1.2 Alfalfa yield

Alfalfa seasonal production in 2016 and 2017 was comparable when alfalfa was established without a companion crop and with at least one of the two Sudangrass companion crop treatments in all three environments (Table 4.1). In contrast, the use of oat and ryegrass companion crops decreased alfalfa seasonal yield compared to solo-seeded alfalfa in two and three environments, respectively.

In 2016, with both seeding dates, among the companion crop treatments, Sudangrass companion treatments produced the highest alfalfa seasonal yields on average and oat the lowest. The ryegrass companion treatment produced intermediate alfalfa yields, which were not different from the other companion crop treatments. In 2017, both Sudangrass treatments produced higher alfalfa seasonal yields in comparison to other companion crops treatments, intermediate yields were observed with oat and lowest yields with ryegrass.

Many previous studies have reported the effect of companion crops on alfalfa yields and its establishment. In accordance with our results, it was reported that there is a negative relationship between the yields of alfalfa and associated companion crops (Tan et al., 2004). The companion crop vigour and seeding rate are also factors that were reported to impact alfalfa yields in the seeding year (Lanini et al., 1991). In our case, oat and ryegrass were seeded at rates at which they had the potential to be detrimental to alfalfa as reported by Sulc et al. (1993). The competitiveness toward alfalfa of the oat companion crop compared to other treatments was particularly important for both seeding dates in 2016. This could be associated in the different growth patterns of the various companion crops evaluated. Indeed, oat produced most of its yield at the first harvest, total yields substantially decreasing between the first and subsequent harvests (Table 4.2). In addition, unlike in other treatments, alfalfa yields in the oat companion treatment did not increase from the first to the second harvest but rather were constant. An increase in alfalfa yields was observed for all other treatments between the first and second harvests. In the case of the other companion crop treatments, it was possible to observe an increase in total yields from the first to the second cut, partially coming from an improvement of alfalfa production whereas in the oat treatment, alfalfa was not able to recover quickly from the stress caused by the companion crop, as reported by Lanini et al. (1991) (Figure 4.4).

Based on the above observations, it can be assessed that Sudangrass, at the seeding rates we evaluated, is less competitive to alfalfa than oat or ryegrass and thus allows for better growth of alfalfa stands (Figure 4.6). Indeed, the prompt emergence of small-grain cereals and ryegrass improves the ability to set a dense canopy earlier at the expense of establishing alfalfa. This was not observed with Sudangrass.

4.2.1.3 Companion crop yield

In 2016 when seeded in June, oat and Sudangrass produced the highest companion crop yields. However, in 2017, oat produced greater yields in comparison to all other companion crop treatments. That year, oat was favored by cold and wet conditions, leading to much greater yields than Sudangrass. Overall, ryegrass produced inconsistent yields in the different environments but higher companion crop yields were produced when ryegrass was seeded in May (2016 and 2017) versus June (2016).

As other perennial species, it is commonly accepted that alfalfa is not very competitive nor highly productive during its establishment year (Putnam et al., 2012). Thus, the biomass produced by the companion crop is not likely to be reduced by the competition exerted by the alfalfa. The differences in companion crop yields were found to be inconsistent across environments most likely because of prevailing climatic conditions. Indeed, in 2017, oat produced the highest yields under wet and cold conditions that prevailed whereas Sudangrass established poorly, resulting in low yields. These results are in accordance with previous studies where small grain cereals were performing well as companion crops and often produced high yields in cool and wet environments (Sheaffer et al., 2014).

4.2.1.4 Weeds yield

In 2016 with both seeding dates, all treatments produced equivalent seasonal weed yields, which remained minimal in all treatments averaging 374 kg ha^{-1}. However, differences between treatments were observed in 2017. There was a heavy weed pressure in the field where the plots were established. Lamb's-quarters (*Chenopodium album* L.), shepherd's-purse (*Capsella bursa pastoris* L.), barnyard grass (*Echinochloa crusgalli* L.) and large crab grass (*Digitaria sanguinalis* L.) were the most frequent and abundant weeds. Lamb's-quarters and Barnyard grass are two weed species that can grow over 1.5 m high and can compete with alfalfa and companion crops. The pressure was such that an herbicide treatment had to be performed in July to limit the competition to alfalfa and companion crops. In these conditions, oat and ryegrass were more successful in limiting weed growth as seasonal weed yield in these treatments was 199 kg ha^{-1} on average. In contrast, seasonal weed yield was of 1082 kg ha^{-1} in Sudangrass treatments and 1713 kg ha^{-1} in alfalfa plots established without a companion crop (Figure 4.3).

Nowadays, weed control remains one of the major challenges during alfalfa establishment. To reduce weed encroachment, alfalfa can be established using companion crops. Still, there is a risk associated as the companion crop can also interfere with alfalfa growth. However, annual weeds are reported to be even more competitive to alfalfa during its establishment causing long term damages to the stands (Canevari et al., 2007; Coruh et al., 2016). In accordance with our results, establishing alfalfa with a companion crop improved weed control when compared to the solo-seeded alfalfa treatment. However, the extent to how many and which weeds were controlled was dependant on the companion crop itself (Coruh et al., 2016).

In our study, the potential to suppress weeds appeared to be lower with Sudangrass than oat or ryegrass at the seeding rates evaluated. The potential for Sudangrass to control weeds was also evaluated in previous studies. Holmes et al. (2017) studied the weed control potential of 12 different species used as cover crops seeded in solo and in mixtures at different seeding time (April vs. July). They reported that Sudangrass was among the most effective at controlling weeds when seeded in pure (45 kg ha^{-1}) in July. Also, weed control was superior when Sudangrass was present in the mixture (9 kg ha^{-1}) in contrast to other mixtures or solo-seeded options. Other studies also found that Sudangrass was efficient at controlling weeds, specifically with certain species such as Canada thistle (*Cirsium arvense* L.) (Bicksler et al., 2009). However, the effect of high yielding species on weeds is reported to be inconsistent. Indeed, in accordance with our results, such crops can be ineffective in reducing weed encroachment if germination takes too much time and if seedling vigour is too weak, leading to poor establishment of the companion crop (Holmes et al., 2017; Noland et al., 2017).

4.2.2 Second year

The effects of the various companion crops on seasonal yields during the year following establishment were inconsistent (Table 4.3). In 2015, all companion crop treatments used during establishment in the previous year reduced seasonal total alfalfa yields, compared to when no companion crops were used. Yield reduction ranged between 20% with Sudangrass and 34% with wheat.

In 2017, results differed depending on the 2016 seeding date. For the May 2016 seeding, higher seasonal total alfalfa yields were observed when wheat harvested for grain was used in the previous year as a companion crop for the establishment of alfalfa, compared to all other treatments. For the June 2016 seeding, all treatments produced equivalent seasonal total alfalfa yields.

In our experiment, the negative effect of the companion crop was only significant over the first three cuts in 2015, and over the first two cuts for 2017 (May seeding) (Table 4.3). These results are in accordance with Sheaffer et al. (2014) who reported a significant effect of the seeding rate of the companion crop over subsequent alfalfa yields which was only present at the first cut

Overall, the use of Sudangrass as a companion crop for the establishment of alfalfa did not consistently affect alfalfa yield in the post-seeding year. Yield reduction of 20% was only observed in one out of three environments. Comparable yield reduction frequency and level were observed when using other companion crops. Other studies also reported a lack of consistency in the impact of annual companion crops used for the establishment of alfalfa on yields in post-seeding years when compared to alfalfa established without a companion crop. For example, Sheaffer et al. (2014) reported inconsistent post-seeding seasonal yields not only from site to site but also from year to year. The ability of the companion crops to compete with new alfalfa stands is well documented (Brink et al., 1986; Lanini et al., 1991). However, it seems that many factors could play a role in the long-term effects of companion crops, resulting in inconsistent results. In this experiment, weather parameters were highly different from year to year. Indeed, a well-established companion crop favoured by optimal and unusual weather conditions could become unexpectedly detrimental towards the alfalfa, leading to subsequent negative effects on seasonal yields.

4.3 Quality

In this experiment, fiber and crude protein content was determined for all treatments during the year of establishment. Wiersma et al. (1999) have underlined that one of the disadvantages of using companion crops was the potential reduction in quality, where solo-seeded legumes usually produce high-quality forage, superior to many species used as companion crops. However, some species could produce better forage quality than others. Previous studies on the nutritional quality of Sudangrass reported that silage from Sudangrass was of excellent quality (Bakıcı et al., 2004). Also, ryegrass is often reported as being better than oat in terms of animal nutrition (Wiersma et al., 1999).

4.3.1 Fiber

In all environments, companion crop treatments produced forage of acceptable quality in comparison to alfalfa established without the use of a companion crop. In 2014, both average seasonal NDF and ADF concentrations were higher for all companion crop treatments in comparison to values obtained in 2016 and 2017 (Table 4.4). By comparing 2016 and 2017 values to typical target values (i.e., NDF<40% for alfalfa, NDF<50% for grasses, ADF<30% for all species; Belisle, 2016), we can conclude that all treatments are of acceptable quality for dairy cows.

Differences between treatments were observed for NDF and ADF concentrations in 2014 and for both seedings in 2016. However, in 2017, no differences in seasonal weighted average of NDF and ADF concentrations were found between treatments. This lack of difference between treatments might be due to several factors including the high weed pressure and the lower alfalfa contribution to total forage yields caused by the potato leafhopper infestation observed that year.

Differences between treatments in 2014 and 2016 depended on the environment. In 2014 and 2016, average seasonal NDF concentration was 44% greater when alfalfa was established with a Sudangrass or oat companion crop than when solo-seeded (Table 4.4). ADF concentration of Sudangrass treatments were comparable to that observed for solo-seeded alfalfa for the May 2016 seeding, but was on average 19% greater in 2014 and for the June 2016 seeding. In contrast, the use of an oat companion crop treatment resulted in average seasonal ADF concentration that was consistently greater than that of the solo-seeded alfalfa. Finally, the use of a ryegrass companion crop resulted in NDF and ADF concentrations that were comparable to those observed when alfalfa was solo-seeded with both seeding dates in 2016, but were greater in 2014.

Wiersma et al. (1999) also reported that the use of ryegrass as a companion crop for the establishment of alfalfa can result in lower seasonal average forage NDF concentrations than when oat is used. They however reported that this difference may be restricted to the first harvest, something we also observed in 2014 and 2016 (Table 4.5). Sulc et al. (1993b) also reported lower NDF and ADF concentrations for the first harvest when using ryegrass as a companion crop for the establishment of alfalfa in comparison with the use of an oat companion crop, underlying the fact that the contribution of alfalfa was always very low under the oat companion crop treatment at the first harvest, which was also the case in our experiment; the oat contribution to the second and/or third harvests being minimal most of the forage harvested being alfalfa.

4.3.2 Crude protein

In terms of seasonal weighted average crude protein concentration, the Sudangrass and oat companion treatments resulted in lower CP concentrations (155 g/kg on average) than solo-seeded alfalfa (227 g/kg on average) in three out of four environments. Both companion crop treatments had similar seasonal average CP concentrations in two out of four environments and depending on Sudangrass' seeding rate when established in May (2016 and 2017). On the other hand, the ryegrass treatment resulted in lower CP concentrations than solo-seeded alfalfa in two out of four environments, being similar to solo-seeded alfalfa in the two others.

It was observed that the Sudangrass treatments had a lower crude protein concentration than the ryegrass treatment when seeded in June (2014 and 2016). As predicted, alfalfa established without the use of a companion crop was measured to have a higher crude protein content than most treatments established with a companion crop, but was not different from ryegrass in 2016 and from Sudangrass in 2017. In accordance with our results, Noland et al. (2017) recently reported ryegrass to have higher CP when compared to Sudangrass.

In our experiment, an increase in the crude protein concentration of all treatments was measured from the first harvest to the second or third (Table 4.5). For example, in May 2016, the average CP concentration for all companion crop treatment harvested varied from 170 g/kg at the first harvest to 233 g/kg at the third harvest. The same trend was observed in all environments evaluated. This is most likely due to an increase in the proportion of alfalfa present in the mixture as its regrowth was more vigorous and productive after the first cut. Wiersma et al. (1999) previously measured the CP concentration of different legumes established using various companion crops. They reported a strong correlation between the protein concentration of the different treatments and the percentage of legumes present in the mixture; this was also the case in our experiment.

4.3.3 Consistency in forage quality throughout the establishment year

When establishing alfalfa with a companion crop, it is preferable to have a botanical composition that will be as constant as possible throughout the season, as this would often ensure consistency in forage quality, which is important for animal producers (Reneau et al., 2018). In our experiment, we observed that the Sudangrass and ryegrass treatments offered a better balance between legumes and grasses, therefore, ensuring a relatively stable forage quality throughout the growing season. In contrast, oat was predominantly present during the first harvest, but was almost absent for the subsequent cuts (Figure 4.5). This influenced the forage quality, as measured by NDF, ADF and CP concentrations, more specifically when three harvests were performed with plots established in May 2016. Indeed, for example in that year, the NDF concentration of the oat companion crop treatment was of 504 and 268 g/kg at the first and third harvests, respectively (Table 4.5). On the other hand, the crude protein concentration of the oat companion crop treatment increased from 141 to 253 g/kg from the first to the third harvest. For the other companion crop treatments, NDF, ADF and CP content also varied from the first harvest to subsequent ones, but the oat companion crop treatment was the least consistent.

Keeping balance between grasses and legumes is important as grasses and legumes species are known to be complementary and will provide a more balanced diet and optimize fermentation during ensiling (Allard et al., 1998). Furthermore, the balance between energy and protein is even more important, influencing directly nitrogen use efficiency by the animals (Tremblay et al., 2015). Thus, based on this experiment, using Sudangrass and ryegrass as companion crops to establish alfalfa would be preferable over oat since they provide a more constant quality from harvest to harvest.

4.4 Alfalfa Establishment and Winter Survival

Determination of the number of stems per surface area is a simple method that can be used to assess yield potential of an alfalfa field. Indeed, over the years, models were developed based on the stem density to help producers deciding whether to keep or not a field in production. Based on the OMAFRA's model, 592 stems/m^2 represents a maximum yield potential (Banks, 2000). Between 430 and 592 stems/m^2, yields would mostly decrease between 75 and 92% of the maximum yield potential and finally, under 430 stems/m^2, the stands are considered too thin to be kept into production (Banks, 2000). These numbers vary +/- 5 stems depending on the references. In order to assess the potential detrimental effect of the companion crop treatments on alfalfa, alfalfa stems were counted in every plot and differences between treatments were found.

4.4.1 Alfalfa stem density in the establishment year

In 2015, on average, alfalfa established without a companion crop produced more stems (613 stems/m^2) than when established with ryegrass (281 stems/m^2), oat (433 stems/m^2) and wheat (362 stems/m^2) companion crops (Table 4.6). On the other hand, Sudangrass treatments produced more alfalfa stems than other companion crop treatments (i.e., 546/m^2 on average), density observed with this companion crop species not being different from alfalfa established without a companion crop.

For the May 2016 establishment, in the fall, alfalfa stem density was not different for when alfalfa was established with Sudangrass, oat, and wheat companion crops compared to when alfalfa was established without a companion crop. The use of a ryegrass companion crop again produced the lowest number of stems (417 stems/m^2) compared to all other treatments (average of 581 stems/m^2). For the June 2016 establishment, no differences in fall stem density were observed between all treatments.

In 2017, wheat was found to have a greater stem density (630 stems/m^2) when compared to all of the other treatments. Ryegrass was again found to have the lowest stem density (191 stems/m^2). Oat, Sudangrass and alfalfa established without a companion crop were not different from one another. That year, in most treatments, alfalfa density was low in comparison with previous years due to many factors including weather events, weed invasion and an infestation of potato leafhopper.

Overall, a trend could be observed where a ryegrass companion crop seemed to be the most aggressive of all the treatments, increasing competition and reducing the number of alfalfa stems. In three out of four environments, plots in which alfalfa was established with ryegrass would not be sufficient to maximize yields based on the projection tool described above (stems density being under 430/m^2). As reported by Tan et al. (2004) ryegrass seeded at a higher rate interferes with alfalfa growth and stand establishment. In the same study, poor regrowth of alfalfa was reported in plots established with small-grain cereals harvested at the milk stage. In our experiment, the effects of the oat treatment harvested as a forage (also at the milk stage) and the wheat treatment harvested as a grain were inconsistent with a number of stems below 430 stems/m^2 in two out of four environments for both treatments. Lanini et al. (1991) reported a decreasing alfalfa density with an increase of the oat companion crop seeding rate, but also a reduced density when no companion crop was used as a result of weed pressure. In our experiment, this was also observed where in some cases, alfalfa stem density was greater when alfalfa was established with a companion crop. On the other hand, some companion crops (in our case ryegrass and sometimes small-grain cereals) had a detrimental effect greater than weeds in terms of the resulting fall alfalfa stem density.

Finally, both Sudangrass companion crop treatments were found to be less aggressive to alfalfa than other companion crops, stem density not being different from solo-seeded alfalfa in all environments. This suggests that Sudangrass has a minimal impact on alfalfa and is less aggressive than other companion crops evaluated. This is in accordance with yield measurements as described in previous sections.

4.4.2 Winter survival

In spring 2017, alfalfa stems were again counted to assess winter survival. For both 2016 seeding dates, no differences were found between all treatments evaluated (Table 4.6). This might be because alfalfa stem density in subsequent years is related to different factors. In this experiment, winterkill occurred and was influenced by weather events and agronomic decisions, which are frequently reported to have an important impact on alfalfa survival (Wells et al., 2014). This statement was verified in a survey of Midwest's alfalfa producing farms in which almost every participant reported winter injury on their own farm (Wells et al., 2014). In that study, an insufficient snow cover coupled with other winter events was reported to cause alfalfa mortality. The authors also reported an increasing incidence of winterkill in relation to management decisions. In our experiment, management of the field could have had an impact on survival of the alfalfa plants and in turn on alfalfa stem density. In 2016, alfalfa stem density was greater in most treatments seeded in June than for the plots seeded in May. This could be caused by a third harvest performed later in October for the May seeding in order to allow alfalfa to reach the optimal stage for harvesting. Indeed, a 6 weeks critical period is generally recommended in order to let alfalfa build up reserves prior to the first killing frost (Bagg, 2009). In addition, a problem of water accumulation related to compaction in the middle of the field was also observed, coupled with a thaw-frost episode (Figure 4.1 and Figure 4.2). Therefore, the average winter kill for May 2016 seeding was greater than for June 2016 seeding. These results are in accordance with Wells et al. (2014)'s observations.

Figure 4.1. Field conditions during a thaw episode on 30 March 2017. Alfalfa stands were exposed to a killing frost with a lack of snow cover and ice encasement.

Figure 4.2. Results of alfalfa winterkill on 19 May 2017 after establishment in May 2016.

Figure 4.3. Difference in weed density in alfalfa plots seeded with an oat (a) and Sudangrass (b) companion crop in 2017 (Photo taken on 12 July 2017)

Figure 4.4. Regrowth of Sudangrass (a) and oat (b) companion crops three weeks after the first harvest (Photo taken 21 August 2017)

Figure 4.5. Difference in botanical composition between the first harvest (26 July) (a) and the second harvest (12 September) (b) in a plot of alfalfa established with an oat companion crop in 2017. (Photo taken 12 July and 12 Sept 2017)

Figure 4.6. Alfalfa density and development established in 2017 with oat (a) and Sudangrass (b) companion crops [Photos taken on 26 July (a) and 12 July (b)]

Table 4.1. Average annual forage yields and contribution to yield of alfalfa, companion crops, and weeds in the establishment year of alfalfa seeded (in May 2014, May 2016, June 2016, and May 2017) with different annual companion crops in Ste-Anne-de-Bellevue, QC.

	Seeding: 9 June 2014	Seeding: 18 May 2016				Seeding: 13 June 2016				Seeding: 20 May 2017			
Treatments	Total	Total	Alfalfa	Comp.	Weeds	Total	Alfalfa	Comp.	Weeds	Total	Alfalfa	Comp.	Weeds
	-------------------------kg ha^{-1}-------------------------												
Alfalfa	1616^{c}	3639^{bc}	3023^{a}	—	616	1121^{c}	959^{a}	—	162	2806^{b}	1093^{a}	—	1713^{a}
Alfalfa + Sudangrass (15 kg ha^{-1})	4562^{a}	5118^{a}	2373^{ab}	2136	608	2207^{ab}	408^{bc}	1560^{a}	239	2754^{b}	993^{a}	517^{c}	1244^{ab}
Alfalfa + Sudangrass (20 kg ha^{-1})	5025^{a}	4534^{ab}	2127^{b}	1907	500	2635^{a}	715^{ab}	1546^{a}	374	2720^{b}	1001^{a}	801^{c}	919^{bc}
Alfalfa + Ryegrass	2073^{c}	3154^{c}	1576^{bc}	1343	235	1097^{c}	526^{bc}	211^{b}	360	3206^{b}	320^{b}	2519^{b}	366^{cd}
Alfalfa + Oat	3782^{b}	4625^{ab}	1094^{c}	3065	467	1567^{bc}	193^{c}	1193^{a}	181	4723^{a}	681^{ab}	4009^{a}	32^{d}
p-value	<.0001	0.0262	0.0027	0.18400	0.369	0.0143	0.0135	0.0379	0.3162	0.0087	0.0301	0.0003	0.0002
SEM	207.18	395.6	267.839	506.27	142.48	307.24	131.237	304.88	86.0156	347.87	161.69	369.66	184.85

Means in a column followed by different letters are significantly different (P<0.05).
SEM, Standard error of mean
Comp., Companion crop

Table 4.2. Average forage yields and contribution to yield of alfalfa, companion crops and weeds per cut in the establishment year of alfalfa seeded (in May 2014, May 2016, June 2016, and May 2017) with different annual companion crops in Ste-Anne-de-Bellevue, QC.

Cut	Treatments	Seeding: 9 June 2014	Seeding: 18 May 2016				Seeding: 13 June 2016				Seeding: 20 May 2017			
		Total	Total	Alfalfa	Comp	Weeds	Total	Alfalfa	Comp	Weeds	Total	Alfalfa	Comp	Weeds
		-----------------kg ha^{-1}-----------------												
1	Alfalfa	400^{c}	560^{b}	435^{ab}	—	125	204^{b}	181	—	24	1738^{bc}	380^{a}	—	1359^{a}
	Alfalfa+Sudangrass (15 kg ha^{-1})	2233^{b}	1083^{b}	378^{ab}	520^{b}	185	972^{a}	88	795^{a}	90	1674^{c}	291^{ab}	333^{c}	1050^{ab}
	Alfalfa+Sudangrass (20 kg ha^{-1})	2368^{b}	1099^{b}	466^{a}	483^{b}	150	1226^{a}	216	794^{a}	217	1662^{c}	418^{a}	492^{c}	752^{bc}
	Alfalfa+Ryegrass	633^{c}	532^{b}	256^{bc}	197^{b}	79	288^{b}	127	52^{b}	109	2235^{b}	115^{bc}	1773^{b}	347^{cd}
	Alfalfa+Oat	3202^{a}	3046^{a}	100^{c}	2768^{a}	178	1151^{a}	49	988^{a}	114	3777^{a}	24^{c}	3746^{a}	7^{d}
	p-value	<.0001	<.0001	0.0083	<.0001	0.6188	0.0081	0.1116	0.0415	0.1181	<.0001	0.0027	<.0001	0.0019
	SEM	223.29	194.77	62.85	187.73	52.26	203.15	43.97	202.59	45.78	170.93	61.75	273.89	186.83
2	Alfalfa	1216^{bc}	1532^{a}	1106^{a}	—	427	917^{b}	778^{a}	—	138	1097	714	—	354^{a}
	Alfalfa+Sudangrass (15 kg ha^{-1})	2329^{a}	1712^{a}	849^{ab}	523	340	1235^{ab}	320^{bc}	766^{a}	149	1183	702	184c^{b}	194^{b}
	Alfalfa+Sudangrass (20 kg ha^{-1})	2657^{a}	1538^{a}	672^{bc}	578	288	1409^{a}	499^{ab}	752^{a}	157	1111	583	309^{b}	167^{bc}
	Alfalfa+Ryegrass	1440^{b}	953^{b}	500^{cd}	317	136	809^{bc}	399^{bc}	159^{b}	251	971	206	746^{a}	19^{c}
	Alfalfa+Oat	580^{c}	527^{c}	191^{d}	229	108	416^{c}	144^{c}	205^{b}	67	945	657	263^{b}	25^{c}
	p-value	0.0001	<.0001	0.0008	0.1087	0.1351	0.0066	0.0090	0.0314	0.3061	0.9167	0.0609	0.0247	0.0022
	SEM	219.24	119.38	109.29	101.14	92.10	157.03	99.50	154.67	135.19	209.40	121.27	111.82	48.95
3	Alfalfa	—	1547	1482	—	64	—	—	—	—	—	—	—	—
	Alfalfa+Sudangrass (15 kg ha^{-1})	—	2322	1146	1093	83	—	—	—	—	—	—	—	—
	Alfalfa+Sudangrass (20 kg ha-1)	—	1896	989	846	62	—	—	—	—	—	—	—	—
	Alfalfa+Ryegrass	—	1669	820	830	19	—	—	—	—	—	—	—	—
	Alfalfa+Oat	—	1052	802	68	182	—	—	—	—	—	—	—	—
	p-value	—	0.0559	0.1077	0.2466	0.3258	—	—	—	—	—	—	—	—
	SEM	—	263.63	180.95	345.91	53.22	—	—	—	—	—	—	—	—

Means in a column for a given cut followed by different letters are significantly different (P<0.05).
SEM, Standard error of mean
Comp., Companion crop

Table 4.3. Average forage yields of alfalfa per cut in the post-establishment year (2015 and 2017) after seeding with different annual companion crops in Ste-Anne-de-Bellevue, QC.

		2015 (June 2014 seeding	2017(May 2016 seeding)	2017(June 2016 seeding)
Cut	Treatments	Total	Total	Total
	----------kg ha^{-1}----------			
1	Alfalfa	4668^{a}	2538^{ab}	2998
	Alfalfa+Sudangrass (15 kg ha^{-1})	3310^{b}	2183^{bc}	2496
	Alfalfa+Sudangrass (20 kg ha^{-1})	3195^{bc}	2092^{bc}	2503
	Alfalfa+Ryegrass	3401^{b}	1693^{c}	2589
	Alfalfa+Oat	2970^{bc}	2557^{ab}	2314
	Alfalfa + Wheat	2409^{c}	3098^{a}	2831
	p-value	0.0007	0.0097	0.5164
	SEM	261.09	225.07	265.50
2	Alfalfa	3444^{a}	1691^{bc}	1848
	Alfalfa+ Sudangrass (15 kg ha^{-1})	3168a^{b}	1688^{bc}	1781
	Alfalfa+Sudangrass (20 kg ha^{-1})	2813^{abc}	1506^{bc}	1708
	Alfalfa+Ryegrass	3176a^{b}	1436^{c}	1880
	Alfalfa+Oat	2577^{bc}	1815^{ab}	1563
	Alfalfa + Wheat	2393^{c}	2143^{a}	1813
	p-value	0.0346	0.0071	0.2372
	SEM	222.98	112.87	93.23
3	Alfalfa	2946^{a}	1537	1589
	Alfalfa+Sudangrass (15 kg ha^{-1})	2603^{ab}	1459	1506
	Alfalfa+Sudangrass (20 kg ha^{-1})	2467^{bc}	1362	1362
	Alfalfa+Ryegrass	2134^{c}	1453	1580
	Alfalfa+Oat	2314^{bc}	1668	1475
	Alfalfa + Wheat	2168^{c}	1747	1422
	p-value	0.0016	0.1708	0.4810
	SEM	116.13	107.59	91.45
4	Alfalfa	2418	1419	1467
	Alfalfa+Sudangrass (15 kg ha^{-1})	2102	1484	1482
	Alfalfa+Sudangrass (20 kg ha^{-1})	2004	1421	1495
	Alfalfa+Ryegrass	1862	1418	1440
	Alfalfa+Oat	1940	1507	1396
	Alfalfa + Wheat	1913	1675	1490
	p-value	0.0612	0.2201	0.9361
	SEM	123.16	78.55	75.95
Total	Alfalfa	13476^{a}	7185^{bc}	7902
	Alfalfa+Sudangrass (15 kg ha^{-1})	11183^{b}	6814^{bc}	7265
	Alfalfa+Sudangrass (20 kg ha^{-1})	10479^{bc}	6382^{bc}	7067

Alfalfa+Ryegrass	10573^{b}	5999^{c}	7490
Alfalfa+Oat	9801^{bc}	7547^{ab}	6748
Alfalfa + Wheat	8883^{c}	8662^{a}	7555
p-value	0.0007	0.0125	0.4891
SEM	544.8433	454.73	418.87

Means in a column for a given cut followed by different letters are significantly different ($p<0.05$).
SEM, Standard error of mean

Table 4.4. Forage nutritive value [neutral detergent fiber (NDF), acid detergent fiber (ADF) and crude protein (CP)] of different annual companion crops in mixture with alfalfa for each establishment year (May 2014, May 2016, June 2016 and May 2017) in Ste-Anne-de-Bellevue, QC.

	Seeding: 9 June 2014			Seeding: 18 May 2016			Seeding: 13 June 2016			Seeding: 20 May 2017		
Treatments	NDF	ADF	CP	NDF	ADF	CP	NDF	ADF	CP	NDF	ADF	CP
	g/kg											
Alfalfa	375^{c}	302^{b}	216^{a}	316^{c}	228^{b}	236^{a}	318^{b}	218^{b}	230^{a}	456	279	150^{a}
Alfalfa+ Sudangrass (15 kg ha^{-1})	603^{a}	378^{a}	124^{c}	390^{b}	254^{b}	195^{bc}	464^{a}	273^{a}	155^{b}	468	285	141^{a}
Alfalfa+Sudangrass (20 kg ha^{-1})	605^{a}	382^{a}	117^{c}	378^{b}	249^{b}	202^{b}	452^{a}	268^{a}	153^{b}	466	281	136^{ab}
Alfalfa+Ryegrass	518^{b}	357^{a}	169^{b}	335^{bc}	231^{b}	215^{ba}	340^{b}	219^{b}	214^{a}	436	270	120^{c}
Alfalfa+Oat	579^{a}	385^{a}	116^{c}	452^{a}	289^{a}	167^{c}	441^{a}	266^{a}	165^{b}	493	292	123^{bc}
p-value	<.0001	0.007	<.0001	0.004	0.007	0.010	<.0001	0.0010	<.0001	0.137	0.253	0.0038
SEM	9.23	13.99	5.14	19.985	9.929	11.023	15.19	9.062	7.304	14.06	6.58	4.73

Means in a column followed by different letters are significantly different (P<0.05).
SEM, Standard error of mean

Table 4.5. Forage nutritive value [neutral detergent fiber (NDF), acid detergent fiber (ADF) and crude protein (CP)] of different annual companion crops in mixture with alfalfa for each cut of each establishment year (May 2014, May 2016, June 2016 and May 2017) in Ste-Anne-de-Bellevue, QC.

		Seeding: 9 June 2014			Seeding: 18 May 2016			Seeding: 13 June 2016			Seeding: 20 May 2017		
Cut	Treatments	NDF	ADF	CP	NDF	ADF	CP	NDF	ADF	CP	NDF	ADF	CP
		g/kg											
1	Alfalfa	400^{d}	361	178^{a}	295^{b}	217^{c}	204^{a}	323^{c}	210c	193^{a}	505	303^{b}	113^{a}
	Alfalfa+Sudangrass (15 kg ha^{-1})	615^{ab}	398	115^{bc}	445^{a}	260^{bc}	169^{b}	501^{a}	290a	131^{c}	510	304^{b}	115^{a}
	Alfalfa+Sudangrass (20 kg ha^{-1})	639^{a}	391	120^{bc}	444^{a}	268^{b}	172^{b}	496^{a}	286a	125^{c}	511	302^{b}	107^{a}
	Alfalfa+Ryegrass	540^{c}	386	156^{ab}	353^{b}	240^{bc}	198^{a}	384^{b}	242bc	171^{b}	456	284^{b}	107^{a}
	Alfalfa+Oat	583^{b}	383	109^{c}	504^{a}	313^{a}	141^{c}	456^{a}	268ab	161^{b}	529	336^{a}	69^{b}
	p-value	<.0001	0.7878	0.0121	0.0002	0.0057	0.0007	<.0001	0.0058	<.0001	0.0577	0.0293	0.0012
	SEM	11.24	21.53	13.19	22.06	14.31	7.75	19.31	13.32	7.10	15.58	9.48	6.23
2	Alfalfa	368^{c}	286^{c}	226^{a}	340^{c}	235	224	313^{c}	218bc	239^{a}	371^{a}	246^{a}	196^{a}
	Alfalfa+ Sudangrass (15 kg ha^{-1})	584^{a}	356^{ab}	137^{cd}	399^{ab}	250	195	435^{a}	257a	174^{b}	409^{a}	259^{a}	172^{b}
	Alfalfa+Sudangrass (20 kg ha^{-1})	581^{a}	369^{ab}	123^{d}	381^{abc}	236	206	418^{ab}	250a	179^{b}	389^{a}	251^{a}	172^{b}
	Alfalfa+Ryegrass	507^{b}	344^{b}	175^{b}	353^{bc}	225	221	323^{c}	211c	229^{a}	394^{a}	253^{a}	135^{c}
	Alfalfa+Oat	552^{ab}	388^{a}	161^{bc}	427^{a}	259	203	366^{bc}	240ab	195^{b}	325^{b}	221^{b}	204^{a}
	p-value	<.0001	0.0004	<.0001	0.0308	0.2086	0.0991	0.0015	0.0109	0.0003	0.0049	0.0063	<.0001
	SEM	16.66	11.19	8.00	17.92	10.37	7.74	18.39	8.78	8.26	12.73	5.865	6.18
3	Alfalfa	—	—	—	282	206	264	—	—	—	—	—	—
	Alfalfa+ Sudangrass (15 kg ha^{-1})	—	—	—	323	227	224	—	—	—	—	—	—
	Alfalfa+Sudangrass (20 kg ha^{-1})	—	—	—	306	227	234	—	—	—	—	—	—
	Alfalfa+Ryegrass	—	—	—	300	220	222	—	—	—	—	—	—
	Alfalfa+Oat	—	—	—	268	196	253	—	—	—	—	—	—
	p-value	—	—	—	0.2012	0.2299	0.0799	—	—	—	—	—	—
	SEM	—	—	—	16.20	10.91	11.28	—	—	—	—	—	—

Means in a column for a given cut followed by different letters are significantly different ($P<0.05$).
SEM, Standard error of mean

Table 4.6. Stem density in the fall of each establishment year and in the spring following establishment of alfalfa established using different annual companion crops (May 2014, May 2016, June 2016 and May 2017) in Ste-Anne-de-Bellevue, QC.

Year of establishment	Seeding: 9 June 2014	Seeding: 18 May 2016		Seeding: 13 June 2016		Seeding: 20 May 2017
Year of measurement	Fall 2015	Fall 2016	Spring 2017	Fall 2016	Spring 2017	Fall 2017
Treatment	------Average stem/m^2------					
Alfalfa	613[a]	597a	455	426	491	452b
Alfalfa+ Sudangrass (15 kg ha^{-1})	540[ab]	565a	430	477	493	427b
Alfalfa+Sudangrass (20 kg ha^{-1})	551[ab]	590a	532	505	519	411b
Alfalfa+Ryegrass	281[c]	417b	379	447	442	191c
Alfalfa+Oat	433[bc]	590a	487	616	622	344b
Alfalfa + Wheat	362[c]	563a	542	417	607	630a
p-value	0.0029	0.0426	0.1239	0.1005	0.1165	0.0004
SEM	51.4343	39.2797	43.1425	48.8585	48.4795	47.6576

Means in a column followed by different letters are significantly different (P<0.05).
SEM, Standard error of mean

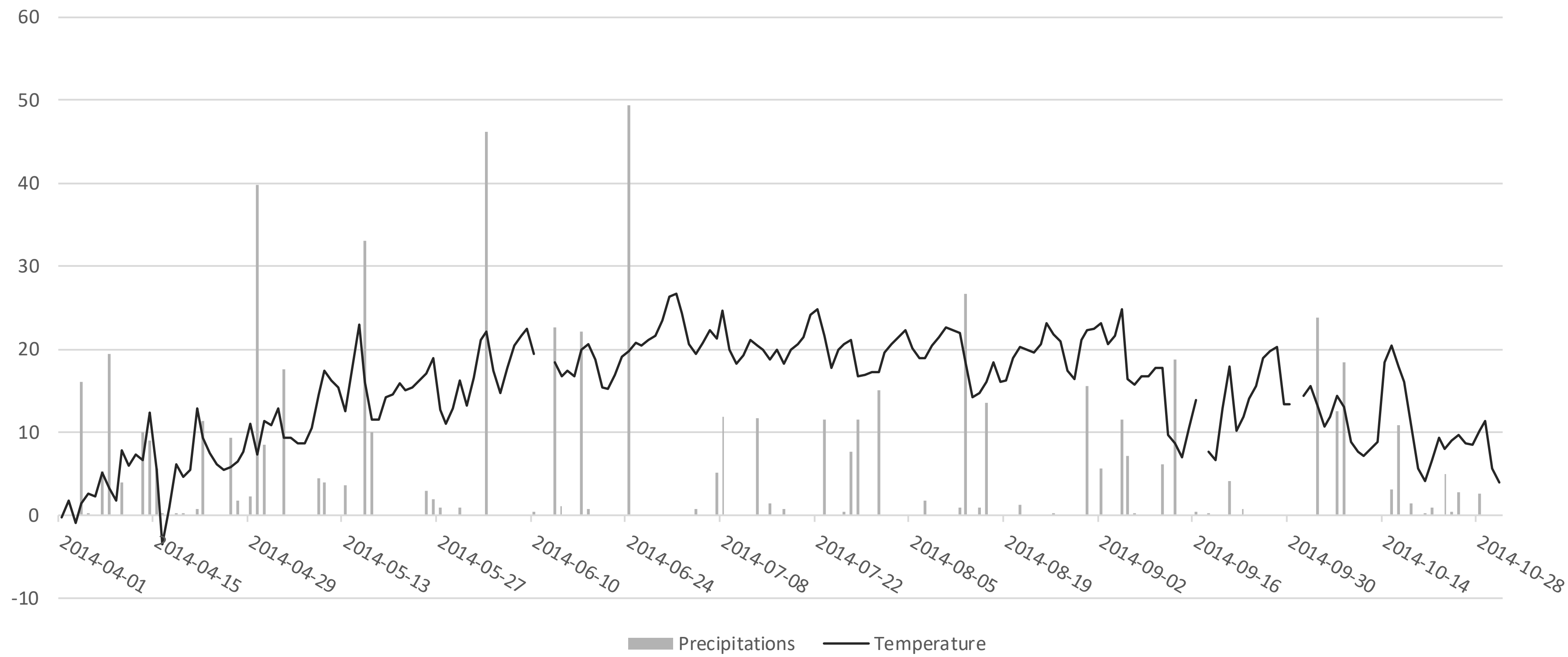

Figure 4.7. Daily average temperature and daily total precipitations from 1 April 2014 to 31 October 2014 recorded at the station in Ste-Anne-de-Bellevue, QC.

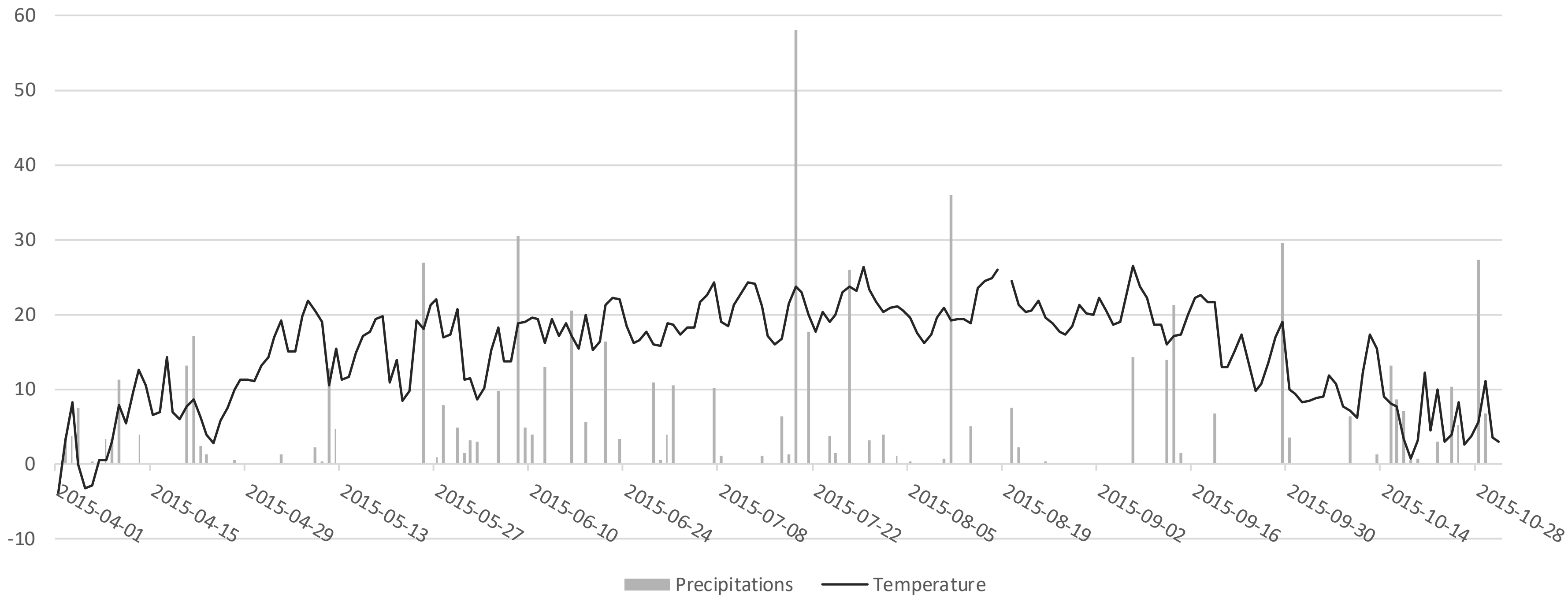

Figure 4.8. Daily average temperature and daily total precipitations from 1 April 2015 to 31 October 2015 recorded at the station in Ste-Anne-de-Bellevue, QC.

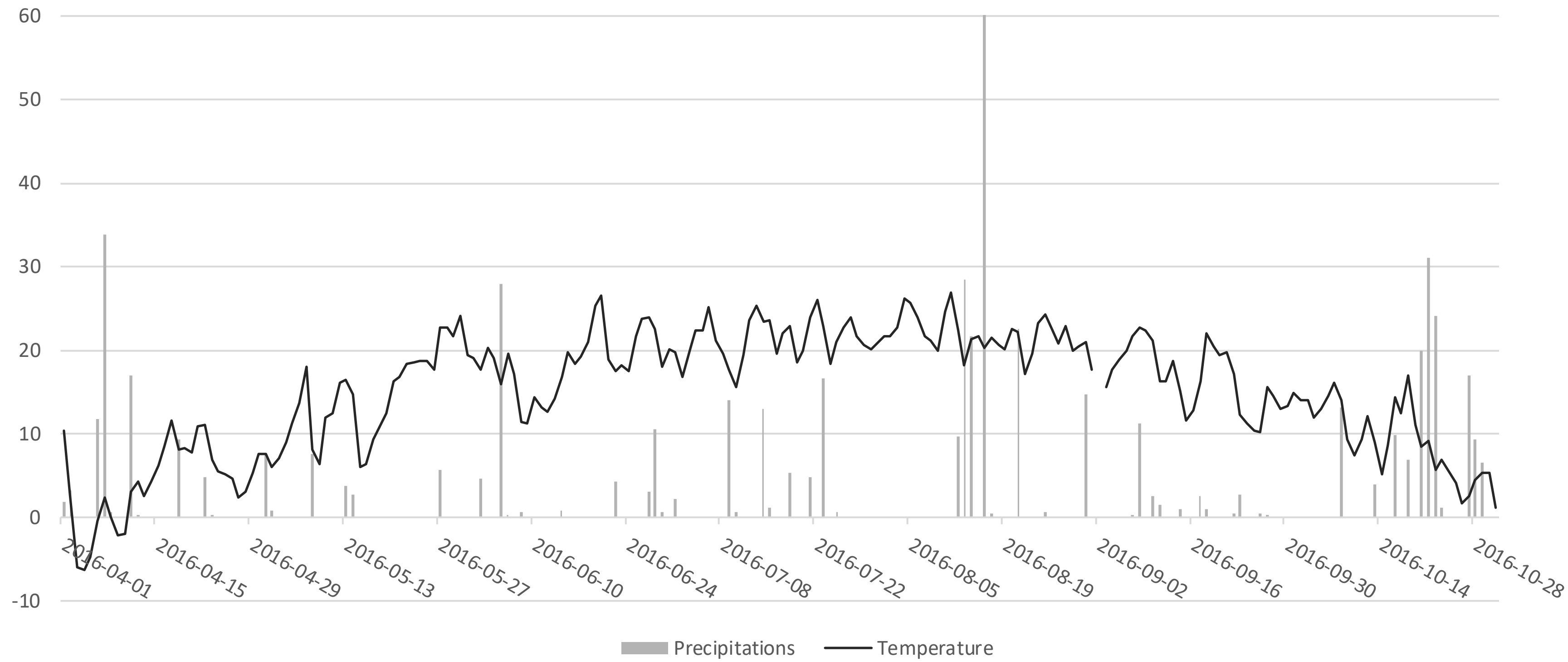

Figure 4.9. Daily average temperature and daily total precipitations from 1 April 2016 to 31 October 2016 recorded at the station in Ste-Anne-de-Bellevue, QC.

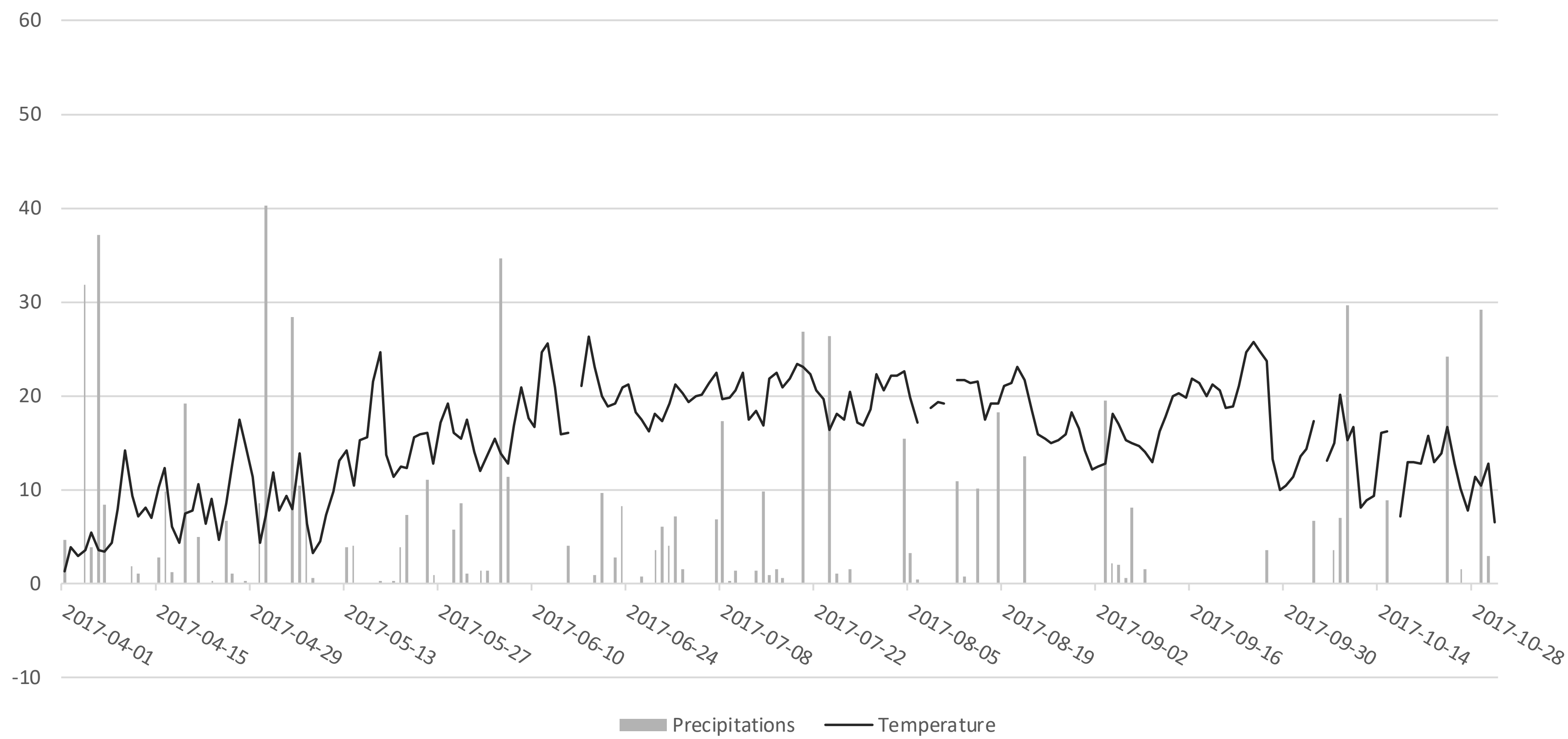

Figure 4.10. Daily average temperature and daily total precipitations from 1 April 2017 to 31 October 2017 recorded at the station in Ste-Anne-de-Bellevue, QC

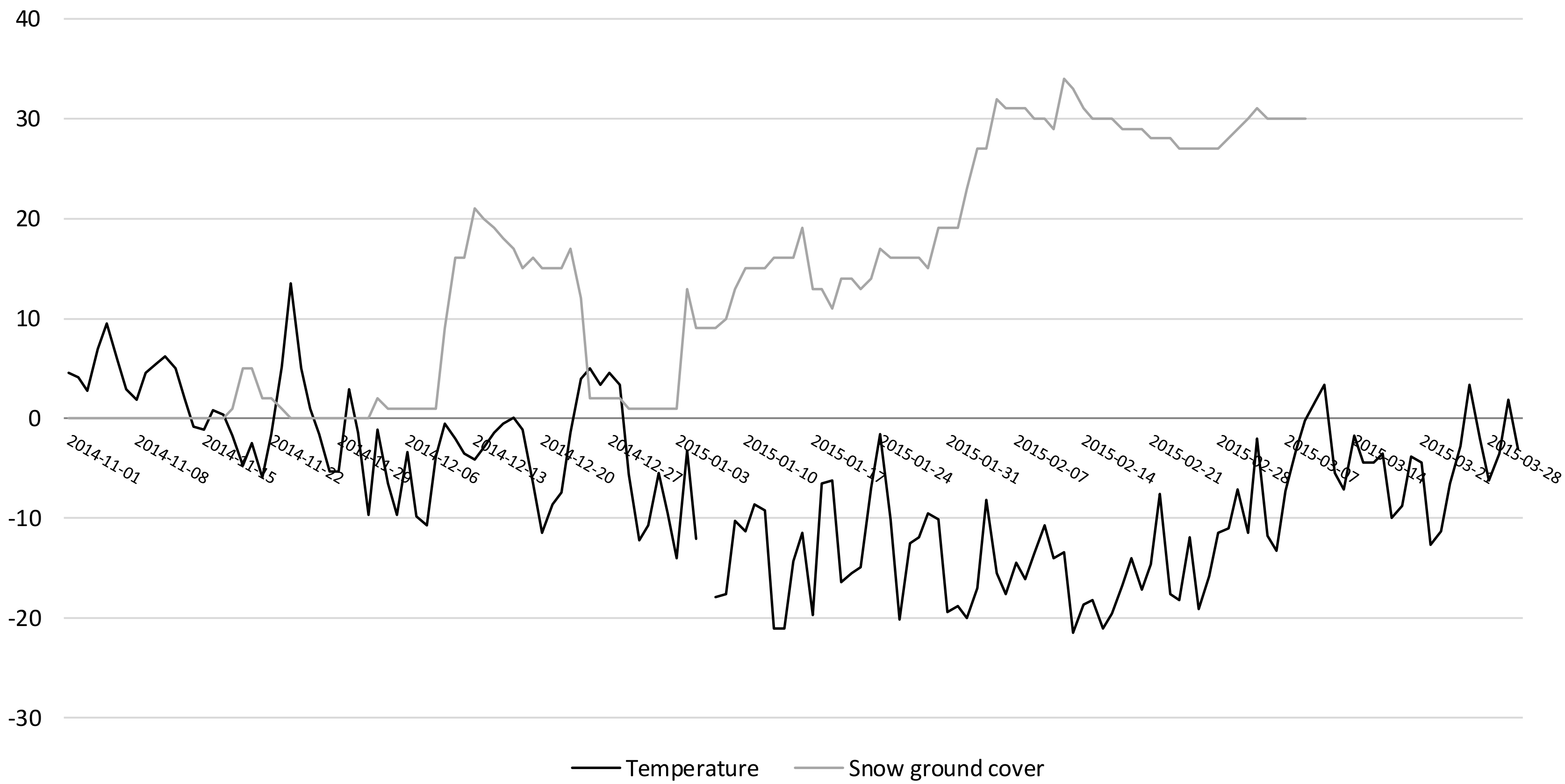

Figure 4.11. Daily average temperature and snow ground cover from 1 November 2014 to 31 March 2015 recorded at the station in Ste-Anne-de-Bellevue, QC.

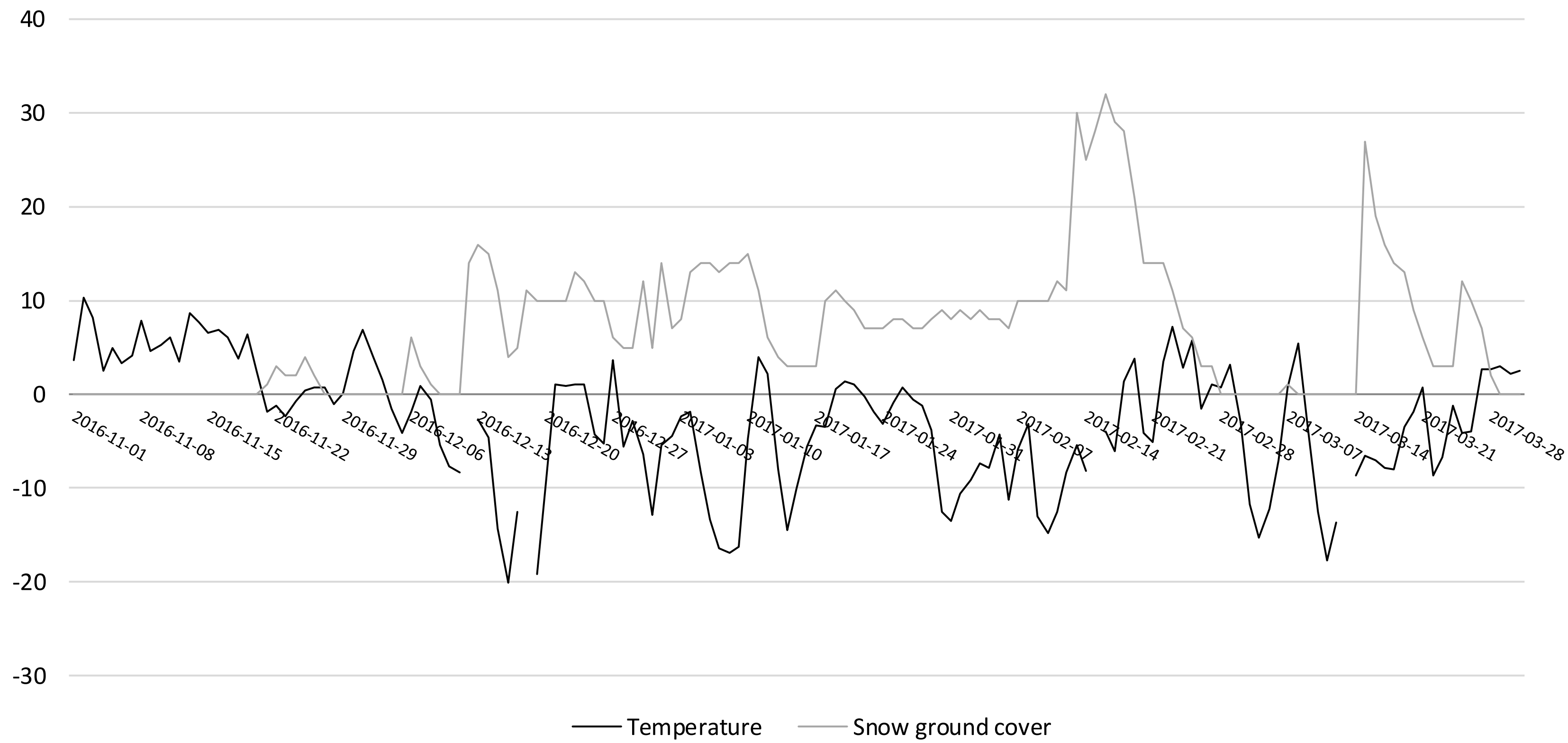

Figure 4.12. Daily average temperature and snow ground cover from 1 November 2016 to 31 March 2017 recorded at the station in Ste-Anne-de-Bellevue, QC.

Chapter 5 General conclusion

In this study, the first objective was to compare the effects on forage yields of establishing alfalfa with annual companion crop species (i.e., Sudangrass and ryegrass) that have been poorly studied in Quebec compared to the use of more traditional small-grain cereals and pure stands. Based on our results, across environments, we concluded that the use of a Sudangrass companion crop overall resulted in the greatest total seasonal forage yields during alfalfa establishment year, followed by an oat companion crop. Ryegrass was the most inconsistent treatment, failing to increase total forage seasonal yields compared to alfalfa seeded without a companion crop. In addition, at the seeding rates we evaluated, Sudangrass, was less competitive to alfalfa than oat or ryegrass and thus allowed for better initial growth of alfalfa stands. Furthermore, Sudangrass was among the most productive companion crops tested along with oat. In our study, Sudangrass weed suppression potential, however, appeared to be lower then oat or ryegrass at the seeding rates evaluated. In post-seeding years, the negative effect of the companion crops on alfalfa yields was inconsistent.

The second objective of that study was to evaluate forage quality of the different companion crop treatments. Overall, we determined that Sudangrass treatments produce a forage of a similar quality than the oat treatment whereas the ryegrass companion crop was closer to solo-seeded alfalfa in terms of average seasonal quality. Based on our analysis, we can conclude, similarly to Sulc et al. (1993a) that ryegrass-used as a companion crop for alfalfa establishment result in a forage of higher nutritional quality when compared to the use of oat and Sudangrass.

Our third and final objective was to assess alfalfa establishment and winter survival after establishing it with our different companion crop treatments. Of all companion crop treatments evaluated, Sudangrass impacted alfalfa the least, although no significant impact over alfalfa stands density was found among treatments in post-seeded years.

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