Evaluation of seedling pest population and their management in the floodplains of Lac Saint-Pierre

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ABSTRACT

Soil-dwelling insects play an important role in affecting the plant ecosystem. Roots are the major victims of soil-dwelling insects as they are attracted by the carbon dioxide released by respiring roots. Most root-feeding instars belong to common insect orders such as Lepidoptera, Diptera, Homoptera, Hymenoptera and Coleoptera. Among them, wireworms (Coleoptera: *Elateridae)*, white grubs and Dipteran larvae (Diptera: *Anthomyiidae*) are considered as the most important pests of field crops. The most common control measure for these pests is using synthetic insecticides as seed treatment and soil application. The present study focused on the seedling pest population in the floodplains of Lac Saint-Pierre, QC, as some conventional agricultural practices (i.e., tillage, pesticides and fertilizers use) in this region have negatively affected the lake biodiversity and water quality. This project aims to determine the seedling pest populations in different crops and to evaluate the effect of buckwheat used in crop rotation on the seedling pest populations. The wireworm, white grub and seed corn maggot populations were recorded in different agricultural fields (corn, soybean and forages) over three years (2019-2021). The effect of region and soil texture on the seedling pest populations were also analyzed. Their populations varied among the fields (forages, soybean and corn) and treatments, but the population did not exceed the proposed economic threshold level. Since the threat of infestation was not severe under no-pesticide conditions, the regular application of synthetic insecticides could be reconsidered in the floodplains.

Keywords: Lac Saint-Pierre, floodplain, seed treatments, wireworms, white grubs, seed corn maggot, corn, soybean, forages, buckwheat, allelopathy, conventional agricultural practices

RÉSUMÉ

Les insectes du sol jouent un rôle important en affectant l'écosystème végétal. Les racines sont les principales victimes des insectes du sol car ceux-ci sont attirées par le dioxyde de carbone dégagé par la respiration des racines. La plupart des insectes causant des dommages aux racinaires appartiennent à des ordres d'insectes communs tels que les lépidoptères, les diptères, les homoptères, les hyménoptères et les coléoptères. Parmi eux, les taupins (Coleoptera: *Elateridae*), les vers blancs et les larves de diptères (Diptera: *Anthomyiidae*) sont considérés comme les ravageurs les plus importants des grandes cultures. La mesure de lutte la plus courante contre ces ravageurs consiste à utiliser des insecticides de synthèse pour le traitement des semences et l'application directement au sol. La présente étude s'est concentrée sur la population de ravageurs des semis dans les plaines inondables du lac Saint-Pierre, QC, car certaines pratiques agricoles conventionnelles (par exemple le travail du sol et l'utilisation de pesticides ou de fertilisants) dans cette région ont un effet négatif sur la biodiversité et la qualité de l'eau du lac. Ce projet vise à déterminer les populations de ravageurs des semis dans différentes cultures et à évaluer l'effet du sarrasin utilisé dans la rotation des cultures sur la population de ravageurs des semis. Les populations de vers fil-de-fer, de vers blancs et de mouche des légumineuses ont été enregistrées dans différents champs agricoles (maïs, soya et fourrages) sur trois ans (2019-2021 L'effet de la région et de la texture du sol sur les populations de ravageurs des semis a également été analysé. Leurs populations variaient selon les champs (fourrages, soja et maïs) et les traitements, mais la population ne dépassait pas le seuil économique proposé. Étant donné que la menace d'infestation n'était pas grave dans des conditions sans pesticides, l'application régulière d'insecticides de synthèse pourrait être reconsidérée dans les plaines inondables.

<u>Mots clés</u>: Lac Saint-Pierre, plaines inondables, traitement des semences, vers fil-de-fer, vers blancs, mouche des légumineuses, maïs, soya, fourrages, sarrasin, allélopathie, pratiques agricoles conventionnelles

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CONTRIBUTIONS OF THE AUTHORS

Chapter 1 – Palaniappan Ramanathan wrote the first draft, which was reviewed by Dr. Valérie Gravel, McGill University.

Chapter 2 – Palaniappan Ramanathan wrote the first draft, which was reviewed by Dr. Valérie Gravel.

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Chapter 4 – Palaniappan Ramanathan searched the literature and wrote the first draft, which was reviewed by Dr. Valérie Gravel.

Chapter 5 – Palaniappan Ramanathan conducted experiments in 2020 and 2021 with the team of collaborators from MAPAQ and McGill University, led by Dr. Valérie Gravel and Dr. Philippe Seguin. In the year 2019, the experiments were conducted by Dr. Elise Smedbol with the team of collaborators from MAPAQ and McGill University, led by Dr. Valérie Gravel and Dr. Philippe Seguin. Palaniappan Ramanathan wrote the first draft, which was reviewed by Dr. Valérie Gravel.

Chapter 6 – Palaniappan Ramanathan performed the statistical analyses with the help of Césarée Morier-Gxoyiya, led by Dr. Valérie Gravel. Palaniappan Ramanathan wrote the first draft, which was reviewed by Dr. Valérie Gravel.

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Appendix 1 – Palaniappan Ramanathan wrote the first draft, which was reviewed by Dr. Valérie Gravel.

1 Introduction

In many countries, floodplains in river basins are mainly used for agriculture. Floodplain soil is very fertile due to the sediments deposited from flooding (Schilling et al., 2015). Lands in higher elevations are used primarily to cultivate cash crops and lands in lower elevations are used for forages and livestock grazing. There are several floodplains worldwide such as the Yangtze floodplain, Cedar River floodplain, Ganges floodplain, Mississippi River floodplain, Elbe River floodplain, and Danube floodplain (Balcombe et al., 2011; Bayley, 1988; FEMA, 2020; Jia et al., 2020; Karlsson et al., 2020; Xie et al., 2017).

Our focus is on the Lac Saint-Pierre floodplain, located along Quebec's Saint Lawrence River. There is a substantial increase in water level in spring in this floodplain due to snowmelt. Therefore, the riparian and terrestrial areas around this floodplain are submerged, which occurs every two years. It has been home to several aquatic and terrestrial species (MDDEFP, 2013). Most of these species are threatened due to conventional agricultural practices followed in this region. To promote the restoration of the Lac Saint-Pierre ecosystem and its littoral zone, the government of Quebec launched a research initiative the "Pôle d'expertise multidisciplinaire en gestion durable du littoral du Lac Saint-Pierre" in 2018 and this project is part of that program (MDDEFP, 2013).

In 2008, a study stated that insect families in North America hold a significant proportion of root feeders and their impact on plant growth and health is vital (Rasmann and Agrawal, 2008). These soil-dwelling insects play a crucial role in affecting the plant ecosystem as the CO2 released by respiring roots attract them. However, plants have defensive mechanisms such as the exudation of organic compounds from some plant roots, which tend to limit pest incidence. This phenomenon could potentially reduce pest incidence and minimize pesticide use (Hiltpold and Turlings, 2012).

Most of the root-feeding instars belong to standard insect orders such as Lepidoptera, Diptera, Homoptera, Hymenoptera, and Coleoptera. Among them, wireworms are larvae of click beetles and are considered the most critical pest in field crops (Knodel and Shrestha, 2018). Several species are found worldwide such as *Agriotes* sp., *Melanotus* sp., *Limonius* sp., *Hypnoidus* sp., and *Athous* sp. In Europe, wireworms are a severe pest of potatoes and crop damages are severe even at a lower population level (Parker, 1996). A recent study states that there are 400 click beetle species in Canada and 20 of them are considered as an economic threat to major crops (Knodel and Shrestha, 2018). The biodiversity of wireworms is found across the Prairies, Central and Atlantic Canada (Saguez et al., 2017).

In Coleoptera, white grubs (*Scarabaeidae*) are also considered a severe pest in agricultural and horticultural crops. They are the larva of Scarab beetles, consisting of 1400 species in North America and are categorized as annual white grubs, Japanese beetle (*Popillia japonica (*Newman)) and true white grubs (*Phyllophaga* spp.,). The lifecycle of true white grubs varies from 2 to 4 years, whereas annual white grubs and Japanese beetle complete their lifecycle in one year (Jordan et al., 2012; Sappington et al., 2018). However, the grub population is elevated when the field is surrounded by willow or cottonwood trees, a host plant to adult beetles (Hesler, Allen, et al., 2018). In Quebec, species found in greater proportion are *Phyllophaga anxia* (LeConte) (Cranberry white grub), *Popillia japonica* (Newman) and *Amphimallon majalis* (Razoumowsky) (European chafer). These root-feeding larvae are predominant in shallow-rooted crops such as corn, sugarcane, strawberry, and forages. (Simard et al., 2001).

Another severe pest found in this region is seed corn maggot or seed fly (*Delia platura* (Meigan)), belonging to the Order Diptera and Family *Anthomyiidae*. It is also a polyphagous pest with over 40 host plants (Soroka et al., 2020). The distribution of this species is widespread in all continents except Antarctica. Initially, it was reported in Germany and now it is a major pest in Europe, North and South America (Hesler, Allen, et al., 2018). These larvae affect the young seedlings and germinating seeds and are active during spring when the temperature is mild and moist. In Alberta, it has been reported that these maggots have significantly affected canola seed yields (Soroka et al., 2004). Specifically in Quebec, the damages caused by *Delia platura* larvae in corn resulted in reduced plant growth. In soybean, very little damage was observed since the incidence of this pest is intermittent across the fields (Labrie et al., 2020).

Crop protection strategies need to be adequate to enhance food security. An increase in pesticide use did not reduce crop losses substantially, although it helped the farmers minimize their losses from an economic perspective (Oerke, 2006). Thus, the concept of integrated pest management (IPM) has been developed to reduce the dependence on synthetic chemicals to manage pests. It incorporates several methods (chemical, biological, mechanical, and cultural) to control the targeted pests. IPM emphasizes that evaluating a pest population abundance is the key to devising an effective management approach (Pimentel and Peshin, 2014). Another part of IPM is biological control using natural enemies to control pest species, including plants producing secondary metabolites, termed allelopathy (Baker et al., 2020).

In recent years farmers have adopted seed treatment to minimize the damage of soil-dwelling pests. It is effective at a lower population density, but it has adverse effects on other organisms associated with the ecosystem (Esser et al., 2015; Morales-Rodriguez and Peck, 2009). Due to this reason, focusing on alternative control measures is necessary. Many studies have focused on an effective management approach to minimize pest incidence. In this study, we are trying to examine the seedling pest population and its sustainable control measures.

2 Objectives

The overall objective of this project is to develop a sustainable management practice to minimize the seedling pest population in the floodplains of the Lac Saint-Pierre region.

1. To scout seedling pest (wireworm, white grub and Dipteran larvae) populations in corn, soybean and prairie fields within the floodplains of Lac Saint-Pierre to determine their abundance.
   - 1.1. To evaluate the effect of different agricultural practices on the seedling pest populations.
   - 1.2. To evaluate the effect of different soil types on the seedling pest populations.
   - 1.3. To evaluate the effect of different regions on the seedling pest populations.
2. To evaluate the allelopathic effect of buckwheat (*Fagopyrum esculentum* Moench.), used as part of a rotation, on seedling pest populations.
   - 2.1. To evaluate the effect of incorporated and mulched buckwheat on the seedling pest populations.

3 Hypotheses

Based on the objectives, we hypothesized that,

1. The seedling pest population level is above the economic threshold in corn, soybean and prairie fields within the floodplains of Lac Saint-Pierre.

1.1. The seedling pest population is above economic threshold in field under conventional agricultural practices.

1.2. The seedling pest population is above economic threshold in sandy loam soil.

1.3. The seedling pest population is above economic threshold in all the regions of Lac Saint-Pierre.

2. Growing buckwheat in infested fields will negatively impact seedling pest population.

2.1. Incorporated and mulched buckwheat in the soil will have negative impact on seedling pest population.

4 Literature Review

4.1 Agriculture in Canada

In Canada, the agricultural and agri-food sector has contributed $139.3 billion in 2020. Primary agriculture is accountable for 2.1% of the national GDP (gross domestic product). The net cash income forecast in 2021 was $26.6 billion, which was higher than the previous year ($17.8 billion). About 193,492 farms are listed, covering 6.9% of Canada's land area. Farm size has expanded over the last 50 years, producing twice the output with the same amount of input (AAFC, 2021)

Major crops produced in Canada include wheat (*Triticum* sp. L.), corn (*Zea mays* L.), canola (*Brassica napus* L.), barley (*Hordeum vulgare* L.), oats (*Avena sativa* L.), soybean (*Glycine max* (L) Merr.), pulses, and forages (Table 4.1). Productivity for most of the crops has increased consistently over the last 4-5 years (AAFC, 2021).

Table 4.1. Area and production of major field crops for 2020-2021 field season in Canada (AAFC, 2021).

Crop	**2020-2021**	
	Area (000 ha)	**Production (000 t)**
Wheat	10,188.7	35,169.9
Oats	1,553.6	4,575.8
Barley	3,059.9	10,740.6
Corn	1,440.5	13,563.3
Canola	8,410.4	18,719.7
Soybeans	2,051.8	6,355.9
Pulses	3,711.0	8,007.1
Forages	5,253.0	17,868.4

4.2 Major Crops in Quebec

Quebec is a major producer of field crops, especially corn, soybean and oats. In terms of area, it is the second and third largest producing province in Canada for corn (*Zea mays* L.) and soybean (*Glycine max* (L) Merr.), respectively. The forage production area was reduced by 5.7% from 2011 to 2016 (StatisticsCanada, 2017). Recent trends in area and production of field crops are either stable or decresing (Table 4.2) and 80% of the total agricultural production area is in the St. Lawrence valley, primarily in the Montreal plain (AAFC, 2021).

Table 4.2. Total area of major field crops from 2016-2017 to 2020-2021 field season in Quebec (AAFC, 2021).

Crop	**Area (000 ha)**					**Production (000 t)**				
	2016-2017	**2017-2018**	**2018-2019**	**2019-2020**	**2020-2021**	**2016-2017**	**2017-2018**	**2018-2019**	**2019-2020**	**2020-2021**
Wheat	95.8	94.0	95.4	91.6	118.3	310.0	295.0	290.1	276.4	248.6
Oats	84.5	60.0	74.1	73.5	82.6	204.4	149.0	167.1	189.6	173.2
Barley	52.0	53.0	54.6	49.5	51.0	175.0	171.0	157.0	156.6	125.9
Corn	396.8	380.0	385.7	382.5	360.5	4,121.3	3,780.2	3,619.6	3,369.0	3,264.1
Soybeans	351.7	398.0	370.3	366.7	358.3	1,129.4	1,115.0	1,164.0	1,146.0	1,159.7
Forages	658.5	630.5	641.4	651.1	609.1	3,818.3	3,870.1	3,260.2	3,318.4	2,347.5

4.3 Agriculture in Floodplains

Floodplains are unique ecosystems that are adjacent to a river. They form an ecological bond between two environments: aquatic and terrestrial. Modification in these ecosystems by humans has changed their biodiversity (Bardhan and Jose, 2012; Jia et al., 2020; Julian et al., 2012). For instance, areas around rivers have faced seasonal flooding, drought and degradation in soil structure (Bardhan and Jose, 2012). Construction of dams and levees prevents the nutrient exchange between river and the floodplain, thus lead to change in ecological structures of the floodplain (Myers and White, 1993). It has also been reported that construction of levees in Mississippi river caused increased flood stages (Myers and White, 1993).

Also, the likelihood of flooding tends to increase due to global climate change (Milly et al., 2002). In England and Wales, a model predicted that flood risk is likely to increase (20-90%) due to anthropogenic GHG emissions (Pall et al., 2011). Similar to flooding, droughts have impacted the agricultural production and the severity have increased in amazon floodplain (da Cunha Ávila et al., 2021). Farmlands in river corridors are severely impacted due to the heavy deposition of sand and silt, which has altered the soil ecosystem and has caused reduced yield (Bardhan and Jose, 2012).

4.3.1 Floodplains around the world

There are several floodplains worldwide: the Yellow River (2267 km^2) and Yangtze floodplains (15,770 km^2) in China, the Cedar River floodplains (20,163 km^2) in Iowa, the Chesapeake Bay watershed (165,800 km^2) in Maryland and Virginia, and the Lake Champlain watershed (1215 km^2) in Vermont, New York and Quebec. Crops such as corn, soybean, switch grass, sunflower, and rice are cultivated in those regions (Hou et al., 2020; Jantz et al., 2005; Jia et al., 2020; Schilling et al., 2015).

4.3.2 Problems in floodplains

Pesticides pollute the floodplains and adjacent riverine ecosystems (Schulz, 2004). In flooding events, the sedimentation of pesticide particles in floodplain soils over the growing season is transported to river streams (Topaz et al., 2018). Therefore, water quality monitoring is required in those regions (Karlsson et al., 2020). In France, perennial crop strips, 5-10m wide are planted along the rivers to minimize nitrates pollution in the water (Velthof et al., 2014). In Lac Saint-Pierre, 20 pesticides were detected and the concentrations of atrazine, clothianidin and thiamethoxam has increased (Giroux et al., 2016).

4.3.3 Crop losses by flooding

In the past 50 years, there have been several floods in farmlands which are not located in the flood prone areas with a rising intensity. A yield reduction in the United States has been recorded. The insurance payout was about US $3 billion (Figure 4.1), and most losses were in corn (Albajes et al., 2003) and soybean (*Glycine max* (L) Merr.) (Bailey-Serres et al., 2012). Meanwhile, the rest of the world has suffered similar issues due to flooding. For example, in Australia, wheat (*Triticum* spp.) production and prices were seriously impacted by floods in 1992 (Whetton et al., 1993). In 2010, US $4.45 billion of crop losses were recorded because of flooding in Pakistan (Arshad and Shafi, 2010). Also, about 35% of rice fields in Asia and Africa are in flood-prone zone (Bailey-Serres et al., 2012).

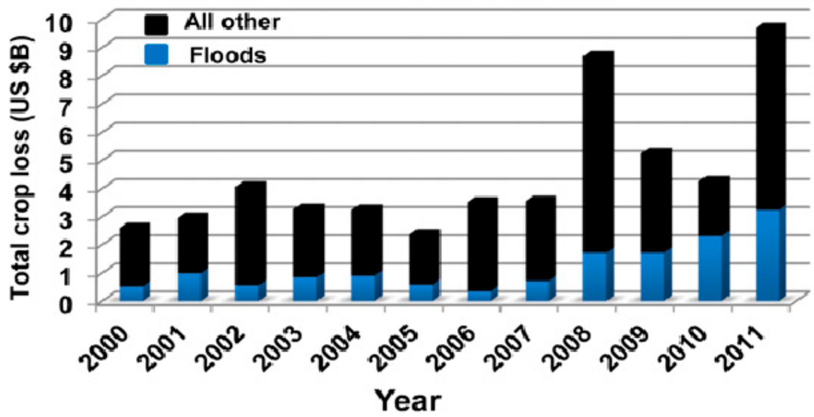

Figure 4.1. From 2000-2011, total crop losses and the proportion of total loss due to floods (Bailey-Serres et al., 2012).

4.4 Lac Saint-Pierre environment

The Lac Saint-Pierre is situated along the Saint Lawrence River in the province of Quebec. It is roughly 30 km long and 13 km wide, with a total area of approximately 500 km^2. For commercial navigation, a central channel was dugged to a depth of 11.3 m while the rest of the lake is comparatively shallow and the water flow of 9500 m^{3}s^{-1} (MDDEFP, 2013). During spring, there is a substantial increase in water level due to snow melt, which frequently cause the areas around the lake to become submerged (MDDEFP, 2013). Hence, it is considered a biosphere reserve by UNESCO (United Nations Educational, Scientific and Cultural Organization) and most of the area is well-preserved. A large population of migratory birds has been recorded in this area, in addition to 27 rare species of plants and numerous aquatic species, making it a unique ecosystem (MDDEFP, 2013).

The littoral zone (nearshore) in this area is mainly wetlands. Since 1960, the cultivated area has decreased from 35.4% to 30.4% and the conversion of perennial to annual crops has progressed (Figure 4.2). From 1997 to 2014, perennial crops cultivated area has decreased from 8.75% to 3% and annual crops area has increased from 17.9% to 20%. Some of the annual crops conventionally (pesticide, tillage and fertilization) grown in this region are corn, soybean, wheat, barley and oats (Dauphin and Jobin, 2016; TCRLSP, 2017).

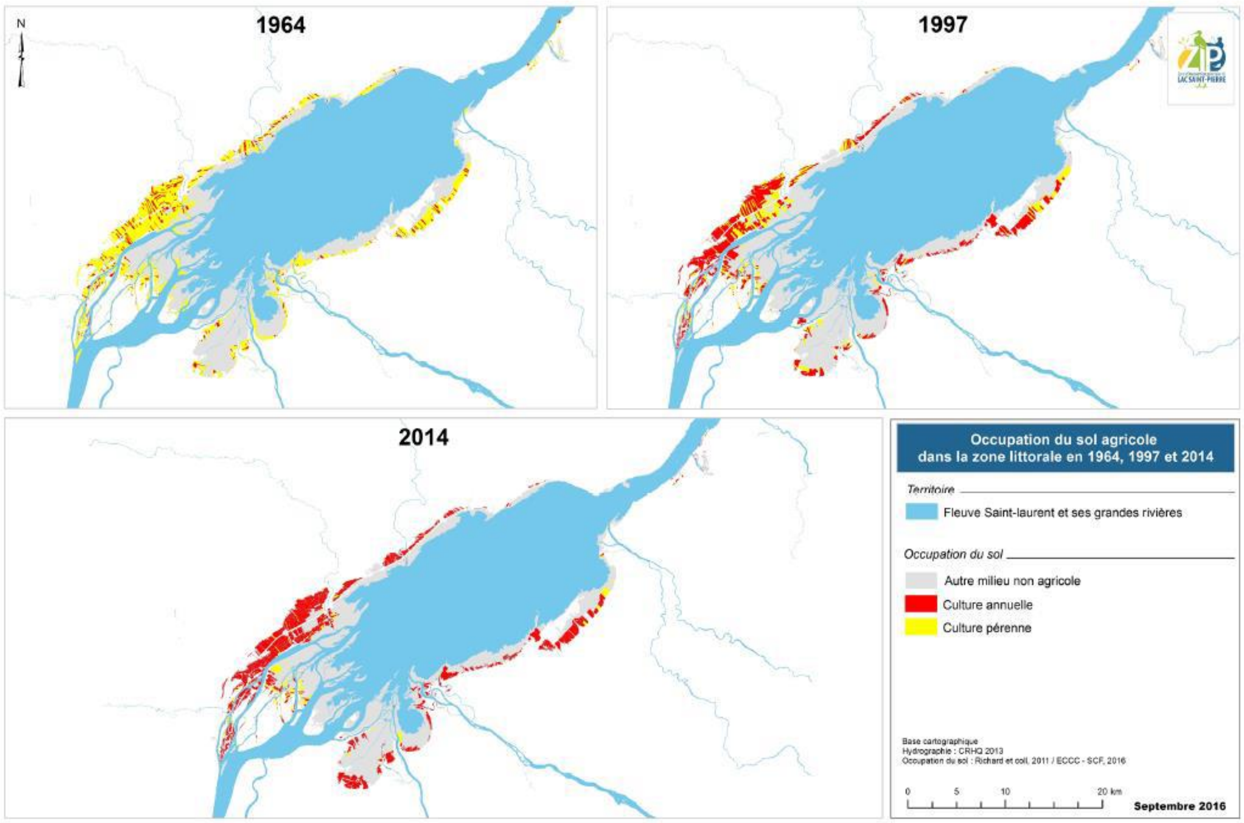

Figure 4.2. Transition of agricultural land use from 1964 to 2014; where blue represents Saint Lawrence River and its great rivers, grey represents other non-agricultural environment, red represents the annual crops and yellow represents perennial crops (TCRLSP, 2017).

In recent years, the aquatic species ecosystem has been significantly tarnished. Especially, the yellow perch (*Perca flavescens*) population has decreased subsequently over the last decade. This decline is caused by the conversion of perennial crops to annual crops, thus creating an unsuitable environment for yellow perch spawning (Magnan et al., 2017). Also, the increase in synthetic pesticides and fertilizer use degraded the water quality and reduced the availability of prey for the yellow perch (TCRLSP, 2017). Hence, the restoration of this habitat needs to be prioritized.

4.5 Wireworm

Wireworms (Coleoptera: *Elateridae*) are serious agricultural pests worldwide, and their spread increases consistently. The injuries are usually below ground, for example, damages to root crops and seedlings. There are about 40 species of wireworms that are considered as agricultural pests (Ritter and Richter, 2013). Depending on the species, they are elongated, between 10 to 40-mm long (Table 4.3), with three pairs of legs closer to the anterior body, and their color varies from yellow to reddish-brown except for cotton and corn wireworm (Hyslop, 1915).

Table 4.3. List of major wireworm species, larvae length and their distribution worldwide (Modified from Vernon and van Herk, 2013).

Genera	**Larvae maximum length (mm)**	**Distribution**
Hypnoidus abbreviatus	15	Canada, United States
Dalopius sp.	16	Canada, United States
Melanotus sp.	29	China, United States, Canada
Agriotes sp.	16	Europe, Canada, China
Limonius sp.	16	Canada
Hemicrepidius sp.	25	United States, Canada
Aeolus sp.	13	Canada, Australia, Africa, South America, United States
Oestodes tenuicollis	14	Canada, United States

4.5.1 Lifecycle of wireworms

In May or June, female beetles lay eggs and hatching occur after 4-6 weeks. Depending on the species, each larva goes through 1 to 3 instars and reaching maturity can take up to 2-5 years (Figure 4.3). After 2-5 years, they pupate at a depth of 5-30 cm below soil surface in the fall and adults emerge in the spring (Knodel and Shrestha, 2018; Parker and Howard, 2001).

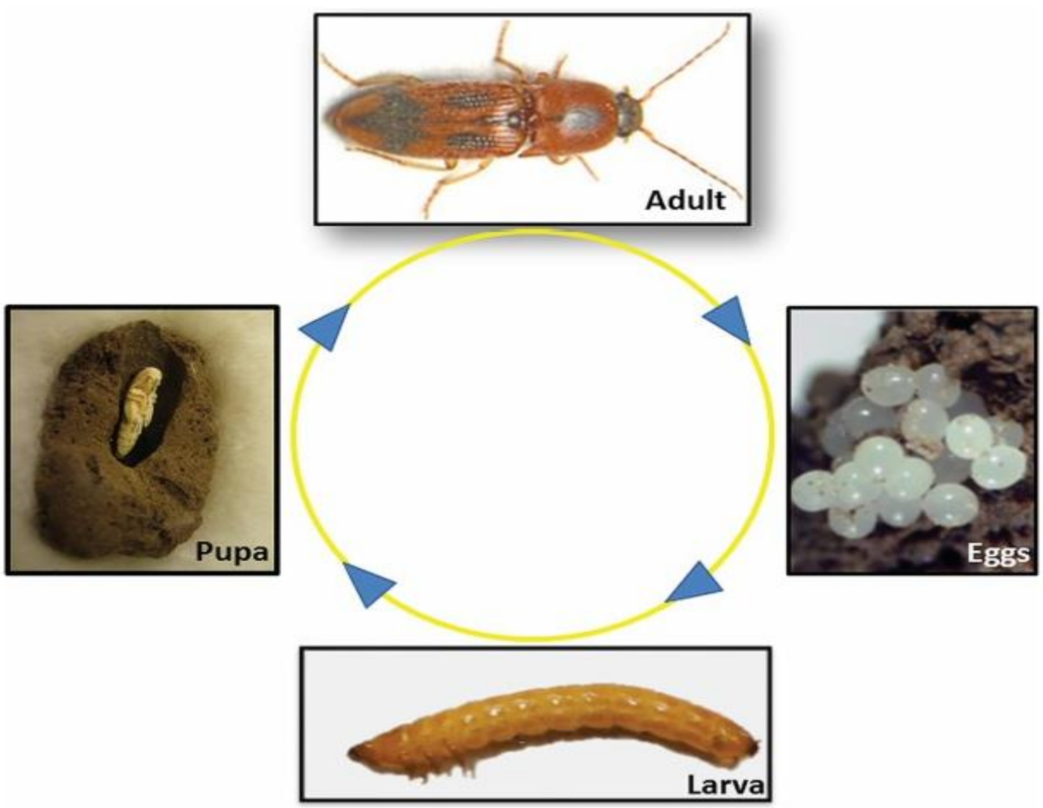

Figure 4.3. Life cycle of wireworm (Aeolus sp.). Under Quebec conditions, the average time spent in each stage is as follows: 1-2years as an adult, 4-6 weeks as eggs, 2-5 years as larvae and 5-6 months as pupae (Knodel and Shrestha, 2018).

A recent study by Poggi et al (2018), a survey was carried out in France to measure wireworm population. A total of 336 sites were investigated and only four species were found *Agriotes lineatus*, *Agriotes sordidus*, *Agriotes sputator* and *Agriotes obscurus*. These species were found using soil sampling method (3 samples per site) in 183 out of 336 sites and the average number of wireworms were 10.2/field (Poggi et al., 2018). In Canada, different wireworm species have been recorded in 600 fields planted with corn, soybean, cereals, canola and grasslands around Quebec province from 2011 to 2015 (Table 4.4) and their distribution between the fields is diverse (Saguez et al., 2017).

Table 4.4. Different genera of wireworms and their percentage of wireworms collected in 600 sites across Quebec (Modified from Saguez et al., 2017).

Genera	Percentage (%) of all wireworms collected
Hypnoidus abbreviates	72
Melanotus sp.	8
Ampedus sp.	7
Limonius sp.	6
Agriotes sp.	4
Aeolus sp., *Dalopius* sp., *Hemicrepidius* sp., *and Oestodes* sp.	3

4.5.2 Damages to crops

In Europe, wireworms are considered a severe pest of potatoes. Damages to the tubers consist of small holes and tunnels, reducing tuber quality. Also, wireworm damage to corn seedling has been significant across Europe (Barsics et al., 2013; Furlan, 2014). In Canada, *Hypnoides bicolor* and *Selatosomus aeripennis destructor* are considered the most damaging pests in wheat and several other cereal crops (van Herk and Vernon, 2013). Under critical conditions, yield losses in wheat can be up to 70% (Esser et al., 2015; Higginbotham et al., 2014). Some of the other crops affected by wireworms are cotton, barley, oats, rye, sweet potatoes, peanuts, and forage grasses. Therefore, managing this serious pest is necessary (Gibson, 1916; Rashed et al., 2017; Vernon et al., 2013).

4.5.3 Wireworm scouting and management

4.5.3.1 Wireworm management

Farmers have been using insecticides containing organochlorides, organophosphates and carbamates for decades. Due to environmental and health concerns, these synthetic chemicals have been withdrawn from the application (Vernon et al., 2009). Thus, the use of neonicotinoids, pyrethroid and phenyl pyrazoles has increased in the last decade (Labrie et al., 2020). These chemicals have significantly reduced wireworm damage in field crops (Wilde et al., 2007). Neonicotinoids are used as seed treatments in cereal crops and it is effective in early stages of the crop. Later the pest tends to recover from the intoxication and continue their life cycle (van Herk and Vernon, 2007; Vernon et al., 2008). However, there are some restrictions on using these seed treatment measures in Ontario and Quebec to minimize non-target exposure (Smith et al., 2020).

Use of synthetic pyrethroids in seed treatments in wheat has shown good yield protection but, it did not reduce the pest population (Vernon, 2005). In cereals and potatoes, phenyl pyrazoles (Fipronil) have shown significant improvement in pest reduction, it kills on contact or several months after contact at lower rates (Kuhar and Alvarez, 2008). In recent years, seed treatments have shown significant improvement in field crops only when there is low pest population and damage (Labrie et al., 2020).

Some cultural methods such as crop rotation, time of planting and tillage can have a negative impact on wireworm population as well (Knodel and Shrestha, 2018). Alfalfa, buckwheat and sweet potato can also be cultivated in rotation because of their minimized likability by wireworms (Adhikari and Reddy, 2017; Knodel and Shrestha, 2018; Landl and Glauninger, 2013). Shallow cultivation of fields could expose the eggs and damaging the larvae (Knodel and Shrestha, 2018). Flooding in summer for an extended time can reduce the wireworm population although it is not possible to practice in the production fields because of the growing season (van Herk and Vernon, 2006).

Use of predators such as stiletto fly larvae (*Thereva nobilitata* Fabricius.) and beetles of the *Carabidae* family did not show any significant impact (van Herk et al., 2015). However, certain strains of entomopathogenic fungi (*Metarhizium anisopliae* and *Beauveria bassiana*) have shown significant results with two genera (*Limonius* and *Hypnoidus*) (Ansari et al., 2009). Also, the bacterium *Rickettsiella agriotidis* has shown some potential in controlling wireworm infestation (Leclerque et al., 2011). Using the entomopathogenic nematode *Steinernema feltiae* was ineffective against *Agriotes sp*. However, *Heterorhabditis bacteriophora* has significantly impacted *Agriotes lineatus* populations (Campos-Herrera, 2015; Eidt and Thurston, 1995; Ester and Huiting, 2007). Nevertheless, in Quebec without effective IPM strategies, pest populations tend to grow (Labrie et al., 2020).

4.5.3.2 Wireworm scouting

In general, scouting is done to evaluate the economic loss due to a certain pest and determine the necessary management strategies. Wireworms tend to attack seeds and seedlings so preventive measures like seed treatments and insecticidal application in the soil at planting are carried out to minimize the impacts (Lefko et al., 1998). The use of insecticide can increase the resistance and it is not economical. Therefore, scouting is necessary to formulate an effective management tactic (Lefko et al., 1998).

4.5.3.2.1 Soil sampling method

This method, predominantly used in the UK, consists in taking 20 soil cores of a diameter of 10 cm per field (4-10 ha) and worms are extracted mechanically using flotation (Fryer, 1944). Several factors are monitored in this method such as size of the sampling unit, number samples per field and examination of the sample (Parker and Howard, 2001). However, this process has shown sampling errors when the population is low (Yates and Finney, 1942). Also, this method is laborious where the soil samples are manually processed in the laboratory and samples are passed through several sieves to get the accurate count of wireworms (Parker and Howard, 2001). Development of improved soil sampling method using self-propelled soil sampler have also resulted in various disadvantages (Smith et al., 1981). Thus, the popularity of this technique is lower among farmers and agronomists (Yates and Finney, 1942).

4.5.3.2.2 Bait traps method

Several baits trap methods are extensively researched across Europe and North America. This method utilizes the theory that wireworms are attracted to the respiring seeds (CO_2) (Doane et al., 1975). About 10 to 20 traps are placed in the field at a 10 - 15 cm depth. Presoaked corn and/or cereal seeds are used as baits and the sampling is done after 7 days. This method is effective in spring when the soil temperature is >10ºC with 30-35% soil moisture (Knodel and Shrestha, 2018; Parker, 1996).

A modification to the previously described baiting technique consists in using plastic pots in the traps and covering the bait using plastic to increase soil temperature. This modified technique was proven more effective for certain species (*Melanotus* sp. and *Aeolus* sp.) (Parker, 1994; Toba et al., 1983). In general, the bait traps method is more effective than the soil sampling method (Knodel and Shrestha, 2018). However, bait traps are less effective when there is a susceptible crop (Parker and Howard, 2001).

4.6 Other seedling pests

In LSP region, we recorded other seedling pests (White grubs: *Scarabaeidae*) and seed corn maggots: *Anthomyiidae*) during our initial scouting process and it is also reported in other studies conducted in this region (Labrie et al., 2020; Saguez et al., 2017). These pests can have serious impacts on crop production and minimize crop stance at early stages (Hesler et al., 2018; Polishchuk et al., 2019; Sappington et al., 2018). Hence, the use of neonicotinoid seed treatment is popular across the province of Quebec, about 500,000 ha area are sown with treated seeds (Labrie et al., 2020). Also, it might be due to its low cost, ease of usage, effectiveness among soil dwelling pests and their low toxicity towards humans (Esser et al., 2015). To discuss in detail about their population morphology and their persistence towards the seed treatment, we included them in our study.

4.6.1 White Grubs

A complex of many species of the *Scarabaeidae* (Coleoptera) are called white grubs. About 1300 species in North America are categorized as true or annual white grubs (Hesler et al., 2018). The length of the lifecycle of true white grubs (*Phyllophaga* sp.) is 2-4 years and for annual white grubs it is one year. Most white grub species are root feeders, whereas their adult beetles feed on the leaves. These grubs are a common pest in corn, soybean, prairies (Grasslands), sugarcane, strawberry, and tuber crops (Crocker, 1981).

4.6.1.1 Damages to crops

Second-year larvae of *Phyllophaga* sp. can cause severe economic loss in corn and soybean fields, affecting the roots of young seedlings throughout the growing season. Damages caused by first-year and third-year larvae are not as severe as the second year because they feed on the host only during some part of the growing season (Hesler, Allen, et al., 2018). At the same time, annual white grub species such as *Cyclocephala* spp., *Popillia japonica* Newman (Japanese beetle) and

Cotinis nitida (Green June Beetle) feed on host plants early in the season and then pupate at the time of planting (Sappington et al., 2018; Hesler et al., 2018).

In corn fields, the risk of infestation is lower when compared with soybean and forage fields, unless the field is bordered by trees such as poplars, willow, ash, and cottonwood, which serve as a host plant to adult beetles (Renkema et al., 2015). In 2013, a survey was conducted in the United States and only 2.4% and 0.8% of corn and soybean farmers, respectively, actively use management practices to control their population (Hurley and Mitchell, 2014; Hurley and Mitchell, 2017).

4.6.1.2 Management

Several factors influence the population of white grub larvae, such as soil moisture, cover crop, soil organic matter, soil temperature, previous crop, border plants, and tillage practices (no-till). Culturally it is controlled by plowing before planting, destroying or exposing the grubs to predators (Pathania and Chandel, 2017). In addition, increasing the organic matter content in soil can reduce the white grub population (Gan et al., 2018) These methods are effective only when the population is under the economic threshold (2 white grubs per trap) (Hesler, Allen, et al., 2018).

Use of entomopathogenic nematodes such as *Heterorhabditis* spp. and *Steinernema glaseri* have significantly affected the white grub population (Kajuga et al., 2018). In Germany and Japan, entomopathogenic nematodes (*Heterorhabditis bacteriophora* and *S. glaseri*) are commercially available to control white grub population on turf grass (Koppenhofer et al., 2004). Commercialization of these parasites around other parts of the world are limited due to its cost and reliance on chemical insecticides (Devi, 2019).

Currently, neonicotinoids, pyrethroids and organophosphates have been used as seed treatments against white grub. Although application of these insecticides is suggested when the true white grub population is above the threshold (2 white grubs per trap), they have little or no effect on the white grub population (Smith et al., 2020). Nevertheless, the popularity of these products is heightened due to the wide range of pest control (Renkema et al., 2015).

4.6.2 Seed corn maggot

Another critical pest found in LSP is seed corn maggot (*Delia platura* (Meigan)), which belongs to the family *Anthomyiidae* (Order: Diptera), distributed throughout the world except for

Antarctica (Nair and Mcewen, 1973). It was initially reported in Germany and currently it is considered a major pest across North and South America (Soroka et al., 2004). Annually these maggots can have up to five generations if the environmental conditions are appropriate. The female fly lays about 270 eggs during their life cycle near the base of young seedlings or on plant residues (Hesler, Allen, et al., 2018). The activity of these maggots is significantly higher in spring when the temperature is cold with high soil moisture (Gill et al., 2013).

4.6.2.1 Damages to crops

Maggots are early-season pests of corn and soybean seedlings, and they feed on seeds and the roots of germinating seedlings. Thus, lead to a considerable reduction in plant population (30-60%) and yield (Soroka et al., 2020). The damage potential of these maggots is significantly higher in early-season crops with cold-damp weather. Horticultural crops such as *Phaseolus* spp., *Cucumis sativus*, *Pisum* spp., *Allium cepa*, *Capsicum annuum*, *Fragaria* x *ananassa* and *Solanum tuberosum* are also affected by seed corn maggot (Gill et al., 2013).

4.6.2.2 Management

Several cultural practices help to prevent the proliferation of seed corn maggot populations, such as late planting, above-average seeding rate, shallow planting, and early incorporation of cover crops (Bessin, 2004). Especially, fields with no-till practices usually have a lesser maggot population (Hammond, 1997). The use of aged manure is recommended and incorporated thoroughly to avoid oviposition. Planting after 450 GDD (Growing Degree Days) accumulation following the incorporation of organic matter helps to minimize maggot damage (Gesell and Calvin, 2000; Pope, 1998). Most of the maggot life cycle is spent below ground, so most natural enemies are ineffective. However, in Colombia, spraying *Steinernema* sp. on germinating spinach seedlings has been proven to control maggot populations (Jaramillo and Sáenz, 2013).

The use of insecticides such as cyromazine and chlorpyrifos was predominant until 2020 (Mlynarek et al., 2020). Currently, neonicotinoid seed treatment is popular among producers due to its vast spectrum of pest control (Labrie et al., 2020).

4.7 Plant protection: Allelopathy

Allelopathy has happened in nature and has influenced ecosystems for over centuries, and it was even discussed by great philosophers such as Theophrastus, Democritus and Plinius (Rizvi, 2012). In 1937, Molisch described the term allelopathy as the biochemical exchanges among all plants including microorganisms (Muller, 1966). It has since evolved as another plant physiologist described it as a natural process in which chemical compounds (allelochemicals) are released in the environment from one organism to another and their effects can be either positive or negative (Rice, 1984). Primarily focusing on releasing chemicals (secondary metabolites) from any part of the plant to repel insect pests is necessary to analyze its allelopathic properties (Farooq et al., 2013; Farooq et al., 2011).

4.7.1 Allelopathic plants

Since the dawn of time plants have evolved to protect themselves. Some have features such as wax coating, thorns, thickness, and fiber content. These defensive mechanism helps to repel insect pests at a minimal abundance (War et al., 2012). In agricultural ecosystems, allelopathic plants have been used to address various challenges in stress mitigation, plant growth, pests, disease and weed management. For example, intercropping with mint (*Mentha* spp.), winter savory (*Satureja montana* L.), sweet potato (*Ipomoea batatas*) and some species from the *Ocimum* genus can help reduce weeds and parasitic plants (*Striga* spp.) (Farooq et al., 2013). Extracts from Neem (*Azadirachta indica* L.) negatively impacts certain dominant pests such as strawberry aphids (*Chaetosiphon fragaefolii* Cockerell.), green cicadellid (*Jacobiasca lybica* Bergevin and Zanon.), white fly (*Bemisia tabaci* Gennadius.) and Pine weevil (Hylobius abietis L.) (Farooq et al., 2011). Certain plants with allelopathic properties are listed in Table 4.5.

Table 4.5. List of allelopathic plants that have a considerable effect on targeted pests (Modified from Farooq et al., 2013 and Farooq et al., 2011)

Allelopathic plants	Insects/pathogens suppressed
Neem (*Azadirachta indica* A.Juss.)	*Fusarium solani*, *Heliothis armigera* Hb., *Meloidogyne javanica* and *Corcyra cephalonica*
Fig-leaf goosefoot (*Chenopodium ficifolium* Sm.)	*Aphis gossypii* Glover
Rice (*Oryza sativa* L.)	*Fusarium oxysporum*
Eucalyptus (*Eucalyptus globulus* Labill.)	*Fusarium solani*
Hot pepper (*Capsicum unnuum* L.)	*Heliothis armigera* Hb.
Spanish flag (*Lantana camara* L.)	*Callosbruchus maculatus* F.
Common rue (*Ruta graveolens* L.)	*Ceratitis capitata* W. and *Culex pipiens* L.

4.7.2 Allelochemicals and its properties

Secondary metabolites may act as an allelochemical depending on the environment (Inderjit and Duke, 2003). These allelochemical may have several uses; for example, tannic acid a play major in Locust tree (*Anacridium melanorhodon* Walker.) growth and it also helps to inhibit pathogenic bacteria (Dillon et al., 2000; Rice, 1984). There are several ways for allelochemicals to get into the environment such as foliar leaching, root exudation, residue decomposition, volatilisation, and debris incorporation (Inderjit and Duke, 2003).

Some of the secondary metabolites identified as allelochemicals include flavonoids, amnio acids, phenolics, alkaloids, terpenoids, momilactone, hydroxamic acids, brassinosteroids, jasmonates, salicylates, glucosinolates and carbohydrates (Farooq et al., 2013). These chemicals are involved in plant growth promotion, seed germination, repelling pests, inhibiting weed growth and are effective at various concentrations (Farooq et al., 2011).

4.8 Buckwheat production and its benefits

Common buckwheat (*Fagopyrum esculentum* Moench.) belongs to the family *Polygonaceae*, a traditional crop in China and Europe (Biacs et al., 2002). It has been a popular food ingredient across Asia and is used as a cover crop to prevent erosion and to increase organic matter percentage in soil (Jacquemart et al., 2012). Recently it has been grown for seed, flour, and groats (dehulled seeds) and produced mainly in Asia and Europe (Figure 4.4) (Bérczi et al., 1988). Two species of buckwheat are commonly grown in North America, common buckwheat and tartary buckwheat (*F. tartaricum*). In Canada, the productivity of buckwheat has been increasing lately, producing 18,000 tonnes with the acreage of 13,900 ha in 2019 (FAO, 2020).

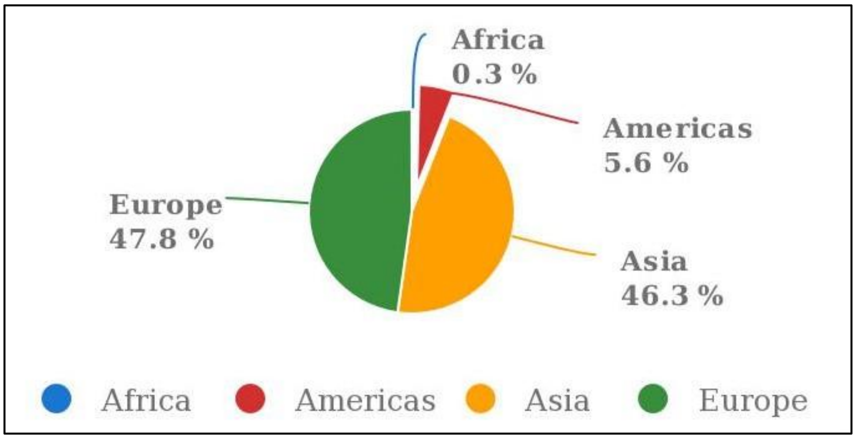

Figure 4.4. Average production share of Buckwheat by region from 1994-2019 (FAO, 2020).

It is a short season crop, grown in wide range of soil types with cool and moist climates (Mazza and Oomah, 2005). In Canada, it is mainly grown for grain production (Izydorczyk et al., 2014). Also, it is used for various purposes such as animal feed, soup, beverage, staple food, and as medicine (Jacquemart et al., 2012). For example, leaves are used to brew tea containing an important pharmaceutical compound, rutin, which helps treat patients with hypertonia (Gondola and Papp, 2010). It also helps bee farmers by producing quality nectar over a long flowering period (Rahman and Rahman, 2000).

4.8.1 Allelopathic effect on weeds

One of the important benefits of this multipurpose crop is its allelopathic properties. In Japan, a study suggested that buckwheat has weed suppression properties by producing certain phenolics and flavonoids (Golisz et al., 2007; Kalinova et al., 2005). In another research, it has been reported that weed suppression activity of buckwheat is due to its rapid growth with a larger canopy, hence the competition for light absorption. Also, residues in the soil can inhibit some weeds (Iqbal et al., 2003; Kalinova et al., 2007). Mainly buckwheat root residue inhibits barnyard grass (*Echinochloa* *crus-galli* L.) and cleavers (*Galium aparine* L.) although incorporation of the entire plant did not show a significant difference in biomass of weeds (Szwed et al., 2019). In rice fields, buckwheat pellets, applied at the rate of 2 tonnes per hectare, helped to reduce weed density by 80%, with a 20% increase in yield (Eom et al., 1999; Iqbal et al., 2002).

4.8.2 Allelopathic effect on pests

In Poland, various studies have observed that buckwheat reduces the damage of cockchafer grubs (*Melolontha* spp.) on scots pine fields (Woreta, 2015). Some studies suggested the reason is due to high tannin content in the plant, which is not a preferred food source for these soil-dwelling insects (Bohorquez Ruiz et al., 2019; Oomah and Mazza, 1996; Woreta, 2015). Furthermore, tannin from buckwheat affects their guts and the adult females did not lay eggs in the buckwheat sown area (Woreta, 2015).

In Nova Scotian potato and carrot fields, wireworm populations are significantly reduced when buckwheat is used as cover or rotation crop (MacKenzie and Hammermeister, 2008; MacKenzie et al., 2010). Wireworms reject a food source when compounds like allyl isothiocyanate and quinine are available, but buckwheat does not produce any of those compounds (Golisz et al., 2007; Oomah and Mazza, 1996). It does produce compounds like eugenol, isoeugenol and methyleugenol, which affects the larvae feeding habit of various soil-dwelling pests (Huang et al., 2002; Kalinova et al., 2011).

5 Materials and Methods

5.1 Objective 1: Determining the abundance of seedling pest populations in the Lac Saint-Pierre region

5.1.1 Field sites

This project is part of the « Pôle d'expertise multidisciplinaire en gestion durable du littoral du Lac Saint-Pierre », established in 2019 and which aims to develop sustainable management practices in the coastline of Lac Saint-Pierre. Fields were selected based on a large-scale project, where different cropping systems were compared:1) Forage fields established for several years (6-10 years), 2) Forage fields established in 2019, 3) Cornfield under conventional cultural practices, 4) Cornfield with improved cultural practices: intercropping with annual ryegrass and 5-meter strips of ryegrass and canary reed grass planted on either side of the field near the ditch line, 5) Soybean field under conventional cultural practices and 6) Soybean field with improved cultural practices: intercropping with autumn wheat in fall and 5-meter strips of ryegrass and canary reed grass planted along either side of the field near the ditch line. Description of all the treatments is listed on Table 5.1 and the information about the fertilization is listed on Table A.2.

Table 5.1. Information on the treatments applied in the large-scale plots: Seeding rate, Spacing between rows, time of tillage, intercrop and perennial grass strips.

Treatment	Seeding rate	Row spacing	Time of tillage	Intercrop	Perennial grass strip
Improved practices Corn	84000 - 88900 plants/ha	76 cm	Spring	Rye grass at the seeding rate of 25 kg/ha	Rye grass sown at the rate of 5.88kg/ha and Reed canary grass sown at the rate of 20kg/ha
Improved practices soybean	345800 - 444600 plants/ha	38-76 cm	Spring	Autumn wheat sown at the seeding rate of 220 kg/ha	Rye grass sown at the rate of 5.88kg/ha and Reed canary grass sown at the rate of 20kg/ha
Conventional practices Corn	85000 - 88900 plants/ha	76 cm	Spring	Not applicable[a]	Not applicable[a]
Conventional practices Soybean	345800 - 444600 plants/ha	38-76 cm	Spring	Not applicable[a]	Not applicable[a]
Old forages	Not available[b]	Not available[b]	No tillage	Not applicable[a]	Not applicable[a]
New forages	Reed canary grass sown at the rate of 20kg/ha and Feed oats sown at the rate of 70kg/ha	18cm	Spring	Not applicable[a]	Not applicable[a]

[a]Not applicable - Intercrop and Perennial grass strips are not applicable in Conventional practices corn and soybean, old and new forages.
[b]Not available - Forage fields were established 6-10 years ago, so the information regarding the seed rate and spacing were not available.

Four areas of the Lac Saint-Pierre floodplain (Baie-du-Febvre, Saint-Barthélemy, La Visitation-de-l'Île-Dupas and Pierreville) were targeted (Table 5.2) (Figure 5.1). In those areas, 23 fields were identified to measure the effect of different cropping systems on seedling pest populations

(Table 5.2) (Table A.1). Number of sites per treatment varied for the years 2020 and 2021 are listed in Table 5.3.

Table 5.2. List of scouted fields in the four areas of the Lac Saint-Pierre region, including cultivated area, scouted years, soil texture and crops planted in 2018, 2019, 2020, and 2021.

Sites	**Cultivated area (ha)**	**Scouted years**	**Crop planted**				**Soil texture**
			2018	**2019**	**2020**	**2021**	
Baie-du-Febvre (BAIE)							
BAIE01	5.26	2020 and 2021	Corn	Soybean	Corn	Soybean	Clay
BAIE02	4.45	2020 and 2021	Corn	Soybean	Corn	Soybean	Clay
BAIE03	4.90	2020 and 2021	Corn	Winter wheat	Soybean	Corn	Clay
BAIE04	4.88	2020 and 2021	Corn	Winter wheat	Soybean	Corn	Clay
BAIE07	6.00	2020 and 2021	Soybean	Forages	Forages	Forages	Sandy clay
BAIE09	1.40	2019, 2020 and 2021	Forages	Forages	Forages	Forages	Sandy clay loam
BAIE10	1.60	2020 and 2021	Forages	Forages	Forages	Forages	Clay
Saint-Barthélemy (BART)							
BART05	3.5	2019, 2020 and 2021	Soybean	Annual ryegrass	Corn	Soybean	Clay loam
BART06	3.4	2019, 2020 and 2021	Soybean	Annual ryegrass	Corn	Soybean	Clay loam
BART07	2.5	2019, 2020 and 2021	Soybean	Soybean	Corn	Corn	Clay
BART08	2.0	2019, 2020 and 2021	Soybean	Soybean	Corn	Corn	Clay loam
BART09	2.1	2021	Forages	Forages	Forages	Forages	Clay loam
BART10	1.6	2019 and 2021	Forages	Forages	Forages	Forages	Clay loam
BART11	1.10	2020 and 2021	Forages	Forages	Forages	Forages	Clay loam
La Visitation-de-l'Île-Dupas (DUPA)							
DUPA01	2.00	2019, 2020 and 2021	Corn	Winter wheat	Soybean	Corn	Clay loam
DUPA02	5.56	2019, 2020 and 2021	Soybean	Winter wheat	Soybean	Corn	Loam
DUPA04	2.00	2019, 2020 and 2021	Corn	Soybean	Corn	Soybean	Clay loam
DUPA05	2.50	2019, 2020 and 2021	Corn	Soybean	Corn	Soybean	Clay loam
DUPA03	1.10	2019, 2020 and 2021	Forages	Forages	Forages	Forages	Loam
DUPA07	2.3	2019 and 2020	Soybean	Soybean	Forages	-	Clay loam
Pierreville (PIER)							
PIER03	13.50	2020 and 2021	Corn	Soybean	Corn	Soybean	Sandy loam
PIER04	13.25	2020 and 2021	Corn	Annual ryegrass	Corn	Soybean	Sandy loam
PIER05	15.50	2020 and 2021	Corn	Annual ryegrass	Corn	Corn	Sandy loam

Figure 5.1. Geographical location of the four areas A) Baie-du-Febvre, B) Pierreville, C) La Visitation-de-l'Île-Dupas and D) Saint-Barthélemy, where scouting was carried out in Lac Saint-Pierre.

Table 5.3. List of 6 treatments and their associated fields implemented in 2019 and compared during the 2020 and 2021 season.

Treatments[Z]	**Sites/Fields**	
	2020	**2021**
Conventional practices Corn (C-C)	BAIE02, PIER04, BART05, BART07 and DUPA05	BAIE03, BART07 and DUPA01
Improved practices Corn (I-C)	BAIE01, PIER03, PIER05 BART06, BART08 and DUPA04	BAIE04, BART08, DUPA02 and PIER03
Conventional practices Soybean (C-S)	BAIE03 and DUPA01	BAIE02, BART05, DUPA05 and PIER04
Improved practices Soybean (I-S)	BAIE04 and DUPA02	BAIE01, BART06, DUPA04 and PIER05
Old Forages (O-F)	BAIE09 and DUPA03	BAIE09, BART09 and DUPA03
New Forages (N-F)	BAIE07, BAIE10, BART11 and DUPA07	BAIE07, BAIE10, BART10 and BART11

[Z] C-C: Corn field under conventional cultural practices; I-C: Corn field with improved cultural practices-intercropping with annual rye grass and 5-meter strips of rye grass or canary reed grass planted on either side of the field near the ditch line; C-S: Soybean field under conventional cultural practices; I-S: Soybean field with improved cultural practices-intercropping with rye grass in fall and 5-meter strips of rye grass or canary reed grass planted along either side of the field near the ditch line; O-F: Forage fields established for several years ;N-F: Forage fields established in 2019.

5.1.2 Scouting and Experimental design

Scouting for seedling pests began in spring when the water had receded from the lower and higher elevations of the field and the temperature was ≥ 8°C, for at least 7 days. Scouting was done within weeks of sowing, as this period is most favourable for trapping wireworms. For 2019, scouting period was from June 11th to July 23rd. For 2020, scouting period was from May 26th to June 22nd. For 2021, scouting period is from May 12th to June 16th.

In 2019, a total of 11 fields were scouted to assess the initial seedling pest population, including wireworms, white grubs and Dipteran larvae. There were 1 field in Baie-du-Febvre (BAIE09), 5 fields in Saint-Barthélemy (BART05, BART06, BART07, BART08 and BART10) and 5 fields in La Visitation-de-l'Île-Dupas (DUPA01, DUPA02, DUPA03, DUPA04 and DUPA05) (Table 5.2). In 2020, a total of 21 fields were scouted: 7 in Baie-du-Febvre (BAIE01, BAIE02, BAIE03, BAIE04, BAIE07, BAIE09 and BAIE10), 5 in Saint-Barthélemy (BART05, BART06, BART07, BART08 and BART11), 6 in La Visitation-de-l'Île-Dupas (DUPA01, DUPA02, DUPA03, DUPA04, DUPA05 and DUPA07) and 3 in Pierreville (PIER03, PIER04 and PIER05) (Table 5.2). In 2021, 22 fields were scouted to measure the abundance level of the seedling pests: 7 in Baie-du-Febvre (BAIE01, BAIE02, BAIE03, BAIE04, BAIE07, BAIE09 and BAIE10), 7 in Saint-Barthélemy (BART05, BART06, BART07, BART08, BART09, BART10 and BART11), 5 in La Visitation-de-l'Île-Dupas (DUPA01, DUPA02, DUPA03, DUPA04 and DUPA05) and 3 in Pierreville (PIER03, PIER04 and PIER05) (Table 5.2).

5.1.2.1 Bait traps method and scouting method

Seedling pests sampling was conducted using a bait trap method (Knodel and Shrestha, 2018; Parker, 1996) (RAP "Réseau d'avertissements phytosanitaires", 2019). In each trap, 250-ml of a mixture of equal portions of organic flour (La Milanaise, Canada), organic oats (La Milanaise, Canada) and untreated winter wheat seeds (var. Ruby) (recuperated seeds from Emile A. Lods Agronomy Research Centre, Canada) were used. Bait was added directly in a hole in the soil (15x15x15 cm) (Figure 5.2). Soil was closely monitored when it was dug and refilled to capture seedling pests that were present.

Figure 5.2. Scouting procedure: A) Trap dug using hand trowel B) Bait ingredients (wheat flour, oats and winter wheat seeds) used in the trap C) Wireworm species captured in one of the fields D) Collected seedling pest specimens stored in a plastic pot with a label.

In each field, 10 traps were installed 25 meters apart in a zigzag pattern, based on field width and length, to cover the most area and flags were placed with appropriate label to facilitate the scouting (A to J; Figure 5.3). Also, each scouting location was geolocated by taking the latitude and longitude points using a handheld GPS GPSMAP 64 (Garmin, Canada). There were four visits to each field at a weekly interval. On the second and third visits, traps were reinstalled one meter away from the previous visit (X and Y; Figure 5.3). At the last visit, scouting was performed, and no new traps were reinstalled.

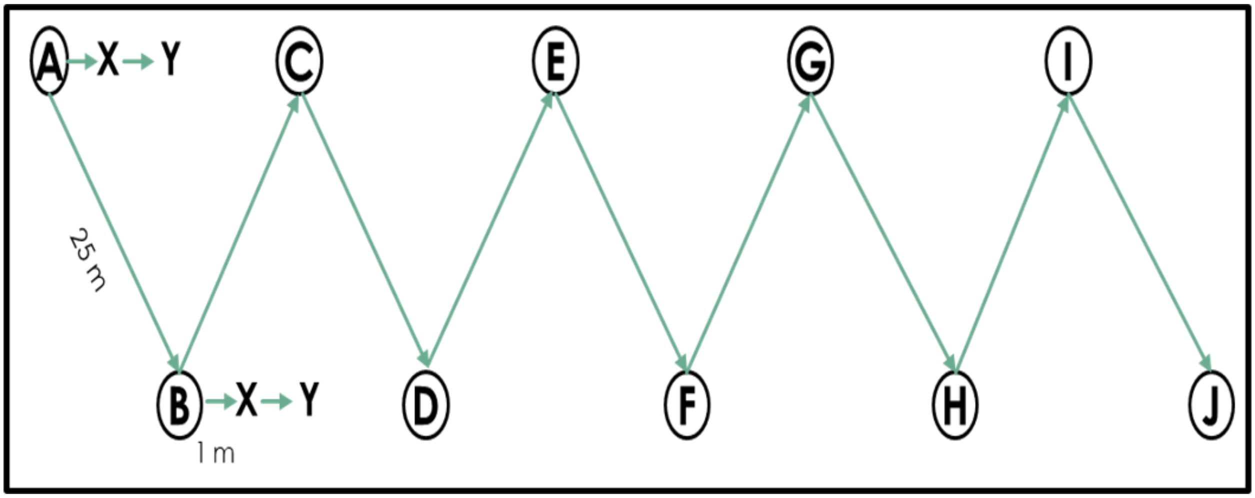

Figure 5.3. Schematic representation of scouting pattern (zigzag), where A-J represents traps, x and y represents subsequent scouting schedule at a weekly interval.

Sample collected from each trap were stored in a plastic pot with labels (Figure 5.2D). Wireworms collected from the trap were stored two per pot, because of cannibalistic behaviour. White grubs and Dipteran larvae or pupa were stored separately. A small amount of bait and a few grams of soil were also placed in the pot to ensure survival. Samples were kept in a cooler until analysis. At the end of the sampling week, samples were sent to the MAPAQ Laboratoire d'expertise et de diagnostic en phytoprotection (Quebec, Canada) for identification of the targeted pests.

The following data was collected during each scouting visit: date the trap was installed, date the scouting was performed, growth stage of the crop (pre-emergence or vegetative), soil temperature at a 10-cm depth using a standard soil thermometer (GSC International Inc, Canada), presence of infill or cover crop in the field (seeded in the spring or fall), overall abundance of weeds, germination of the bait used in the trap (second, third and fourth visits), damages to the traps by machinery or animals, and number of seedling pests (wireworms, white grubs and Dipteran larvae or pupae) found in each trap.

5.1.2.2 Wireworm threshold

The threshold of wireworm per trap is calculated using the following formula:

$$Wireworm\ per\ trap\ abundance = \frac{Total\ abundance\ of\ wireworm\ found\ per\ field}{Total\ number\ of\ traps\ scouted\ per\ field}$$

As per the phytosanitary warning network (RAP), three risk levels (low, moderate and high) are associated with the wireworm thresholds, ranging from 0 to 1.5, 1.6 to 2.9 and >3 (Table 5.4). The damages to the seedlings vary based on risk level. For *Hypnoidus abbreviatus*, the intervention is needed when three or more wireworms are found per trap. The intervention is needed for *Agriotes* sp. and *Melatonus* sp. when one wireworm is found per trap (CEROM, 2017).

Table 5.4. Considerations based on the risk level of wireworm per trap threshold and the damages to the seedlings (CEROM, 2017).

Risk level	Wireworm per trap threshold	Damages to the seedlings (if exceeds the threshold limit)
Low	0 to 1.5	Yield loss and seedlings damage is relatively low
Moderate	1.6 to 2.9	Less than 5% of seedlings could be damaged and the yield loss is low
High	>3	More than 5% of seedlings could be damaged and considerable yield loss

5.1.3 Soil sampling

During the first installation of traps, soil samples were collected following a similar zigzag pattern for scouting using a standard core sampler. Ten samples were collected in random locations for each field and pooled together. Once it was well dried, it was sent to the AgroEnviro Lab (Quebec, Canada) for analysis to know the soil texture, soil organic matter, soil pH and soil nutrient composition. Soil sampling and analysis were carried out for all three years (2019, 2020 and 2021) (Table A.3). For 2019, soil sampling dates were from June 12th to July 5th. Sampling was done between May 26th and June 1st and May 12th and May 26th for 2020 and 2021, respectively.

5.1.4 Statistical analysis

The experimental design used for this experiment was a Completely Randomized Design (CRD) with six treatments (Table 5.1) and ten replicates. The effect of soil texture and region were also evaluated on the seedling pest population (including wireworms, white grubs and Dipteran larvae or pupae). The data were analyzed using the Statistical Analysis Systems software (version 9.4;

Quebec, Canada) using proc GLM and proc GLIMMIX procedure for a one-way ANOVA with a 95% confidence interval.

Two different models were used, a generalized linear model and a generalized mixed model, with two different distributions (the Poisson and Negative binomial distributions). A Pearson Chi-Square/DF approaching 1 indicates the appropriate choice of distribution for the model. For the treatment variable in the 2020 data set, the Negative binomial had a Pearson Chi-Square/DF of 0.92 for wireworm and 0.89 for Dipteran larvae or pupae, which were closest to 1 compared to the Poisson distribution. For soil texture variable, the Negative binomial distribution had a Pearson Chi-Square/DF of 0.89 for wireworm and 1 for Dipteran larvae or pupae and the region variable, it had a Pearson Chi-Square/DF of 1.34 for wireworm and 1.09 for Dipteran larvae or pupae, all of which were closest to 1 compared to the Poisson distribution. Therefore, the Negative binomial distribution was chosen for all the variables as the final model (Table5.5).

Table 5.5. List of dependant variables, Pearson Chi-Square/DF and Akaike Information Criterion (AIC) in terms of distribution in 2020 for wireworm and Dipteran larvae or pupae.

Dependant variable	**Distribution**	**Wireworm**		**Dipteran larvae or pupae**	
		Pearson Chi-Square/DF	**AIC[x]**	**Pearson Chi-Square/DF**	**AIC[x]**
Treatment	Poisson	2.07	392.79	4.43	441.77
	Negative binomial	0.92	331.45	0.89	238.38
Soil texture	Poisson	1.82	380.29	5.29	462.52
	Negative binomial	0.89	329.57	1.00	243.52
Region	Poisson	3.33	433.99	6.46	479.06
	Negative binomial	1.34	349.11	1.09	243.12

[x] Akaike information criterion

For the treatment variable in 2021, the Negative binomial had a Pearson Chi-Square/DF of 1.03 for wireworm and 0.79 for Dipteran larvae or pupae, which were closest to 1 compared to the Poisson distribution. For the soil texture variable, the Negative binomial distribution had a Pearson Chi-Square/DF of 1.28 for wireworm and 0.89 for Dipteran larvae or pupae and for region variable, it had a Pearson Chi-Square/DF of 1.12 for wireworm and 0.90 for Dipteran larvae or pupae, all of which were closest to 1 compared to the Poisson distribution. Therefore, the Negative binomial distribution was chosen for all the variables as the final model (Table 5.6).

Table 5.6. List of dependant variables, Pearson Chi-Square/DF and Akaike information criterion (AIC) in terms of distribution in 2021 for wireworm and Dipteran larvae or pupae.

Dependant variable	**Distribution**	**Wireworm**		**Dipteran larvae or pupae**	
		Pearson Chi-Square/DF	**AIC[x]**	**Pearson Chi-Square/DF**	**AIC[x]**
Treatment	Poisson	2.76	463.12	1.57	252.09
	Negative binomial	1.03	373.91	0.79	225.03
Soil texture	Poisson	1.98	373.85	1.21	215.41
	Negative binomial	1.28	337.72	0.89	204.30
Region	Poisson	1.82	365.46	1.23	313.51
	Negative binomial	1.12	328.80	0.90	201.87

[x] Akaike information criterion

5.2 Objective 2: Allelopathic effect of buckwheat on seedling pest populations

5.2.1 Field site

This experiment was also part of the « Pôle d’expertise multidisciplinaire en gestion durable du littoral du Lac Saint-Pierre ». The experimental site was in Baie-du-Febvre, on the south shore of Lac Saint-Pierre, Quebec and conducted during two growing seasons (2020 and 2021) (Figure 5.4). The field was divided into two parts (high and low elevation) based on sediments from the flooding deposited more in the low elevation than at high elevation, altering the soil texture.

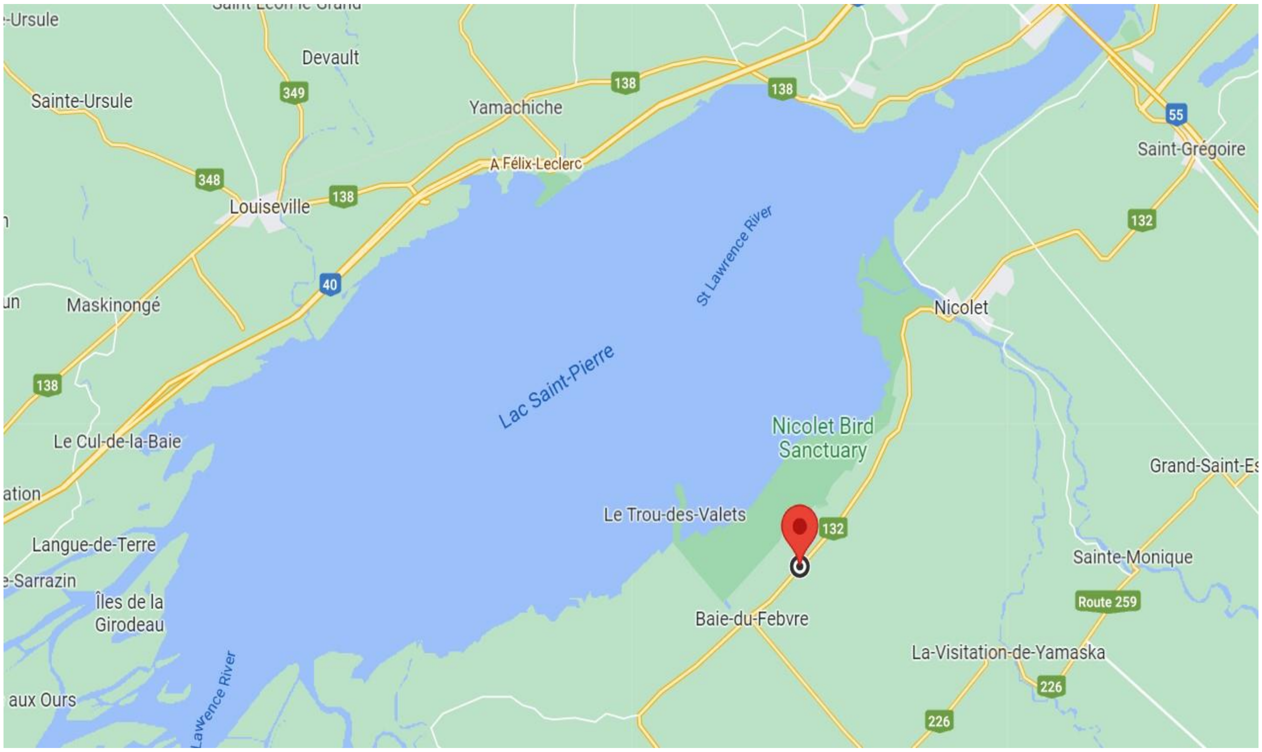

Figure 5.4. Geographical location of the experimental site in 2020 and 2021 for the buckwheat trial in Lac Saint-Pierre floodplain.

5.2.2 Scouting and Experimental design

In 2020, the field was separated into two plots per elevation (high and low): a buckwheat plot and a control plot, for a total of 4 plots (Table 5.7). Scouting of seedling pests was carried out as previously described in section 5.1.2.1 from May 27th to June 16th. Buckwheat (*Fagopyrum esculentum* cv Manisoba) (Semican Inc, Quebec, Canada) was sown on June 16th at a seeding rate of 65 kg/ha. Soybean was sown on May 24th at a seeding rate of 70-100 kg/ha.

Buckwheat plots were mowed on August 23rd using a commercial mower before they reached full maturity to prevent natural seeding and growth the following year. For half of the buckwheat plots, mowed plants were incorporated using a commercial disc plow on September 23rd, creating six plots (Table 5.7). In fall 2020, we initiated the scouting process on September 23rd, but subsequent visits were not completed due to flooding. On September 30th, 2020 Baie-du-Febvre region received a high amount of rainfall (38.4 mm); experimental plots in low elevation were submerged in water and the plots in high elevation were not suitable for scouting. The water was receded on October 15th, 2020 and the temperature was not appropriate to proceed with the scouting. Flags were placed on four corners of the treatment plots and GPS points were taken using GPSMAP64 (Garmin, Canada) in fall 2020 to identify the plot area in spring 2021.

Table 5.7. List of experimental plots, elevation, soil texture and crop cultivated in 2019, 2020 and 2021 for the buckwheat trial.

<table>
<tr><th rowspan="2">Cultivated area in ha</th><th rowspan="2">Elevation</th><th colspan="3">Crop</th><th rowspan="2">Soil texture</th></tr>
<tr><th>2019</th><th>2020</th><th>2021</th></tr>
<tr><td rowspan="2">0.96</td><td rowspan="2">High</td><td rowspan="2">Winter rye</td><td rowspan="2">Buckwheat</td><td>Incorporated Buckwheat</td><td rowspan="2">Clay</td></tr>
<tr><td>Mulched Buckwheat</td></tr>
<tr><td>5.68</td><td>High</td><td>Winter rye</td><td>Soybean</td><td>Corn</td><td>Clay</td></tr>
<tr><td rowspan="2">1.18</td><td rowspan="2">Low</td><td rowspan="2">Winter rye</td><td rowspan="2">Buckwheat</td><td>Incorporated Buckwheat</td><td rowspan="2">Sandy clay</td></tr>
<tr><td>Mulched Buckwheat</td></tr>
<tr><td>5.68</td><td>Low</td><td>Winter rye</td><td>Soybean</td><td>Corn</td><td>Sandy clay</td></tr>
</table>

In 2021, there were two buckwheat treatments (incorporated and mulched) and a control plot per elevation (Table 5.7). The six plots were scouted again for the seedling pest in spring 2021 from May 12th to June 1st. Buckwheat was sown again on June 4th using the same cultivar and seeding rate as previously mentioned. However, in the control plots, corn was sown on May 3rd at a seeding rate of 41kg/ha. Buckwheat plants were again mowed using a commercial mower on August 19th and incorporated in half of the plot using a commercial disc plow on August 29th (Table 5.7).

The scouting process was repeated in the fall 2021 from September 30th to October 20th to analyze the effect of buckwheat on the seedling pest populations. During the fall season, the producer of that specific field started to expand the ditch to promote better drainage for the crops. Therefore, field width was insufficient to follow the original orientation of treatment plots in low elevation. So, the treatment plots (T1 and T2) width was reduced and length was increased to accommodate the scouting process. All other plots area remained same for both years (Figure 5.5).

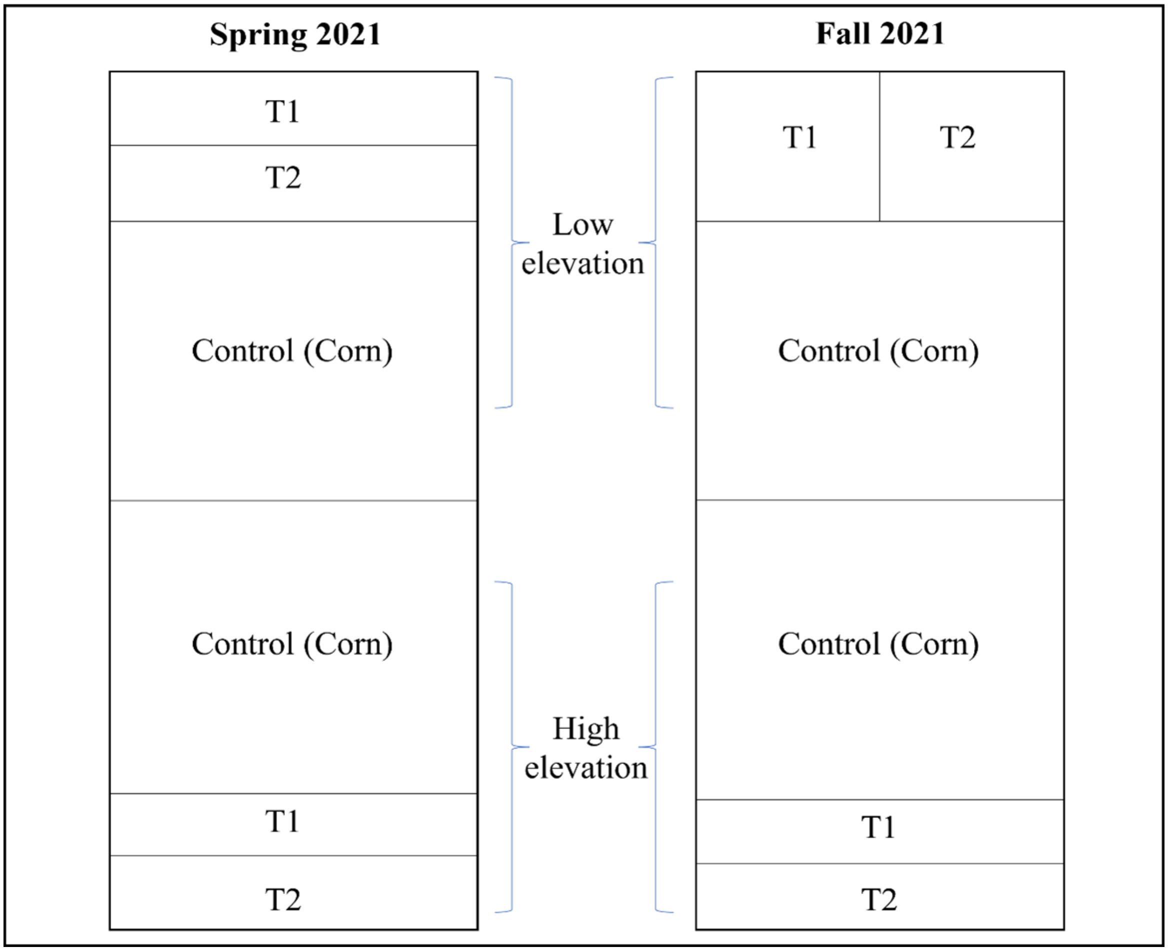

Figure 5.5. Treatment and control plots for buckwheat trial (high and low elevation) in 2021 spring and fall seasons T1: Buckwheat incorporated, T2: Buckwheat mulched (Same field for both seasons).

5.2.2.1 Bait trap method and scouting pattern

The procedure for bait trap method is similar to the previously described experiment (Section 5.1.2.1) except for the scouting pattern. Traps were installed 25 meters apart in a linear pattern to cover the most area based on the field width and length (Figure 5.6). Subsequent installation of the traps was one meter away from the previous visits.

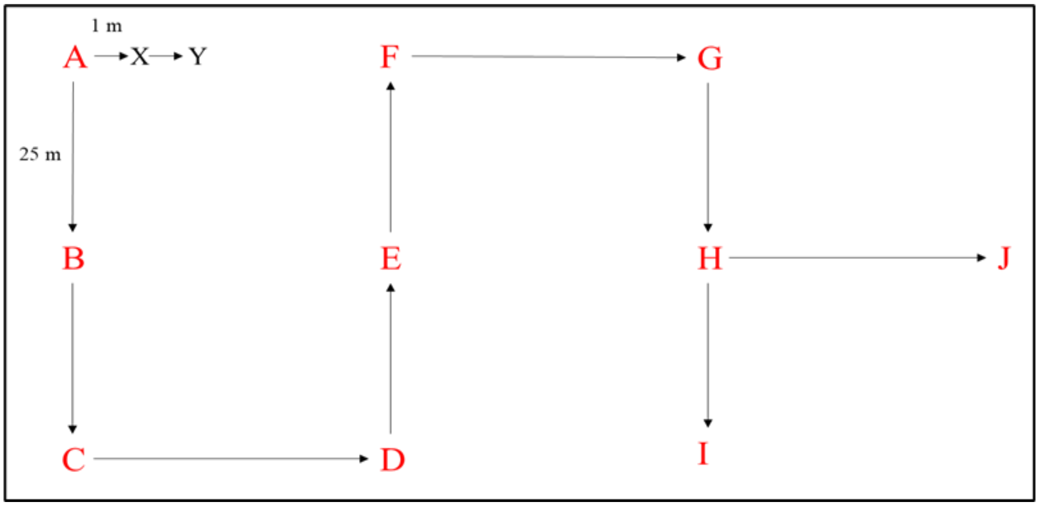

Figure 5.6. Schematic representation of linear scouting pattern, where A-J represents the traps, X and Y represent subsequent scouting schedule at a weekly interval.

5.2.3 Soil sampling

During the first installation of traps, soil samples were collected following a similar linear pattern as for scouting using a standard core sampler. Ten samples were collected in random locations for each plot and pooled together. Once it was well dried, samples were sent to AgroEnviroLab (Quebec, Canada) for analysis to determine the soil texture, soil organic matter, soil pH and soil nutrient composition. Soil sampling and analysis were carried out for both years (2020 and 2021). The sampling dates were May 27th and May 12th, for 2020 and 2021, respectively. Data collection procedures were similar to those previously described (Section 5.1.2.1).

5.2.4 Statistical analysis

The experimental design used for this trial is a Complete Randomized Design (CRD). In 2020, there were two treatments with ten replicates for each elevation; in 2021, there were three treatments with ten replicates for each elevation. The effect of soil texture and treatments was evaluated on the seedling pest populations (including wireworms, white grubs, Dipteran larvae or pupae). The data were analyzed using the Statistical Analysis Systems software (version 9.4; Quebec, Canada) using proc GLM and proc GLIMMIX procedure for one-way ANOVA with a 95% confidence interval. As previously described a generalized mixed model, with 2 different distributions (Poisson and Negative binomial) is used. Although, when using Negative binomial distribution, the data set did not converge properly. Therefore, the Poisson distribution was chosen for all the variables as the final model.

6 Results

6.1 Initial seedling pest population

In 2019, the total number of seedling pest individuals found in the 11 fields scouted was 83 (58 wireworms, 1 white grub and 24 Dipteran larvae or pupae). The risk level associated with the abundance of wireworms in the coastal area of Lac Saint-Pierre was low for all the fields sampled, with the number per trap ranging from 0 to 0.48 wireworms per trap. The abundance of white grubs and Dipteran larvae or pupae were very low and low, respectively although there is no economic intervention threshold limit for these species in Quebec (Table 6.1).

Table 6.1. Total abundance of wireworms, white grubs and Dipteran larvae or pupae in the 11 fields where seedling pest detection was carried out in 2019.

Field	**Culture 2019**	**Soil texture**	**Soil OM (%)**[a]	**Wireworms**			**White grubs (Total abundance per 40 traps)**	**Dipteran Larvae or pupae (Total abundance per 40 traps)**
				Total abundance per 40 traps	**Abundance (# per trap)**	**Risk Level**[b]		
DUPA01	Winter wheat	Sandy clay loam	4.3	1	0.03	Low	0	0
DUPA02	Winter wheat	Sandy clay loam	3.6	3	0.08	Low	0	1
DUPA05	Soybean	Sandy clay loam	3.9	1	0.03	Low	1	0
DUPA04	Soybean	Sandy clay loam	3.9	1	0.03	Low	0	6
DUPA03	Forages	Sandy clay loam	3.3	5	0.13	Low	0	0
BART05	Annual ryegrass	Silty clay loam	4.6	4	0.11	Low	0	2
BART06	Annual ryegrass	Silty clay loam	4.4	3	0.10	Low	0	1
BART07	Soybean	Silty clay loam	5.8	11	0.32	Low	0	0
BART08	Soybean	Silty clay loam	4.7	10	0.33	Low	0	7
BART10	Forages	Clay loam	6.7	0	0	Low	0	0
BAIE09	Forages	Clay loam	4.9	9	0.48	Low	0	7

[a]OM: Soil Organic Matter.
[b]Risk Level (RAP): Low (0 to 1.5 wireworm/trap), Moderate (1.6 to 2.9 wireworm/trap), High (>3 wireworm/trap) (CEROM, 2017).

The seedling pest species found in greater proportions on all the sites sampled were *Hypnoidus abbreviatus* > *Delia platura* > *Agriotes* sp. > *Dalopious* sp. > *Limonius* sp. and *Phyllophaga anxia* (white grub, only one individual for all sites) (Figure 6.1).

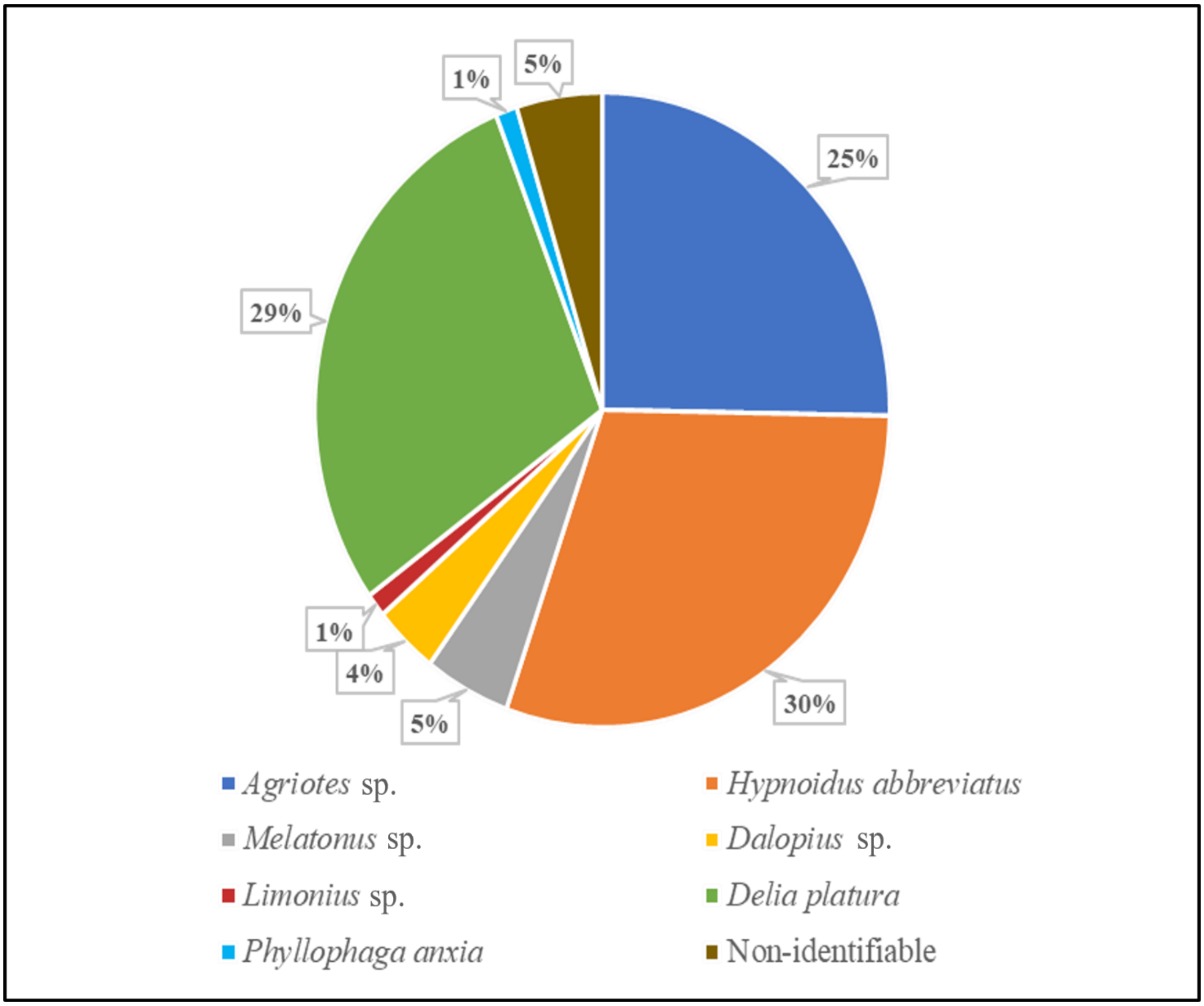

Figure 6.1. Proportion (%) of the different species of seedling pests found and identified by the Phytoprotection Diagnostic Laboratory of the Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec (MAPAQ) in the soils of the 11 fields sampled in the floodplains of Lac Saint-Pierre in 2019.

Table 6.2. List of seedling pests found in 2019 and their proportion based on region.

Seedling pest species (%)	**Region**		
	Saint-Barthélemy	**La Visitation-de-l'Île-Dupas**	**Baie-du-Febvre**
Hypnoidus abbreviatus	55	11	8
Delia platura	26	37	27
Agriotes sp.	16	16	46
Dalopius sp.	-	-	12
Limonius sp.	-	-	4
Phyllophaga anxia	-	5	-
Melanotus sp.	-	16	4
Non-Identifiable	3	16	-
Total number of individuals found in each region	38	19	26

There is some heterogeneity in species composition for each region (Table 6.2). *Hypnoidus abbreviatus*, a species less damaging to crops is found predominantly (55%) only in Saint-Barthélemy, while in Baie-du-Febvre and La Visitation-de-l'Île-Dupas, *Agriotes* sp. was found in greater proportions (46% and 16%). The proportion of the *Delia platura* pupae and larvae (seed corn maggot) varied from 26 - 37% for the regions sampled. Statistical analysis was not performed for the 2019 data set, as this was preliminary data and the treatments were applied only in spring 2019 following the scouting period.

6.2 Second year (2020) - Seedling pest population

In 2020, the total number of seedling pests found in the 21 fields scouted was 181 (including 90 wireworms. 86 Dipteran larvae or pupae and 5 white grubs). The risk level associated with the abundance of wireworms in the floodplains of Lac Saint-Pierre remained low for all sites sampled, with abundance varying between 0 and 0.55 wireworm per bait trap (Table 6.3). The abundance of white grub was very low and the abundance of Dipteran larvae or pupae was low, although there is no set economic intervention threshold limit for these species in Quebec (Table 6.3).

Table 6.3. Total abundance of wireworms, white grubs and Dipteran larvae or pupae in the 21 fields where seedling pest detection was carried out in 2020.

Field	**Culture in 2020**	**Soil texture**	**Soil OM (%)** [a]	**Wireworms**			**White grubs (Total abundance per 40 traps)**	**Dipteran larvae or pupa (Total abundance per 40 traps)**
				Total abundance per 40 traps	**Abundance (# per trap)**	**Risk Level** [b]		
BAIE01	Corn	Clay	7.2	1	0.03	Low	0	24
BAIE02	Corn	Clay	8	1	0.03	Low	0	2
BAIE03	Soybean	Clay	5.5	0	0	Low	0	0
BAIE04	Soybean	Clay	5	0	0	Low	0	0
BAIE07	Forages	Sandy clay	4.2	0	0	Low	0	0
BAIE09	Forages	Sandy clay loam	6.4	22	0.55	Low	0	0
BAIE10	Forages	Clay	4.8	1	0.03	Low	1	0
BART05	Corn	Clay loam	3.8	1	0.03	Low	0	0
BART06	Corn	Clay loam	3.6	3	0.08	Low	0	0
BART07	Corn	Clay	4.9	6	0.15	Low	0	0
BART08	Corn	Clay loam	4.3	3	0.08	Low	0	0
BART11	Forages	Clay loam	4.7	0	0	Low	0	0
DUPA01	Soybean	Clay loam	4.2	7	0.18	Low	0	1
DUPA02	Soybean	Loam	3.1	2	0.05	Low	0	19
DUPA04	Corn	Clay loam	3.7	11	0.28	Low	0	2
DUPA05	Corn	Clay loam	3.5	6	0.15	Low	3	0
DUPA03	Forages	Loam	3.6	2	0.05	Low	1	0
DUPA07	Forages	Clay loam	3.9	1	0.03	Low	0	4
PIER03	Corn	Sandy loam	2.2	15	0.38	Low	0	7
PIER04	Corn	Sandy loam	2.3	1	0.03	Low	0	3
PIER05	Corn	Sandy loam	1.6	7	0.18	Low	0	23

[a]OM: Soil Organic Matter
[b]Risk Level (RAP): Low (0 to 1.5 wireworm/trap), Moderate (1.6 to 2.9 wireworm/trap), High (>3 wireworm/trap) (CEROM, 2017).

Considering all the sites detected, the species of seedling pests found in greater proportions are (in order of importance): *Delia platura* > *Hypnoidus abbreviates* > *Agriotes* sp. > *Melatonus* sp. > *Dalopius* sp. > *Phyllophaga anxia* > *Limonius* sp. (1%), *Popillia japonia* (1%), non-identifiable (1%) and *Aeolus* sp (1%) (Figure 6.2). The pupae and larvae of the seed corn maggot (*Delia platura*) were found in a greater proportion in Baie-du-Febvre, La Visitation-de-l'Île-Dupas and Pierreville, representing between 44 and 59% of the insects detected (Table 6.4). In the region of Saint-Barthélemy, the majority species was the *Agriotes* sp., accounting for 79% of the insects detected.

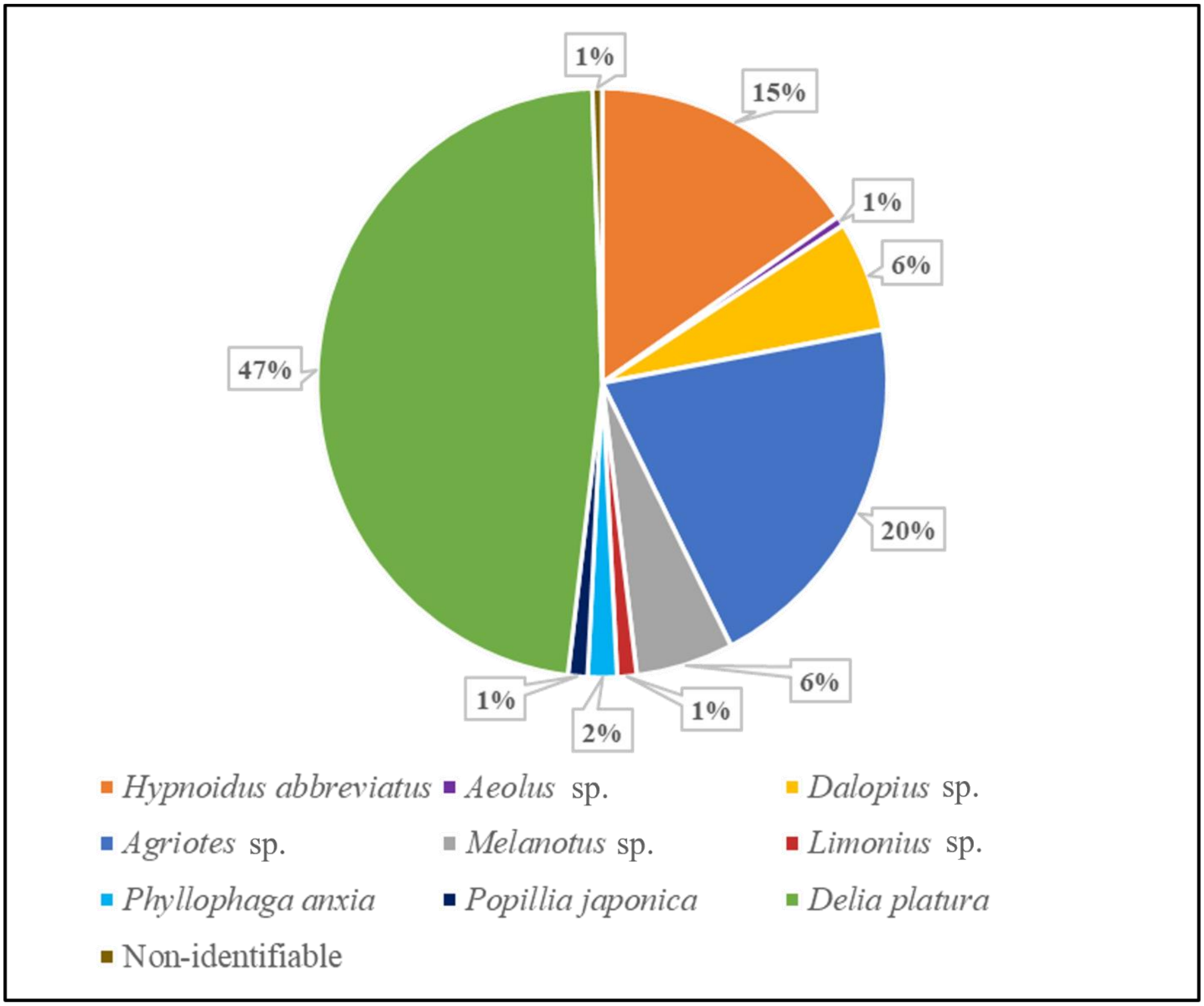

Figure 6.2. Proportion (%) of the different species of seedling pests found and identified by the Phytoprotection Diagnostic Laboratory of the Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec (MAPAQ) in the soils of the 21 fields sampled in the floodplains of Lac Saint-Pierre in 2020.

Table 6.4. List of seedling pests found in 2020 and their proportion based on region.

Seedling pest species (%)	**Region**			
	Saint-Barthélemy	**La Visitation-de-l'Île-Dupas**	**Baie-du-Febvre**	**Pierreville**
Hypnoidus abbreviatus	14	10	2	34
Delia platura	7	44	50	59
Agriotes sp.	79	32	13	-
Dalopius sp.	-	2	19	-
Limonius sp.	-	-	-	4
Phyllophaga anxia	-	5	-	-
Popillia japonica	-	2	2	-
Melanotus sp.	-	5	2	3
Aeolus sp.	-	-	10	-
Non-Identifiable	-	-	2	-
Total number of individuals found in each region	14	59	52	56

Statistical analysis

The wireworm population was significantly higher in the old forage fields compared to all treatments, except improved corn (Table 6.5). The population of wireworm in improved corn and soybean was not significantly different from conventional corn and soybean. In newly established forage fields, the wireworm population was significantly lower than in old forage fields (Table 6.5).

The Dipteran larvae or pupae population was significantly higher in the improved corn treatment when compared to the conventional corn (Table 6.5). In the improved soybean treatment, the population was numerically higher than in conventional soybean and there is significant difference between old and new forages.

Table 6.5. Least square means of wireworm and Dipteran larvae or pupae based on the treatments in 2020.

	Wireworm		**Dipteran larvae or pupae (seed corn maggot)**	
Treatments	**Mean number of individuals[a]**	**±Standard Error**	**Mean number of individuals[a]**	**±Standard Error**
	P = 0.0008		**P = 0.0054**	
Conventional Corn (n = 50)	0.30bc	0.34	0.10b	0.62
Conventional Soybean (n = 20)	0.35bc	0.51	0.05bc	1.21
Improved Corn (n = 60)	0.66ab	0.25	0.95a	0.42
Improved Soybean (n = 20)	0.10bc	0.79	0.95a	0.73
New Forages (n = 40)	0.05c	0.75	0.10b	0.70
Old Forages (n = 20)	1.20a	0.40	0.00c	0.00

[a] Means associated with same letter are not significantly different at p=0.05

Based on the soil texture, the wireworm population was significantly higher in sandy clay loam soil compared to all others. The Dipteran larvae or pupae populations (seed corn maggot) were not significantly different among soil texture (Table 6.6). However, sandy loam soil had higher number of seed corn maggot population (Table 6.6).

Table 6.6. Least square means of wireworm and Dipteran larvae or pupae - on different soil texture in 2020.

	Wireworms		**Dipteran larvae or pupae (seed corn maggot)**	
Soil texture	**Mean number of individuals[a]**	**±Standard Error**	**Mean number of individuals[a]**	**±Standard Error**
	P = 0.0008		**P = 0.0586**	
Clay (n = 60)	0.15bc	0.38	0.43	0.47
Clay loam (n = 80)	0.40bc	0.24	0.10	0.51
Loam (n = 20)	0.20bc	0.60	0.95	0.78
Sandy clay (n = 10)	0.00c	0.00	0.00	0.00
Sandy clay loam (n = 10)	2.20a	0.52	0.00	0.00
Sandy loam (n = 30)	0.76b	0.34	1.10	0.63

[a] Means associated with same letter are not significantly different at p=0.05

Based on the region, there is no significant difference in the wireworm populations observed in this study. However, the seed corn maggot population is significantly higher in the Pierreville area when compared with Saint-Barthélemy (Table 6.7).

Table 6.7. Least square means of wireworm and Dipteran larvae or pupae in different regions of the floodplains of Lac St-Pierre in 2020.

	Wireworms		**Dipteran larvae or pupae (seed corn maggot)**	
Region	**Mean number of individuals[a]**	**±Standard Error**	**Mean number of individuals[a]**	**±Standard Error**
	P = 0.2471		**P = 0.0258**	
Baie-du-Febvre (n = 70)	0.35	0.30	0.37ab	0.46
La Visitation-de-l'Île-Dupas (n = 60)	0.48	0.31	0.43ab	0.49
Pierreville (n = 30)	0.76	0.40	1.10a	0.67
Saint-Barthélemy (n = 50)	0.26	0.38	0.02b	1.11

[a] Means associated with same letter are not significantly different at p=0.05.

6.3 Third year (2021) – Seedling pest population

In 2021, the total number of seedling pests found in the 22 fields scouted was 152 (including 101 wireworms. 45 Dipteran larvae and 6 white grubs). The risk level associated with the abundance numbers varying between 0 and 0.73 wireworm per bait trap (Table 6.8). The abundance of white grubs was very low and the abundance of Dipteran larvae or pupae was low, although there is no set economic intervention threshold limit for this species in Quebec (Table 6.8).

Table 6.8. Total abundance of wireworms, white grubs and Dipteran larvae or pupae in the 22 fields where seedling pest detection was carried out in 2021.

Field	**Culture 2021**	**Soil texture**	**Soil OM (%)[a]**	**Wireworms**			**White grubs (Total abundance per 40 traps)**	**Dipteran larvae or pupae (Total abundance per 40 traps)**
				Total abundance per 40 traps	**Abundance (# per trap)**	**Risk level[b]**		
BAIE01	Soybean	Clay	8.2	1	0.03	Low	0	2
BAIE02	Soybean	Clay	8.7	2	0.05	Low	0	4
BAIE03	Corn	Clay	5.9	1	0.03	Low	0	1
BAIE04	Corn	Clay	8.5	0	0.00	Low	0	3
BAIE07	Forages	Sandy clay	8.6	2	0.05	Low	0	4
BAIE09	Forages	Sandy clay loam	5.7	8	0.20	Low	2	0
BAIE10	Forages	Clay	3.7	12	0.30	Low	0	0
BART05	Soybean	Clay loam	3.8	0	0.00	Low	1	0
BART06	Soybean	Clay loam	4.2	1	0.03	Low	0	0
BART07	Corn	Clay	4.3	0	0.00	Low	0	0
BART08	Corn	Clay loam	4.1	1	0.03	Low	1	0
BART09	Forages	Clay loam	6.4	0	0.00	Low	0	0
BART10	Forages	Clay loam	3.7	1	0.03	Low	0	0
BART11	Forages	Clay loam	4.3	0	0.00	Low	0	3
DUPA01	Corn	Clay loam	3.6	6	0.15	Low	0	2
DUPA02	Corn	Loam	3.3	0	0.00	Low	1	1
DUPA04	Soybean	Clay loam	3.3	1	0.03	Low	0	0
DUPA05	Soybean	Clay loam	4.4	0	0.00	Low	0	0
DUPA03	Forages	Loam	3.4	8	0.20	Low	1	0
PIER03	Soybean	Sandy loam	2.5	29	0.73	Low	0	14
PIER04	Soybean	Sandy loam	2.3	19	0.48	Low	0	2
PIER05	Corn	Sandy loam	2	9	0.23	Low	0	9

[a]OM: Soil Organic Matter
[b]Risk Level (RAP): Low (0 to 1.5 wireworm/trap), Moderate (1.6 to 2.9 wireworm/trap), High (>3 wireworm/trap) (CEROM, 2017).

Considering all the sites scouted, the species of seedling pests found in greater proportions were (in order of importance): *Delia platura* > *Melatonus* sp. > *Hypnoidus abbreviates* (12%), *Aeolus* sp. (12%) > non-identifiable > *Dalopius* sp. > *Agriotes* sp. (2%), *Phyllophaga anxia* (2%) and *Popillia japonia* (2%) (Figure 6.3). There is still some heterogeneity in species proportion for each region (Table 6.9). In the region of Baie-du-Febvre, *Melanotus* sp. and *Delia platura* were found in greater proportions, accounting for 24 and 33 %, respectively. In the region of La Visitation-de-l'Île-Dupas, *Melanotus* sp. and *Agriotes* sp. were found in greater proportions, accounting for 35 and 25 %, respectively. In the region of Pierreville, *Hypnoidus abbreviates* and *Delia platura* were found in greater proportions, accounting for 43 and 30 %, respectively. In Saint-Barthélemy, the major species were *Agriotes* sp. and *Delia platura*., accounting each for 37.5% of the insects detected (Table 6.9).

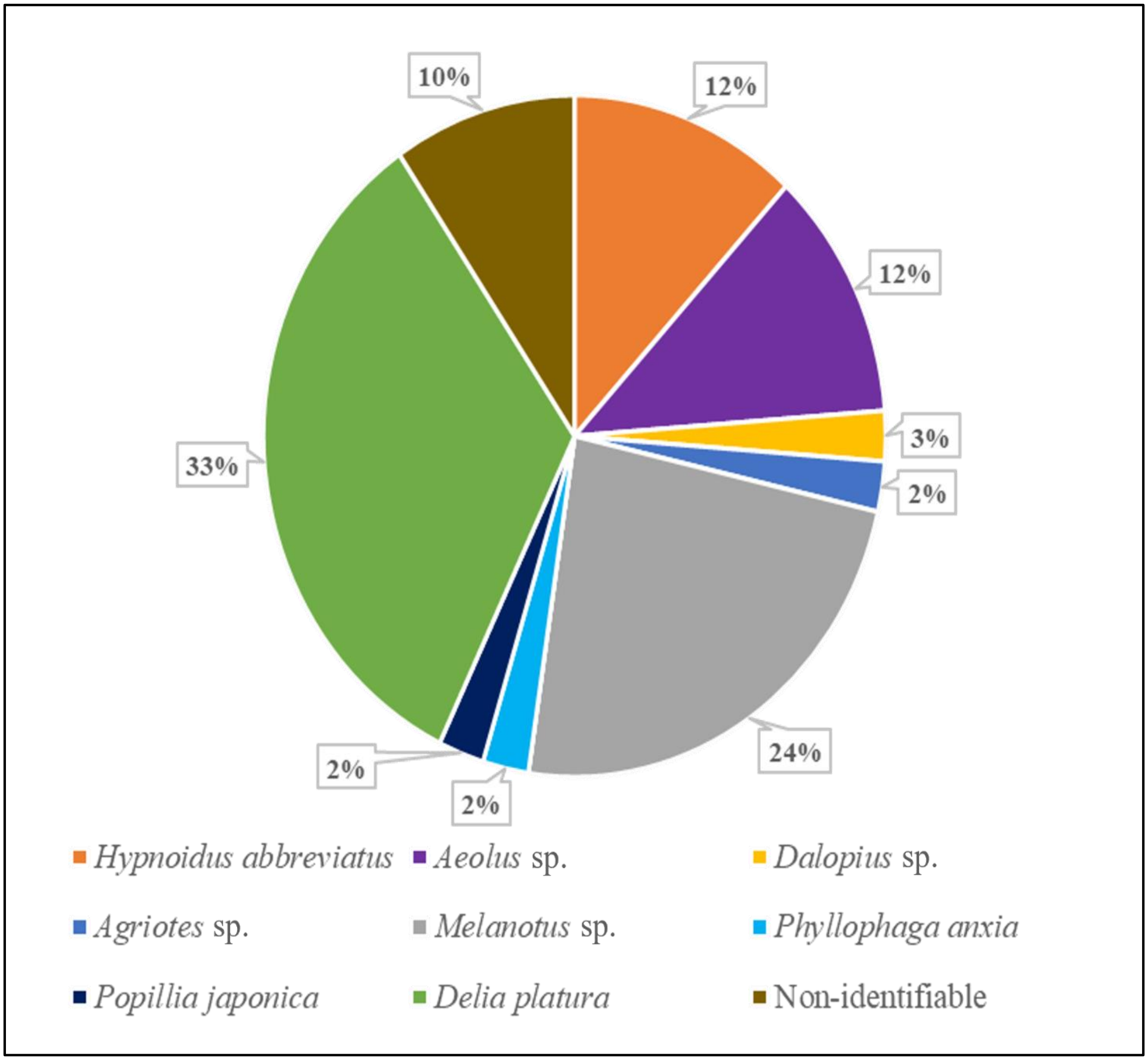

Figure 6.3. Proportion (%) of the different species of seedling pests found and identified by the Phytoprotection Diagnostic Laboratory of the Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec (MAPAQ) in the soils of the 22 fields sampled in the floodplains of Lac Saint-Pierre in 2021.

Table 6.9. List of seedling pests found in 2021 and their distribution based on region.

Seedling pest species (%)	**Region**			
	Saint-Barthélemy	**La Visitation-de-l'Île-Dupas**	**Baie-du-Febvre**	**Pierreville**
Hypnoidus abbreviatus	-	5	12	43
Delia platura	37.5	15	33	30
Agriotes sp.	37.5	25	3	-
Dalopius sp.	-	-	3	-
Limonius sp.	-	-	-	15
Phyllophaga anxia	25	5	3	-
Popillia japonica	-	5	-	-
Melanotus sp.	-	35	24	11
Hemicrepidius sp.	-	-	-	1
Aeolus sp.	-	5	12	-
Non-identifiable	-	5	10	-
Total number of individuals found in each region	8	20	42	82

Statistical analysis

Based on the treatments, there is no significant difference in wireworm and Dipteran larvae or pupae (*Delia platura*) populations (Table 6.10). However, the seedling pest populations were numerically higher in improved soybean when compared with other treatments.

Table 6.10. Least square means of wireworm and Dipteran larvae or pupae - based on the treatments in 2021.

	Wireworms		Dipteran larvae or pupae (seed corn maggot)	
Treatments	**Mean number of individuals[a]**	**±Standard Error**	**Mean number of individuals[a]**	**±Standard Error**
	P = 0.0957		**P = 0.4818**	
Conventional Corn (n = 30)	0.40a	0.37	0.30a	0.42
Conventional Soybean (n = 40)	0.52a	0.35	0.15a	0.51
Improved Corn (n = 40)	0.03a	1.05	0.13a	0.61
Improved Soybean (n = 40)	0.80a	0.33	0.40a	0.39
New Forages (n = 40)	0.37a	0.38	0.15a	0.51
Old Forages (n = 30)	0.53a	0.41	0.0a	0.0

[a] Means associated with same letter are not significantly different at p=0.05

Based on the soil texture, the wireworm population is significantly higher in sandy loam soil when compared with other soil textures (Table 6.11). The Dipteran larvae or pupae population were also significantly higher in sandy loam compared with the other soil textures, except for sandy clay (Table 6.11). The wireworm and Dipteran larvae population were significantly higher in Pierreville compared with the other regions (Table 6.12).

Table 6.11. Least square means of wireworm and Dipteran larvae or pupae - based on the soil texture in 2021.

	Wireworms		Dipteran larvae or pupae (seed corn maggot)	
Soil texture	**Mean number of individuals[a]**	**±Standard Error**	**Mean number of individuals[a]**	**±Standard Error**
	P < 0.0001		**P < 0.0001**	
Clay (n = 60)	0.26b	0.29	0.16b	0.35
Clay loam (n = 90)	0.11b	0.33	0.04b	0.51
Loam (n = 20)	0.40b	0.43	0.05b	1.04
Sandy clay (n = 10)	0.20b	0.79	0.40ab	0.63
Sandy clay loam (n = 10)	0.80b	0.50	0.00b	0.00
Sandy loam (n = 30)	1.90a	0.24	0.83a	0.30

[a] Means associated with same letter are not significantly different at p=0.05.

Table 6.12. Least square means of wireworms and Dipteran larvae or pupae - based on the region in 2021.

	Wireworms		**Dipteran larvae or pupae (seed corn maggot)**	
Region	**Mean number of individuals[a]**	**±Standard Error**	**Mean number of individuals[a]**	**±Standard Error**
	P < 0.0001		**P < 0.0001**	
Baie-du-Febvre (n = 70)	0.37b	0.23	0.20b	0.30
La Visitation-de-l'Île-Dupas (n = 50)	0.30b	0.30	0.06b	0.60
Pierreville (n = 30)	1.90a	0.24	0.83a	0.31
Saint-Barthélemy (n = 70)	0.04b	0.59	0.02b	0.72

[a] Means associated with the same letter are not significantly different at p=0.05.

6.4 Buckwheat trial

In Spring 2020, the risk level associated with the presence and abundance of seedling pests in the field was very low floodplain (Table 6.13). Only one wireworm (*Agriotes* sp.) and one Dipteran larvae or pupae (*Delia platura*) was found in the low elevation control plot. In 2021, the scouting in the spring showed that the risk level associated with the presence and abundance of the seedling pests in the field used for this trial was again very low. In total, three wireworms (*Aeolus* sp.) and one Dipteran larvae or pupae (*Delia platura*) was found (Table 6.13).

Fall season screening showed the level of risk associated with the presence and abundance of seedling pest population in the field used for this trial was very low. In high elevation treatment plots, two *Aeolus* sp., one *Hypnoidus abbreviatus* and six *Delia platura* was identified (Table 6.13).

Table 6.13. Total abundance of wireworms, white grubs and Dipteran larvae or pupae in the buckwheat trail where seedling pest detection was carried out in spring 2020, spring 2021 and fall 2021.

Field[c]	**Elevation**	**Culture**	**Soil OM (%)**[a]	**Wireworms**			**White grubs (Total abundance per 40 traps)**	**Dipteran larvae or pupae (Total abundance per 40 traps)**
				Total abundance per 40 traps	**Threshold (# per trap)**	**Risk level** [b]		
Spring 2020								
T	High	Buckwheat	10	0	0	Low	0	0
Control	High	Soybean	10	0	0	Low	0	0
T	Low	Buckwheat	5	0	0	Low	0	0
Control	Low	Soybean	5	1	0.03	Low	0	1
Spring 2021								
T2	High	Buckwheat	9.2	0	0	Low	0	0
T1	High	Buckwheat	8.6	1	0.03	Low	0	0
Control	High	Corn	8.8	0	0	Low	0	0
T2	Low	Buckwheat	3.2	1	0.03	Low	0	0
T1	Low	Buckwheat	5.2	1	0.03	Low	0	0
Control	Low	Corn	4.5	0	0	Low	0	1
Fall 2021								
T2	High	Buckwheat	9.2	2	0.06	Low	0	0
T1	High	Buckwheat	8.6	1	0.03	Low	0	6
Control	High	Corn	8.8	0	0	Low	0	0
T2	Low	Buckwheat	3.2	0	0	Low	0	0
T1	Low	Buckwheat	5.2	0	0	Low	0	0
Control	Low	Corn	4.5	0	0	Low	0	0

[a]OM: Soil Organic Matter

[b]Risk Level (RAP): Low (0 to 1.5 wireworm/trap), Moderate (1.6 to 2.9 wireworm/trap), High (>3 wireworm/trap) (CEROM, 2017).

[c]T: Initial buckwheat plots, T1: Buckwheat incorporated plots, T2: Buckwheat mulched plots and Control: Plots sown with corn or soybean.

Statistical analysis

Based on the treatments, there is no significant difference in wireworm and Dipteran larvae or pupae (*Delia platura*) populations in all three-sampling seasons (Table 6.14). However, in spring 2020 the seedling pest population is numerically higher in low elevation control plot when compared to other treatments (Table 6.14). In spring 2021, the wireworm population is numerically higher in high elevation incorporated buckwheat plots, low elevation incorporated and mulched buckwheat plots when compared to other treatments (Table 6.14). In spring 2021, the Dipteran larvae or pupae population is numerically higher low elevation control plots when compared to other treatments (Table 6.14). In fall 2021, the wireworm population is numerically higher in high elevation mulched buckwheat plot when compared to other treatments (Table 6.14). In fall 2021, the Dipteran larvae or pupae is numerically higher in high elevation incorporated buckwheat plots when compared to other treatments (Table 6.14).

Table 6.14. Least square means of wireworm and Dipteran larvae or pupae in buckwheat trial - based on the treatments in spring 2020, spring 2021 and fall 2021.

Year	**Treatment**[b]	**Wireworms**		**Dipteran larvae or pupae (seed corn maggot)**	
		Mean number of individuals[a]	**±Standard Error**	**Mean number of individuals**[a]	**±Standard Error**
Spring 2020		**P = 1.0000**		**P = 1.0000**	
	T-High Elevation	0.00a	0.00	0.00a	0.00
	Control-High elevation	0.00a	0.00	0.00a	0.00
	T-Low elevation	0.00a	0.00	0.00a	0.00
	Control-Low elevation	0.10a	0.10	0.10a	0.10
Spring 2021		**P = 1.0000**		**P = 1.0000**	
	T2-High elevation	0.00a	0.00	0.00a	0.00
	T1-High elevation	0.10a	0.10	0.00a	0.00
	Control-High elevation	0.00a	0.00	0.00a	0.00
	T2-Low elevation	0.10a	0.10	0.00a	0.00
	T1-Low elevation	0.10a	0.10	0.00a	0.00
	Control-Low elevation	0.00a	0.00	0.10a	0.10
Fall 2021		**P = 0.9971**		**P = 1.0000**	
	T2-High elevation	0.20a	0.14	0.00a	0.00
	T1-High elevation	0.10a	0.99	0.60a	0.24
	Control-High elevation	0.00a	0.00	0.00a	0.00
	T2-Low elevation	0.00a	0.00	0.00a	0.00
	T1-Low elevation	0.00a	0.00	0.00a	0.00
	Control-Low elevation	0.00a	0.00	0.00a	0.00

[a] Means associated with the same letter are not significantly different at p=0.05.
[b]T: Initial buckwheat plots, T1: Buckwheat incorporated plots, T2: Buckwheat mulched plots and Control: Plots sown with corn or soybean.

Based on the soil texture, there is no significant difference in wireworm and Dipteran larvae or pupae (*Delia platura*) populations in all three-sampling seasons (Table 6.15). However, in spring 2020 and spring 2021, the seedling pest population is numerically higher in sandy clay when compared to clay soil (Table 6.15). In fall 2021, the seedling pest population is numerically higher in clay when compared to sandy clay soil (Table 6.15).

Table 6.15. Least square means of wireworm and Dipteran larvae or pupae in buckwheat trial - based on the soil texture in spring 2020, spring 2021 and fall 2021.

Year	**Soil**	**Wireworms**		**Dipteran larvae or pupae (seed corn maggot)**	
		Mean number of individuals[a]	**±Standard Error**	**Mean number of individuals[a]**	**±Standard Error**
Spring 2020		**P = 0.3236**		**P = 0.3236**	
	Clay	0.00a	0.00	0.00a	0.00
	Sandy clay	0.05a	0.05	0.05a	0.05
Spring 2021		**P = 0.5614**		**P = 0.3215**	
	Clay	0.03a	0.03	0.00a	0.00
	Sandy clay	0.06a	0.04	0.03a	0.03
Fall 2021		**P = 0.0779**		**P = 0.1046**	
	Clay	0.10a	0.05	0.20a	0.12
	Sandy clay	0.00a	0.00	0.00a	0.00

[a] Means associated with the same letter are not significantly different at p=0.05.

7 Discussion

As we mentioned earlier this project is part of the Pole, whose primary goal is to develop crops and agricultural practices adapted to the littoral zone of the LSP and able to positively impact its ecological integrity. The major environmental concern in this region is directly related to pesticide use and potentially harmful effects on wildlife. Our study focused on the necessity of pesticide use by evaluating the seedling pest populations and their sustainable management practices.

In our study, seedling pest populations varied for each region and year (2019, 2020, 2021). In three years, we collected 249 wireworms, 155 Dipteran larvae or pupae and 12 white grubs. Overall, the abundance of seedling pests found in the LSP region was low; therefore, the use of insecticide-treated seeds should be reconsidered in the LSP floodplain. Each year the wireworm species proportion varied due to several factors such as soil texture, current crop, preceding crop, soil organic matter and geographical location. Studies suggest that wireworms are attracted to volatile compounds released by roots (Barsics et al., 2017; Doane et al., 1975). It implies how the current crop affects the abundance of wireworms. However, a large-scale study in 68 regions across the province of Quebec stated that current and preceding crops did not impact the wireworm population due to the regular crop rotation practices (Corn-Soybean and Corn-Soybean-Wheat) (Saguez et al., 2017).

Another predominant pest we found in our study was Dipteran larvae or pupae (Seed corn maggot: *Delia platura* (Meigan)). In total, we collected about 155 larvae and their abundance was higher in 2020 (86 larvae) when compared to 2019 (24 larvae) and 2021 (45 larvae). In each year, their population varied across the regions sampled. These variations could be due to cultural practices (tillage, early planting date and incorporation of cover crop or organic manure). Their population is significantly lower in the no-till soybean field and substantially increases when conventional tillage is used (Hammond, 1995, 1997). This was proven by our results showing that the maggot population was considerably lower in old forage fields than in other treatments. Also, this could explain that these maggots did not seem attracted to the established forages (Gill et al., 2013).

Another pest found in our study was white grubs (*Phyllopaga anxia* Leconte and *Popilla japonica* Newman). In three years, we found 12 white grubs; their population was highest in 2021 (6 grubs). In 2019 and 2020, we found 1 and 5 white grubs respectively. Most of the grubs were found in corn and old forage fields. It could be related to conventional agricultural practices (crop rotation, insecticide-treated seeds and tillage) used in those regions for several years, which might have reduced their population level (Saguez and Labrie, 2017). Similar to our results, white grubs were also very low in a study conducted in 2012-2015 across 68 regions in the province of Quebec, Canada (Saguez et al., 2017).

Based on the treatments applied to our field study in 2020, we found that the mean number of wireworms is higher in old forage fields and improved corn fields. It might be related to the fact that wireworms are attracted more to the grasses than soybean (Willis et al., 2010). However, their population is considerably lower in new forages, which leads us to focus on the preceding crop (Soybean) that may have affected the wireworm population. Further research is required to find the underlying factor which caused this difference. In 2021, there is no significant difference among treatments. However, the mean number of wireworms was numerically higher in the improved soybean fields, where the preceding crop was corn. A study suggests that corn provides more canopy for the female beetle to oviposit in the previous growing season, thus promoting increased abundance (Willis et al., 2010). This might have played a role in the present study.

In both years, improved corn and soybean treatment had cover crops such as ryegrass and autumn wheat respectively and that may have influenced the abundance of wireworms (Crotty et al., 2016; Milosavljevic et al., 2016; Saussure et al., 2015; Traugott et al., 2015; Willis et al., 2010). In Florida, Sorghum - Sudan grass was used as summer cover crop in potato fields and led to significant loss due to wireworms (Jansson and Lecrone, 1991). In another study, winter wheat as a cover crop increased the wireworm population (Furlan et al., 2021). However, annual rye grass showed significant reduction in wireworm population (Sarrantonio and Gallandt, 2003)

Several studies state that seed corn maggots prefer soybean over corn (Hesler, Allen, et al., 2018; Pope, 1998; Smith et al., 2020). However, in our study, we found that the seed corn maggot population was not significantly different between soybean and corn fields. In improved cultural practices plot the seed corn maggot population was significantly higher than conventional cultural practices plot. That made us to investigate the presence of cover crops may have influenced their population (Gerald E Brust et al., 1997; Furlan et al., 2017). Also, there might be a correlation between the perennial grass strips and the maggot population (Smith et al., 2020). Further research is required to analyze the correlation between cover crops and perennial strips on maggot populations.

We hypothesized that the seedling pest populations is above the economic threshold in sandy loam soil. However, in 2020 and 2021 the mean number of wireworms was comparatively higher in sandy clay loam (BAIE09) and sandy loam soils (PIER03, PIER04 and PIER05). The preferred soil texture is loamy sand with lower moisture content when compared with heavier soils (Jung et al., 2014; Poggi et al., 2018). Heavy deposition of sand is accumulated in the regions of LSP due the sediments deposited by the clay soils tend to hold more moisture and smaller pores, thus affecting the vertical movement of the larvae (Ensafi et al., 2018).

Also, soil pH influenced the damage caused by wireworms (Poggi et al., 2018). Higher pH resulted in lower levels of damage, implying that wireworms prefer acidic soils to feed on their host plants (Poggi et al., 2018). Nevertheless, their damages substantially decrease when the pH ranges from 5.4 to 6.4 (Jung et al., 2014). In our study the soil pH ranged from 5.3 to 6.9, which coincides with the findings of Jung et al. (2014).

Soil temperature and moisture can also influence the wireworm population level. The activity of wireworms is elevated when the temperature is between 11 - 13^{o}C at 15 cm depth with 31 % soil moisture (Jung et al., 2014; Lafrance, 1968). In this study soil temperature varied between 7 - 15^{o}C at the beginning of the sampling and at the end of sampling, it ranged between 24 - 29^{o}C. It is also stated that higher temperature and lower soil moisture can increase wireworm feeding habits (van Herk and Vernon, 2013). Also, when the temperature is less favorable, these pests can burrow deep into the soil (Villani and Wright, 1990).

The mortality of these larvae is significantly affected when there is excessive moisture for a more extended period (Hall and Cherry, 1993; Lane and Jones, 1936; van Herk and Vernon, 2006). In LSP, spring flooding occurred on an average of every two years and that might have affected the seedling pest population. Forcing the wireworms to emerge when the water is receded. Also, the flooding is not consistent in this region, which may have influenced the number seedling pests captured each year.

In both years Pierreville region had a higher number of maggots population than any other region, which might be correlated to the soil texture (sandy loam) in that region. This soil texture strongly influences the seedling pests lateral and vertical movement (Hutchins, 2020). Soil temperature may also impact their population level. These maggots' activity is significantly increased when the temperature is cold and moist (Hammond, 1995, 1997; Hammond and Cooper, 1993). Soil temperature from our study ranged from 7^{o}C - 25^{o}C for both years (2020 and 2021). In the beginning of scouting period our soil temperature ranged between 7^{o}C - 15^{o}C, which may have increased the maggot population and our results coincides with the study conducted in Indiana shows that maggot population is increased in muskmelon (*Cucumis melo* var. Superstar) fields when the temperature is below 18^{o}C (G. E. Brust et al., 1997).

Preliminary data from 2019 and the data set from 2020 showed that *H. abbreviatus* was found in all regions sampled. However, in 2021 *H. abbreviatus* was only present in La Visitation-de-l'Île-Dupas, Baie-du-Febvre and Pierreville. We also found *Agriotes* sp. in all regions sampled in 2019, but in 2020 and 2021 it was only found in Saint- Barthélemy, La Visitation-de-l'Île-Dupas, and Baie-du-Febvre. In 2020, the Pierreville region had a numerically higher numbers of wireworm population than other regions, although no significant difference was found when compared to other regions. In the following year (2021) wireworm population doubled in Pierreville and we noticed a significant difference among the regions. The predominant species found in this region was *H. abbreviatus*, which correlated with another large-scale study conducted in Centre-du-Québec in 2017 (Saguez et al., 2017). Reason for the elevated population level in 2021 may be due to fact that these larvae have a one-year development cycle and female beetles tend to lay their eggs in the same fields due to poor flight patterns (Labrie et al., 2020).

Buckwheat trial

We hypothesized that incorporated and mulched buckwheat will harm the seedling pest populations. However, our results did not show any impact due to the minimal abundance of seedling pests in the field. We found seven wireworms and eight Dipteran larvae or pupae across three sampling seasons (spring 2020, spring 2021 and fall 2021). Percentage of clay was considerably high in our field, as discussed previously, in clay soils relatively low level of seedling pest population was observed when compared with other soil texture types (Jung et al., 2014; Poggi et al., 2018).

We also believe that the insecticide's residual effect has impacted the population level. The concentration of neonicotinoids is increased in the soil after repeated application over the years (Goulson, 2013). These concentrations can be found in the soil after six years of insecticide use (Schaafsma et al., 2015; Xu et al., 2016). In another study, it has also been observed that pesticides can be detected in the soil several years later (Hladik et al., 2017). In depth soil analysis could be done on the field to know the exact concentration of neonicotinoids and it might help us to formulate a mitigation strategy.

It is also possible that the toxin (glucosinolates) produced from the roots of buckwheat prevents the seedling pest population from growing by affecting their feeding habit. (Abbasi et al., 2019; Ruiz et al., 2019). Also, it has been reported that glucosinolates produced in crucifers and brown mustard deterred wireworms and or their feeding activity (Bohorquez Ruiz et al., 2019; MacKenzie et al., 2010). There is specific relation between the toxin and wireworms, so feeding assay could be done to find the underlying factor.

8 General Conclusion

In conclusion, seedling pest abundance is relatively low across the three years of sampling in the LSP region. *Hypnoidus abbreviatus* Say and *Agriotes* sp. were predominant wireworms in this region, although they did not exceed the set economic threshold. Seed corn maggot was sporadic in these regions and no significant damage was recorded. The white grub population was very low; hence the intervention was unnecessary. We discussed several factors associated with the seedling pest populations and found that region and soil texture played a significant role. Future research can be focused on those factors, which will help us to develop an effective management strategy. We should also investigate the residual effect of prior neonicotinoid use in these regions, which will help us to minimize pesticide use and might also help remove the toxicity from the soil. Since the overall seedling pest population is very low and there was no economic loss by seedling pests recorded in this region throughout this project, use of chemical seed treatment could be minimized to promote a sustainable ecosystem around the LSP floodplain.

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Appendix 1

Table A.1. List of scouted fields and their latitude and longitude coordinates in the four areas of the Lac Saint-Pierre region in, 2019, 2020, and 2021.

Sites	**Latitude**	**Longitude**
Baie-du-Febvre (BAIE)		
BAIE01	46.145234	-72.712158
BAIE02	46.145345	-72.711268
BAIE03	46.148459	-72.705599
BAIE04	46.148787	-72.7049
BAIE07	46.152047	-72.699698
BAIE09	46.1853605	-72.658651
BAIE10	46.167536	-72.694959
Saint-Barthélemy (BART)		
BART05	46.1533694	-73.06861
BART06	46.1537879	-73.0684436
BART07	46.1548112	-73.068888
BART08	46.1537357	-73.0667495
BART09	46.167006	-73.0456280
BART10	46.165772	-73.0420591
BART11	46.16746	-73.039166
La Visitation-de-l'Île-Dupas (DUPA)		
DUPA01	46.1150967	-73.1116535
DUPA02	46.1182473	-73.1149493
DUPA04	46.1188462	-73.107046
DUPA05	46.1191395	-73.1061877
DUPA03	46.1189333	-73.1150475
DUPA07	46.107031	-73.087761
Pierreville (PIER)		
PIER03	46.114393	-72.879095
PIER04	46.11294	-72.875956
PIER05	46.112085	-72.875119

Table A.2. Fertilization schedule and amount of nitrogen, phosphorus and potassium applied for field crops in LSP region 2021.

Site	**Crop**	**Nitrogen**		**P_2O_5 (Kg P_2O_5/ha)**	**K_2O (Kg K_2O /ha)**
		Period of application	**(Kg N / ha)**		
BAIE01 BAIE02	Soybean	At sowing	30	37	30
BAIE03 BAIE04	Corn	At sowing	45	65	15
		6-7 leaf stage	130	0	0
BAIE07	Feed oats and Reed canary grass	1 cut, no fertilization			
BAIE09	Old forage	2 cuts, no fertilization			
BAIE10	Reed canary grass	After 1st cut	50	0	0
		After 2nd cut	50	0	0
PIER03	Soybean	At sowing	30	20	30
PIER04 PIER05	Corn	At sowing	50	47	62
		6-7 leaf stage	190		
BART05 BART06	Soybean	No fertilization			
BART07 BART08	orn	Before sowing	127	0	17
		At sowing	48	58	9
BART09	Old forage	After 1st cut	0	0	0
		After 2nd cut	0	0	0
BART10	Feed oats and Reed canary grass	1 cut, Before sowing	50	0	0
BART11	Reed canary grass	After 1st cut	50	0	0
		After 2nd cut	50	0	0
DUPA01	Corn	At sowing	50	70	66
DUPA02	Corn	Before sowing	103	0	0
		At sowing	47	18	18
DUPA03	Old forage	1 Cut	0	0	0
DUPA04 DUPA05	Soybean	No fertilization			
DUPA07	Feed oats and Reed canary grass	Before sowing	50	0	0

Table A.3. Soil pH, available nutrients in soil, estimated density and estimated porosity of all sites sample in LSP.

Site	Soil pH	P (kg/ha)	K (kg/ha)	Ca (kg/ha)	Mg (kg/ha)	Al (ppm)	Estimated density (g/cm^3)	Estimated porosity (%)
BAIE01	6.3	109	712	5760	1376	1005	0.8	68.2
BAIE02	6.2	70	478	6092	1367	992	0.82	67.4
BAIE03	6.2	101	370	4727	1076	895	0.9	64.7
BAIE04	6.8	128	370	5318	1368	807	0.93	63.8
BAIE07	6.9	69	273	4697	1110	764	0.98	62.1
BAIE09	6.3	36	282	3583	826	724	0.9	64.5
BAIE10	6.8	43	317	5528	1409	810	0.93	63.9
BART05	5.7	47	188	3227	645	979	0.86	66.7
BART06	5.7	44	177	2979	755	862	0.9	65.3
BART07	5.3	79	189	3676	806	1085	0.85	67.1
BART08	5.5	88	166	3673	737	927	0.89	65.5
BART09	5.9	37	140	2543	706	956	0.7	57.3
BART10	5.7	56	129	3115	691	808	0.93	52
BART11	5.8	26	143	2912	939	933	0.83	67.8
DUPA01	6	52	150	4875	550	827	0.87	66.1
DUPA02	6.4	225	223	4293	474	681	0.96	63.2
DUPA04	5.5	77	164	4021	589	928	0.92	64.6
DUPA05	5.6	69	152	3383	479	919	0.91	64.9
DUPA03	5.7	17	91	2959	549	694	0.95	63.2
DUPA07	6.3	14	82	4269	581	890	0.91	64.9
PIER03	5.3	64	149	1168	84	529	1.07	58.9
PIER04	5.9	88	210	1850	136	739	1.02	60.9
PIER05	6.4	93	108	1620	122	430	1.17	55.4