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Blueberry/Forest production model layout and experimentation

Final Report
August 2006 to November 2009

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August 2006 to November 2009

Conducted by

Agrinova

Submitted to

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1. INTRODUCTION

In Saguenay–Lac-Saint-Jean, the dynamics inherent to natural resource regions highlight two inevitable forces of nature: the forest and the blueberry. Based on 1997-98 data, regional forestry represented 8 % of total potential in the province of Québec, while blueberry production areas made up nearly 70 % of provincial totals.

From 1987 to 2000, the total area developed for blueberry farming grew from 8,956 ha to 17,838 ha in Saguenay–Lac-Saint-Jean, an increase of more than 7,500 ha. Blueberry production is a first-rate industrial segment for the region, making it vital to make every effort to foster the growth and development of this agroforestal industry. To this end, the Québec Blueberry Producers' Union (*Syndicat des producteurs de bleuets du Québec*, SPBQ) wants to develop greenfield blueberry production on public land. In a report to the minister, the interdepartmental committee on the contribution of State land to blueberry industry development (MRNF–MAPAQ) stated that approximately 8,500 ha of State land should be slated for the development of new blueberry fields within the next few years (MRNF-MAPAQ Committee, 2002). This would open up the potential for 50 new lowbush blueberry agricultural projects, in compliance with existing forestry rights.

With a view to developing new lowbush blueberry fields while maintaining forestry potential, the forest/blueberry alternating-strip production model was singled out. With sustainable development in mind, the Québec Ministry of natural resources and wildlife stands behind this integrated resource management principle.

However, the forest/blueberry production model needed to be experimentally validated since no scientific data was available at the time. Several parameters had to be analyzed before the best model could be prescribed, particularly as concerns the width and alignment of blueberry and forest strips. This forest/blueberry experimental and implementation project ran from May 2006 to November 2009. It was designed to assess a number of blueberry/forest-type land development setups to determine which offered the best production performance for the two resources on one and the same territory. Publication of the results will provide future land users with the information they need to develop a viable, validated, and optimum production models.

The project was conducted on *Corporation d'aménagement forêt Normandin* (CAFN) lands, located north of Lake Saint-Jean. CAFN has been planning and conducting land development on a 450 ha portion of the *Forêt Normandin* territory. Land was leased to the group for the purposes of the forest/blueberry production research project. In total, 166 ha were reserved for the experimental setup.

2. OBJECTIVES

2.1 Principal objective

The forest/blueberry production model was designed to maximize yield for both resources (forest and blueberries) on the same plot of land, while maintaining forest potential and respecting the rights consented by Timber Supply and Forest Management Agreements (TSFMA).

The goal of the project was therefore to validate and optimize the forest/blueberry alternating-strip production model, and thus provide potential users with essential data for knowledge development and transfer.

2.2 Specific objectives

The project specifically aimed to :

- Measure the impact of various land management setups (strip width and alignment) on agroclimatic conditions within the blueberry strips;
- Determine the impact of land management models on blueberry yield;
- Understand how pesticides evolve in the environment following use for blueberry production in a forest/blueberry context;
- Analyze the effects of the various land management setups on indigenous pollinator populations;
- Compare two forestry/logging residue management modes in relation to blueberry strips.

3. METHODOLOGY

This section describes the research focus areas, experimental setups, and project and data gathering schedules.

3.1 Research focus areas and experimental setups

3.1.1 Research focus areas

The project was divided into four focus areas, three of which were the responsibility of Agrinova and are described below. Focus area 2 dealt with agricultural optimization, focus area 3, with pesticide evolution following use in forest/blueberry production, and focus area 4, with production environment optimization. Focus area 2 comprised two constituents, one concerning variations in agroclimatic conditions (2A), and the other looked at the effects of the forest/blueberry production model on blueberry yield (2B). Focus area 3 dealt with the environmental impacts, with reference to a study of the evolution of hexazinone in ground and surface water. Focus area 4 also had two constituents. The first concerned the effects of different types of forest/blueberry setups on pollinator populations (4A), and the second, the effects of forest residue management on the formation and yield of blueberry stems (4B).

3.1.2 Experimental design

The experimental design was based on a number of strip width and alignment combinations making up the different types of setups within the forest/blueberry production model. The experimental setups were established as follows :

Blueberry strip alignments

- 10° north (O1)
- 45° north (O2)

The preferred alignment was north/south to position the strips were perpendicular to the prevailing westerly winds and with the slope of the land. However, land slope has to be considered in terms of cold airflow. The setup of air corridors is based on generally recognized principles from research conducted at the University of Québec at Chicoutimi (UQAC). The optimum setup is based on very accurate profiling of the land (soil type, plants, topography, obstacles, etc.). Therefore, a second alignment scheme was adopted, northeast/southwest, in cases where the slope was oriented in that direction, or east to west.

Strip widths (forest/blueberry respectively)

- 42 m/45 m (L_1): This model brings the forest occupation ratio to 48 %. It allows for increasing the forest potential and to possibly maintain the blueberry yield by increasing the proximity effects, i.e. radiation effect.
- 42 m/60 m (L_2): This ratio represents the basic model based on the minimum forest width and maximum blueberry field width, according to government experts.
- 60 m/45 m (L_3): This ratio features the combined effect of increased forest width and decreased blueberry field width on the overall yield, compared to the basic model. This model brings the forest occupation ratio to 57 %.
- 60 m/60 m (L_4): By comparing with the basic model, this ratio is designed to determine if increased forest width can increase the overall forest yield without decreasing blueberry production. This model brings the forest occupation ratio to 50 %.

The following combinations of strip alignments and widths were compared: O_1L_1, O_1L_2, O_1L_3, O_1L_4, O_2L_1, O_2L_2, O_2L_3, O_2L_4. Every setup is a unique process. To ensure accurate territorial representativeness, each setup combination was repeated three times, for a total of 24 experimental units (two alignments x four widths x three repetitions).

Experimental units and sampling

Four setups were tested within each experimental unit to determine the radiation effect generated by forest strips. Gradients were set to make sure representativeness was as accurate as possible within corresponding strips. To this end, transects were placed halfway between the upper and lower sections of the blueberry strips. Four sampling locations were selected, one at

the edge of the forest strip, then one sixth, one third, and halfway into the blueberry strips. The experimental method was based on a factorial analysis. Hence, there were two alignments x four widths x three repetitions per treatment x four gradients = 96 samples.

For a blueberry strip to be suitable for measurements, the strip had to be enclosed within two forest strips (Figure 1). Each experimental unit was made up of three strips, one blueberry strip between two forest strips. However, a blueberry strip had to be added on either side of the forest strips (strips 1 and 5), so that the forest strip widths 2 and 4 could be maintained (42 m and 60 m), and be wide enough to insulate the experimental unit. This setup enabled valid measurements on the central blueberry strip only (strip 3). However, depending on the overlap between the forest/blueberry strips, adding one forest strip (6) and one blueberry strip (7) was made possible, in compliance with experimental unit requirements, so that two blueberry strips could be sampled on the same setup type.

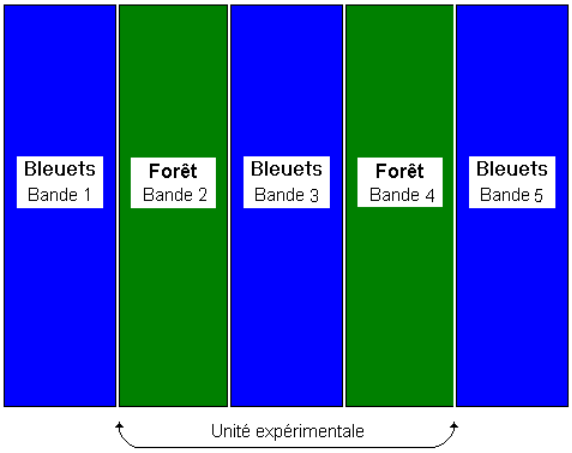


Figure 1. Illustration of an experimental unit

Figures 2 and 3 show the *Corporation d'aménagement forêt Normandin* (CAFN) territory with the land areas under study and corresponding experimental setups.

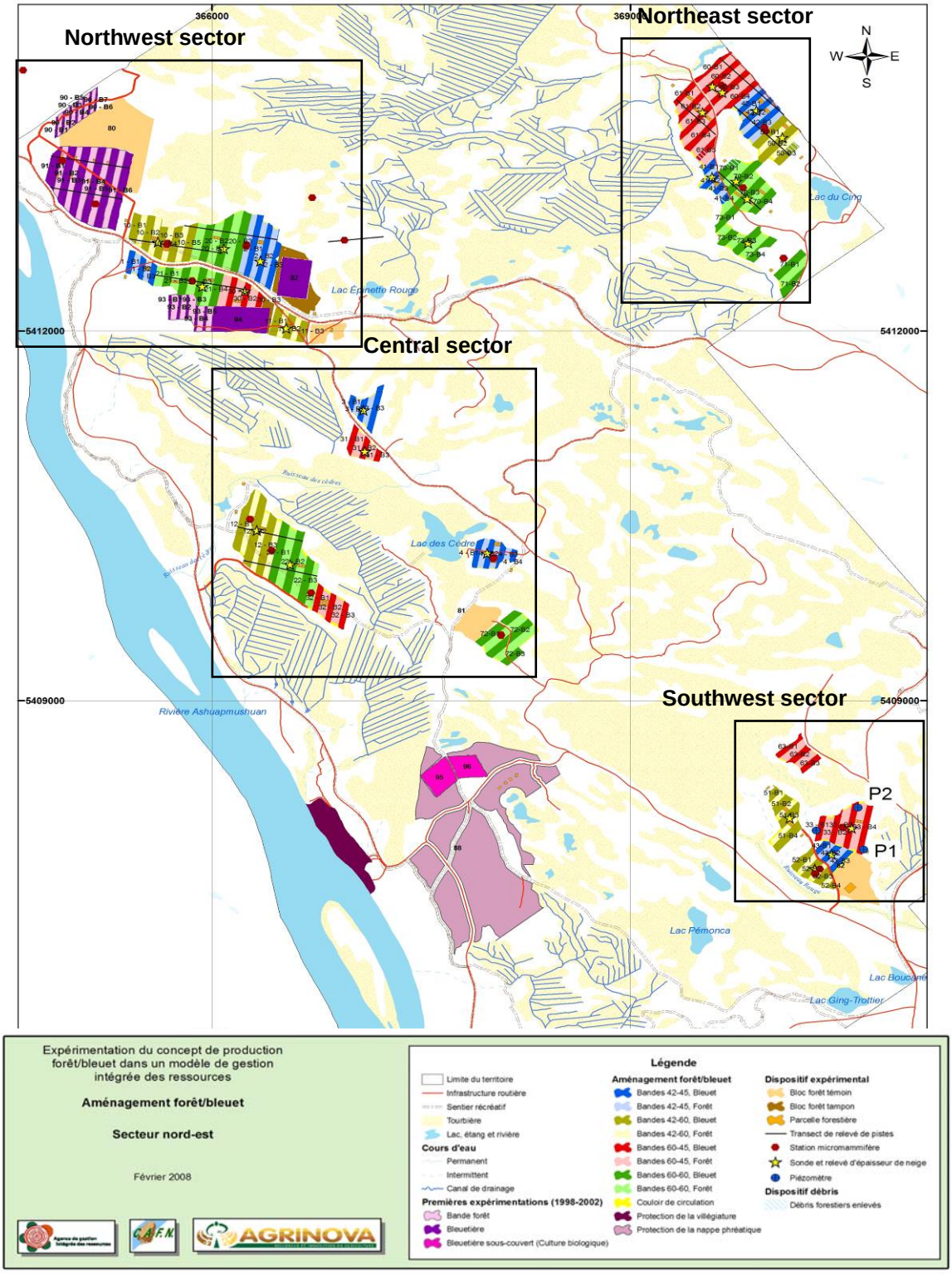
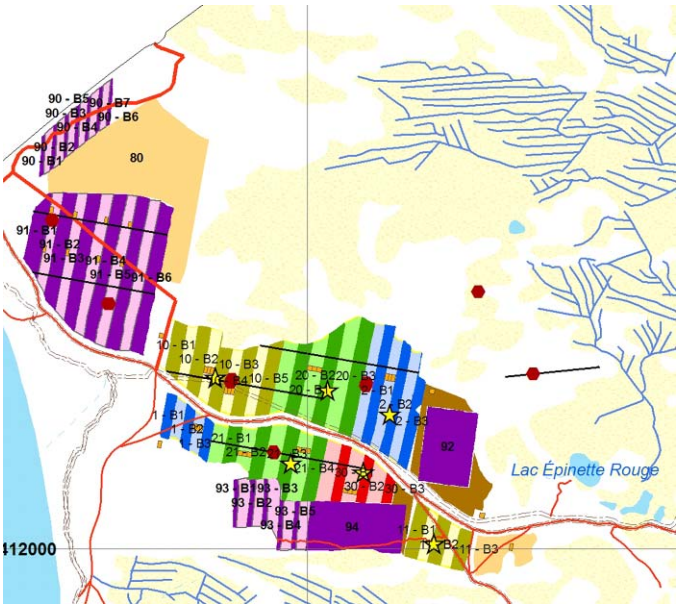
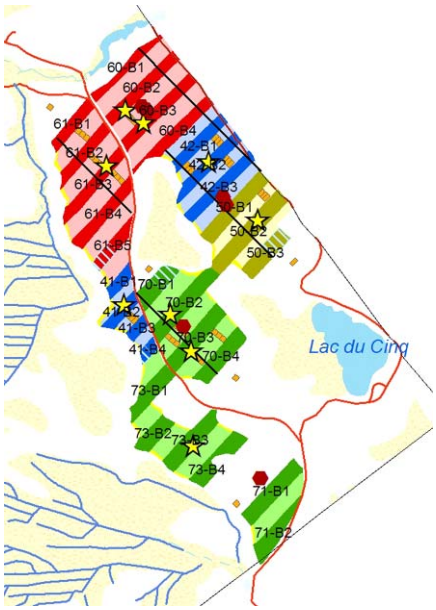


Figure 2. Map of CAFN territory

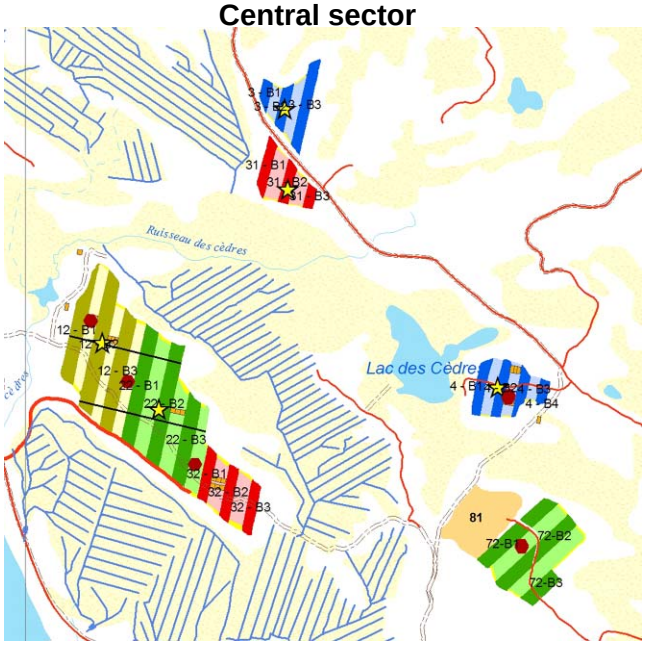
Northwest sector



Northeast sector



Central sector



Southwest sector

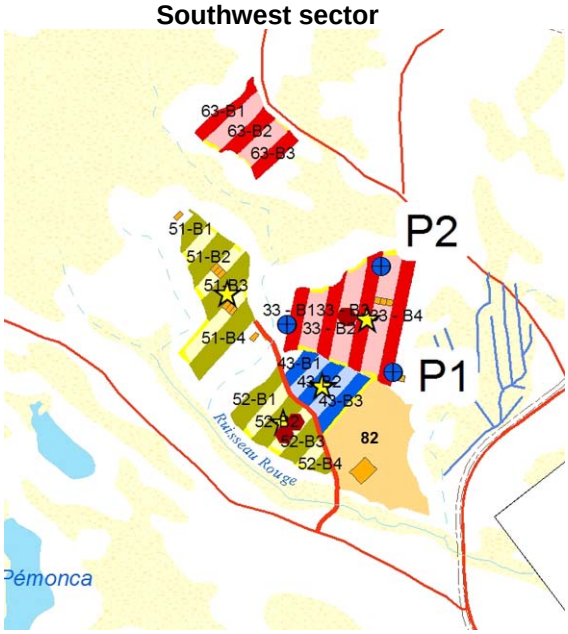


Figure 3. Sectors under study

3.1.3 Conventional blueberry control field

In order to compare the forest/blueberry model data to those of conventional blueberry production, blueberry farms neighbouring the CAFN territory were used as control units; they are the Bleuetière coopérative de Saint-Thomas-Didyme (for 2006-07) and Bleuetière coopérative de Normandin (for 2008-09). The Bleuetière coopérative de Normandin control field was set up in 2006 and the second crushing was made in the spring of 2007. The site produced in 2008 and was cut in the spring of 2009. In 2009 the plants were dormant. The control blueberry fields were considered non-conform to the experimental parameters because they did not have the strip alignment and width combinations found in the setup. Non-statistical comparison will therefore be performed to verify the effect of the forest/blueberry setup on the different variables of the study.

3.1.4 Setup and production stage monitoring

All forest and blueberry strips were established by 2007. In 2008, blueberry strips 2 to 33, set up in the fall of 2005, were in their first year of production. Leafcutting bees (Megachilidae) were introduced into these strips during the blueberry flowering period to enhance pollination. The strips were cut in the fall of 2008 and returned to dormant state in 2009. The other half of the blueberry strips, established in the fall of 2006 (strips 41 to 73), or 50 % of all strips, were in their second dormant year in 2008, and produced berries in 2009.

3.2 Focus areas of the study

Again, here are the focus areas studied by Agrinova :

Focus area 2A : *Variation of agroclimatic conditions in the forest/blueberry design*

The objective of this focus area was to determine which strip alignment and width combinations would yield the best agroclimatic conditions for the development of a productive blueberry field. The climate conditions measured were temperatures within the blueberry strips, blueberry bush drying index, and snow cover thickness.

Focus area 2B : *Effects of the different forest/blueberry setups on blueberry yield*

The objective of this focus area was to determine which strip alignment and width combinations would provide the best blueberry yield. The biological variables measured were stem formation (dormant and productive years), bud production (dormant and productive years), and blueberry yield (productive year).

Focus area 3B : *Monitoring pesticide use for forest/blueberry farm design implementation*

The objective of this focus area was to assess the pesticide content in the water table and draw a realistic picture of the evolution of hexazinone in ground and surface water. Hexazinone concentration in ground and surface water was the environmental variable considered.

Focus area 4A : *Effects of the different forest/blueberry model setups on pollinator populations*

The objective of this focus area was to analyze the effects of the different forest/blueberry setups on indigenous pollinator populations, according to the various strip alignments and widths. The biological variables were indigenous pollinator numbers and diversity.

Focus area 4B : *Effects of forest residue management on the growth and productivity of blueberry bushes, alternate-strip forest/blueberry design*

The objective of this focus area was to compare two forestry/logging waste management modes during the blueberry strip setup process, either removing the residue from the plot or leave the shredded residue on the ground. It was decided to use the most common practice and leave the residue on the CAFN plots. The variables measured were residue cover thickness (2008), the number of blueberry stems per transect (dormant year), and blueberry yield (productive year).

4. RESULTS AND ANALYSES

This section describes the final results of the project, and summarizes the results presented in the 2007 and 2008 progress reports. The results of this research project conducted on CAFN lands are applicable to the Normandin site, but cannot be generalized for the entire Saguenay−Lac-Saint-Jean region or other Québec regions.

4.1. Research focus area 2 : Agricultural optimization

4.1.1. Variation of agroclimatic conditions in the forest/blueberry design (2A)

Statistical processing of the data collected from 2006 to 2009, relative to average monthly temperatures, monthly minimum and maximum temperatures, cumulative degree-days by month, number of periods per month with temperatures below 0° C, -2° C, and -5° C, and number of periods per month with temperatures between 10° C and 30° C, led to a number of findings, as described below. The blueberry bush drying index and snow cover thickness analyses are also discussed in this section.

a) Temperatures within the blueberry strips

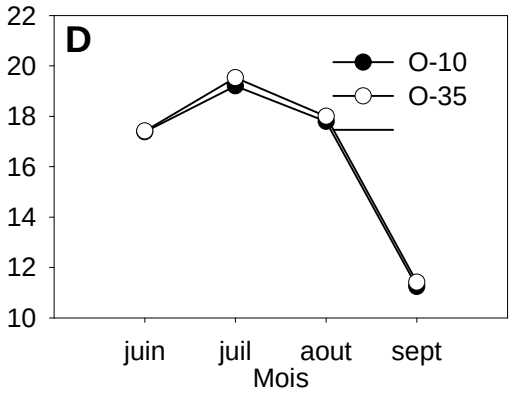
Comparisons were made between strip alignments, strip widths, and blueberry strip gradients according to monthly data (June to October). The experimental method is a split-plot-type design (three factors) with repeated measures. Indeed, the principal plots were formed from the combination of strip alignments (2) x forest strip widths (2) x blueberry strip widths (2). The gradients (four temperature sensors) were considered as nested in sub-plots and the month factor as nested in “sub-sub-plots” repeated measures. The experimental units (EU) were repeated three times for a total of 96 EU.

Again, the data gathered for the years 2006 and 2009 only corresponded to half the experimental units, while those of 2007 and 2008 represented all 96 experimental units. The data for 2006 and 2009 did not allow for comparing strip alignments. Indeed, in 2006 only the strips with 10° alignment were compared, and in 2009, only the 45° strips were compared.

Variance analyses (ANOVA) of average, minimum and maximum temperatures, and cumulative degree-days by month within the blueberry strips for 2006, 2007, 2008, and 2009 are presented in four tables in Appendix 1.

As concerns the **average temperature** variable, the results show that :

- In 2006 and 2007, there were no significant differences between the four strip widths as far as average temperatures are concerned, while differences were noted for 2008 and 2009, but only for some of the blueberry strip gradients.
- In 2008, the average temperatures of 45° strips were higher than those of 10° strips. This tendency was particularly notable in July (see Figure 15). On the other hand, in 2007, there were no significant differences between the two alignments.
- In 2008, the average monthly temperatures in the 10° forest/blueberry plots were generally lower than those of the conventional blueberry control field, particularly in September (see Figure 16), while in 2006 and 2007; the average forest/blueberry plot temperatures were undistinguishable from those of the control field.



Note : The 0-35 symbol corresponds to the 45° north alignment

Figure 4. Effect of strip alignment on 2008 average temperatures

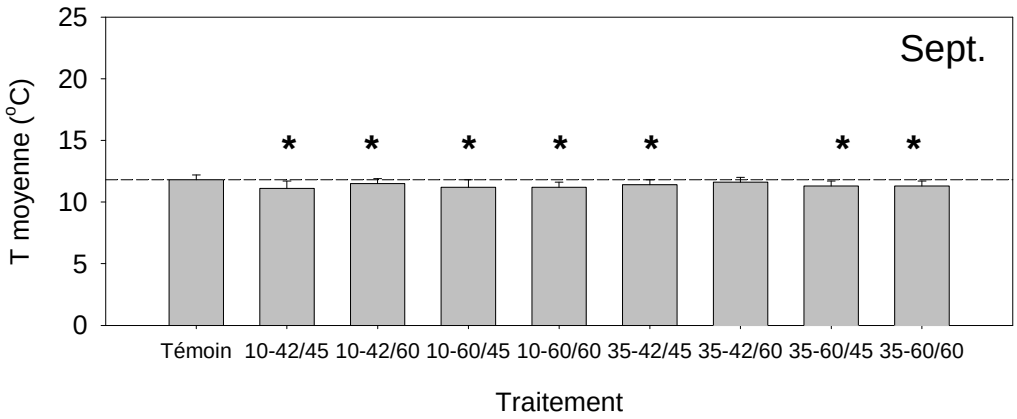
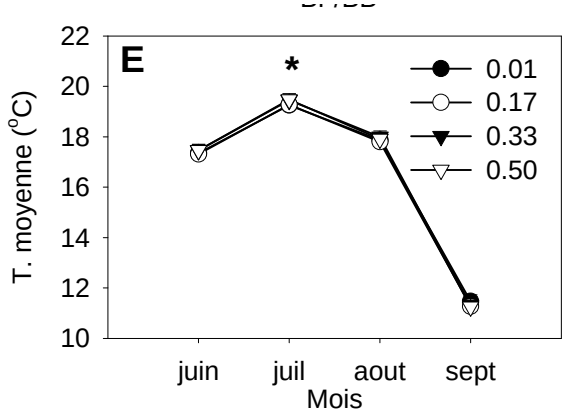


Figure 5. Average temperatures for September 2008, comparison between the forest/blueberry strips and the control field

- Radiation effect from the forest strips was noted for the July 2008 monthly average temperatures (Figure 17). The centre of the blueberry strips showed higher average temperatures. In 2009, radiation effect was also noted, but this time relative to blueberry strip width. The average temperatures of the 60-metre blueberry strips were higher at the centre of the strips, while the 45-metre strips showed higher temperatures along the edges of the forest strips (Figure 18). Average temperatures would therefore be higher at the centre of the blueberry strips.



Note : Gradient 0.01 corresponds to the edge of forest strips and gradient 0.5, to the centre of blueberry strips

Figure 6. Effect of the gradients on 2008 average temperatures

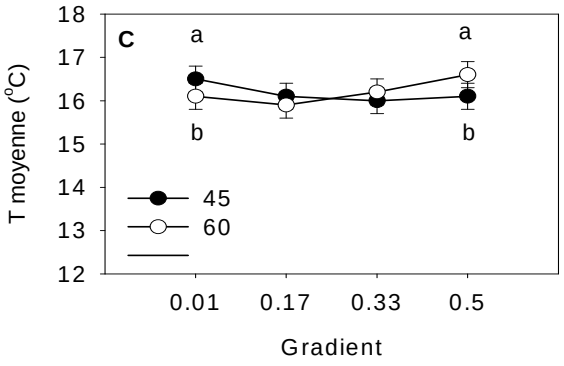
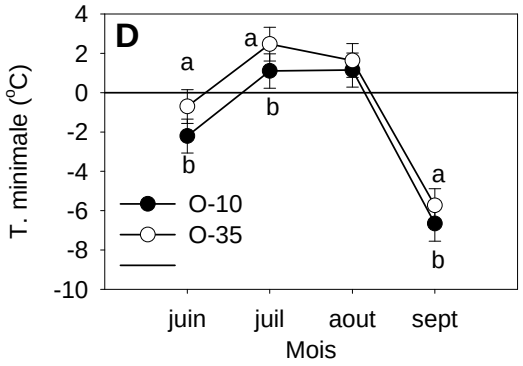


Figure 7. Effect of forest strip width and gradient on 2009 average temperatures

As concerns the **minimum (T° min.) and maximum (T° max.) temperature** variables, the results from 2006-09 show that :

- From 2006 to 2008, there were no differences between the strip widths in terms of minimum temperatures, while in 2009 differences appeared for some months, but only for specific blueberry strip gradients.
- The average minimum temperatures in the 45° forest/blueberry plots for 2008 were generally higher than those of the 10° strips, especially in June, July and September (Figure 19). It is therefore warmer in the 45° strips.



Note : The number 10 represents the 10° north alignment and 35 stands for 45° north.

Figure 8. Effect of strip alignment on 2008 monthly minimum temperatures

- Radiation effect (strip gradients) from the forest strips on monthly minimum temperatures was noted in 2007, 2008, and 2009. Minimum temperatures decreased from the edge of the forest strips towards the centre of the blueberry strips. In 2008, this radiation effect was more pronounced in August (Figure 20), while in 2009 minimum temperatures were lower in the 60-metre strips, but only in September (Figure 21). Therefore, there seems to have been a greater number of cold temperature extremes at the centre of blueberry strips for those three years. In 2009, the temperatures recorded in the 60-metre strips seemed to be different from the other years of the study. This strong relation between blueberry strip width and month warrants consideration, without necessarily being generalized.

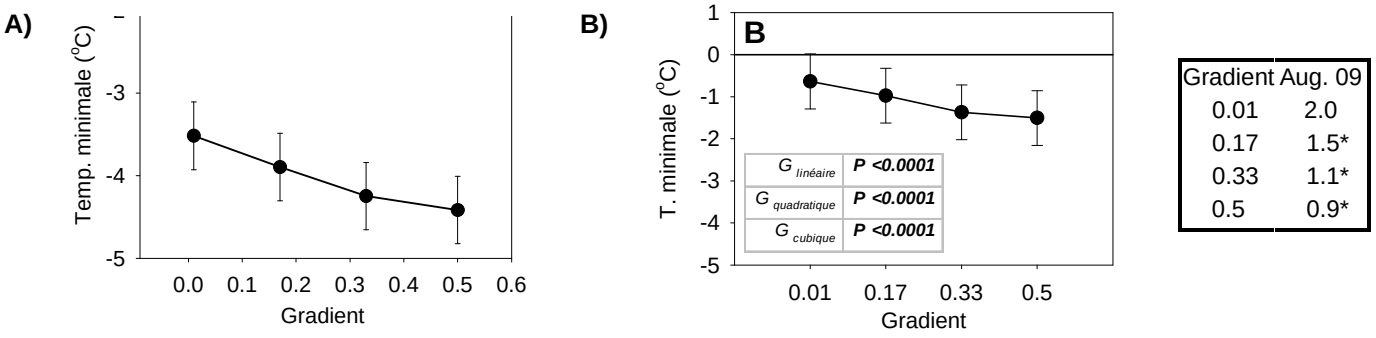


Figure 9. Effect of gradients on minimum temperatures in A) 2007 and B) 2008

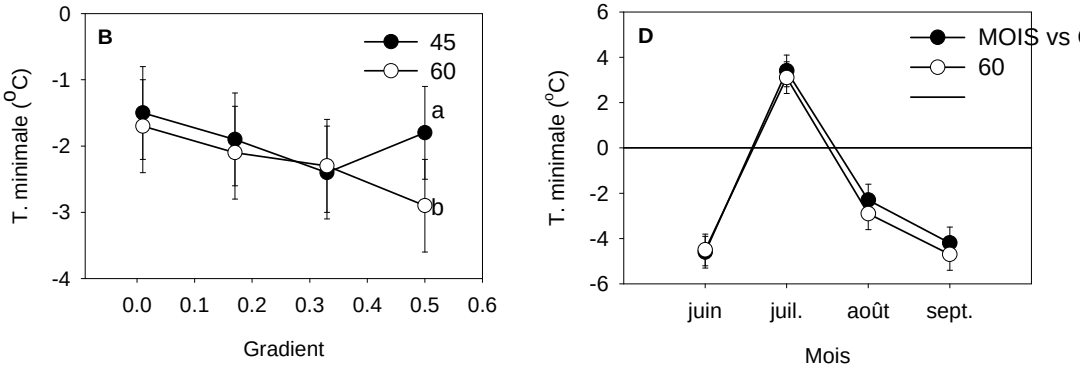


Figure 10. Effect of gradients and blueberry strip width on minimum temperatures, June to September 2009

- For 2006 and 2007, no difference was noted between the four strip widths as concerns maximum temperatures, while some differences were found in 2008 and 2009, but only for some blueberry strips, relative to gradients and month.
- Comparisons made with a conventional blueberry field show that, in 2006 and 2007, the minimum temperatures of forest/blueberry compartments were higher (Figure 22). The comparisons were however made with the Saint-Thomas-Didyme blueberry farm, while the 2008 and 2009 comparisons were made between each setup combination and the Normandin farm.
- In 2008, minimum temperatures in the 10° strips were lower than control field temperatures during June and July, while temperatures in the 45° strips were higher than control during August and September (Table 4). This relation between alignment and month occurred at a crucial time for lowbush blueberry production, as the risk of frost comes into play. Moreover, in August and September 2008 maximum forest/blueberry temperatures were more frequent than control (Table 5). For the same growth reasons, it seems difficult to determine if the forest/blueberry production model can be compared to conventional farms in terms of temperature extremes.

- It however seems that the conventional blueberry farm had more frequent extremely cold temperatures (2006, 2007 and 2008) and fewer extremely warm ones at the end of the 2008 growth season.
- In 2009, only the 60/60 strips had significantly lower temperatures than the control farm, but only relative to gradients.
- A four-year study does not seem to be long enough to determine if there is a true difference between the forest/blueberry production model and conventional farms in terms of temperature extremes.

A) **B)**

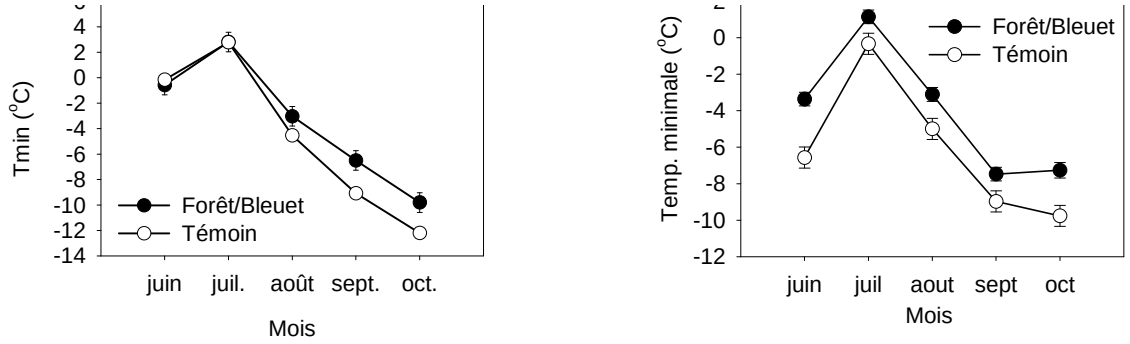


Figure 11. Comparison of minimum monthly temperatures in A) 2006 and B) 2007 between the forest/blueberry plots and conventional farm

Table 1. Minimum temperatures per setup measured from June to September 2008, compared with control temperatures

Setup	T minimum (°C)			
	June	July	August	September
Control	-0.8	2.3	-0.3	-7.8
10-42/45	-2.2*	0.9*	0.9	-6.9
10-42/60	-2.9*	0.5*	0.6	-7.0
10-60/45	-1.3	1.9	1.6*	-6.4
10-60/60	-2.4*	0.9*	1.0*	-7.0
45-42/45	-0.2	2.7	1.8*	-5.6*
45-42/60	-0.3	2.8	2.2*	-5.5*
45-60/45	-1.0	2.3	1.3*	-5.9*
45-60/60	-1.4	2.1	1.3*	-5.9*

Note : The averages followed by an asterisk (*) are significantly different from control values; the comparisons are valid within each month.

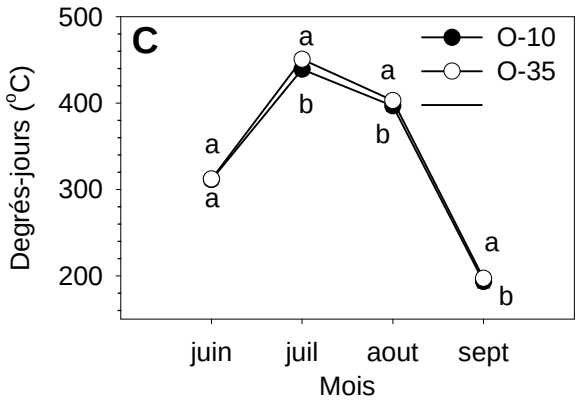
Table 2. Maximum temperatures per setup measured from June to September 2008, compared with control temperatures

Setup	T minimum (°C)			
	June	July	August	September
Control	38.3	39.4	37.7	37.7
10-42/45	39.5	39.4	40.5*	40.9*
10-42/60	39.4	38.8	41.9*	42.5*
10-60/45	41.6*	39.4	40.7*	41.1*
10-60/60	39.7	39.9	40.1*	41.0*
45-42/45	40.1	39.6	39.8	39.3
45-42/60	40.3	39.6	40.7*	40.3*
45-60/45	39.2	39.5	39.9	39.1
45-60/60	39.2	39.5	40.2*	40.3*

Note : The averages followed by an asterisk (*) are significantly different from control values; the comparisons are valid within each month.

As concerns the **degree-days** variable, the results show that :

- For 2006, significant differences between the four strip widths were noted, but only for specific gradients within the blueberry strips and some months.
- For 2007, there were no significant differences between the two strip alignments, four strip widths, and blueberry strip gradients.
- For 2008, the number of degree-days of the 45° strips was higher than that of the 10° strips. This tendency was particularly pronounced during July, August, and September (Figure 23), and the heat was more pronounced in the 60-metre blueberry strips in July.



Note : The 0-35 symbol corresponds to the 45° north alignment

Figure 12. Cumulative number of degree-days for June to September 2008, relative to alignment

- For 2009, differences between strip widths were noted. Heat accumulation was higher for the 42-metre strips (Figure 24) and radiation effect from the forest strips was observed, but only for some blueberry strips. Heat accumulation in the 45-metre strips was higher along the edges of the forest strips, while heat accumulation in the 60-metre strips was higher in the centre of the strips (Figure 25). The cumulative number of degree-days for 2009 may have been affected by the 60-metre strip data, which seems to stand apart from the other years of the study, as discussed above.

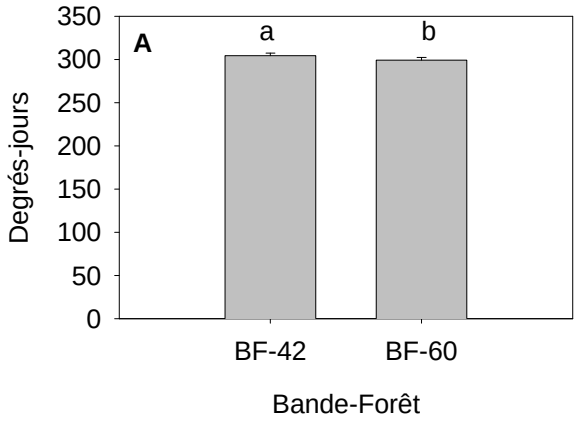


Figure 13. Effect of forest strip width on the cumulative number of degree days for 2009

- In 2006 and 2007, the cumulative degree-days for the forest/blueberry plots were not different from those of the control field. In 2008, the cumulative degree-days were lower for the 10° strips, and month dependent. In fact, in September 2008 and 2009, most of the forest/blueberry strips accumulated fewer degree-days (Tables 6 and 7).

Table 3. Average number of degree-days per setup from June to September 2008, compared with the control field

Setup	Degree-days (°C)			
	June	July	August	September
Control	315	448	409	208
10-42/45	310	437*	391*	189*
10-42/60	311	438*	403	199
10-60/45	313	437*	398*	192*
10-60/60	311	445	393*	192*
45-42/45	312	450	401	196*
45-42/60	314	456	408	203
45-60/45	310	450	402	194*
45-60/60	312	447	401	194

Note : The averages followed by an asterisk (*) are significantly different from control values; the comparisons are valid within each month.

Table 4. Average number of degree-days per setup from June 1 to September 11, 2008, compared with the control field

Setup	Degree-days (°C)			
	June	July	August	September
Control	375.0	397.8	397.1	65.9
45-42/45	358.4*	387.3*	376.5*	86.6*
45-42/60	362.4*	391.7	380.6*	90.5
45-60/45	356.1*	384.6*	375.4*	84.4*
45-60/60	356.7*	385.2*	370.2*	81.8*

Note : The averages followed by an asterisk (*) are significantly different from control values; the comparisons are valid within each month.

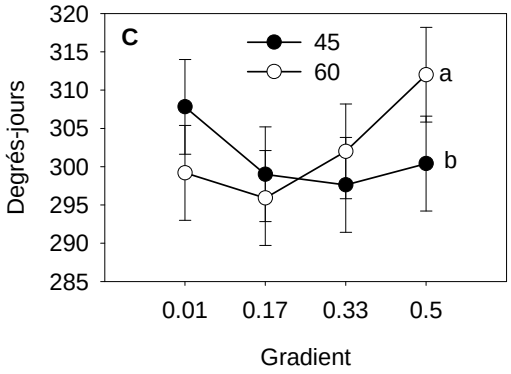
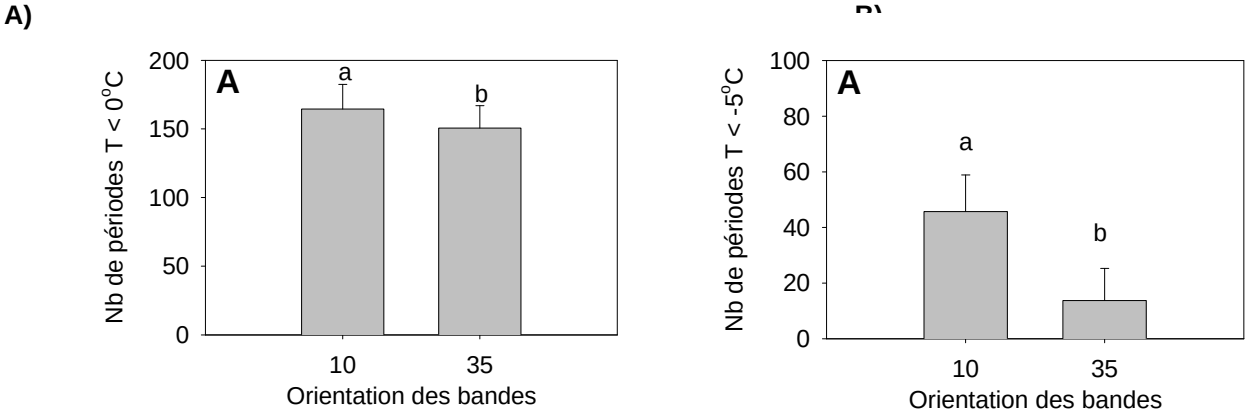


Figure 14. Cumulative number of degree-days relative to blueberry strip width and gradient, during the 2009 season

As concerns the **risk of frost** variable, the variance analyses (ANOVA) of the periods with temperatures below 0° C, -2° C and -5° C during the 2006, 2007, 2008 and 2009 seasons are shown in four tables in Appendix 2.

The results show that :

- In 2006, no differences were noted between the four strip widths.
- From 2007 to 2009, significant differences appeared between the two alignments and four strip widths, but only for some of the blueberry strips relative to gradient and month.
- In 2008, temperatures below 0° C and -5° C were more frequent for the 10° strips (see Figure 26).



Note : The number 35 represents the 45° north alignment

Figure 15. Number of 2008 periods with temperatures below A) 0° C and B) -5° C, relative to alignment

- In September 2008, temperatures below -2° C and -5° C were more frequent for the 45-metre blueberry strips than the 60-metre strips (Figure 27).
- In September 2009, the 45° 60/60 strips were subjected to a greater number of temperature occurrences below -2° C and -5° C. It seems that they were more at risk than the other setups (see Figure 28).

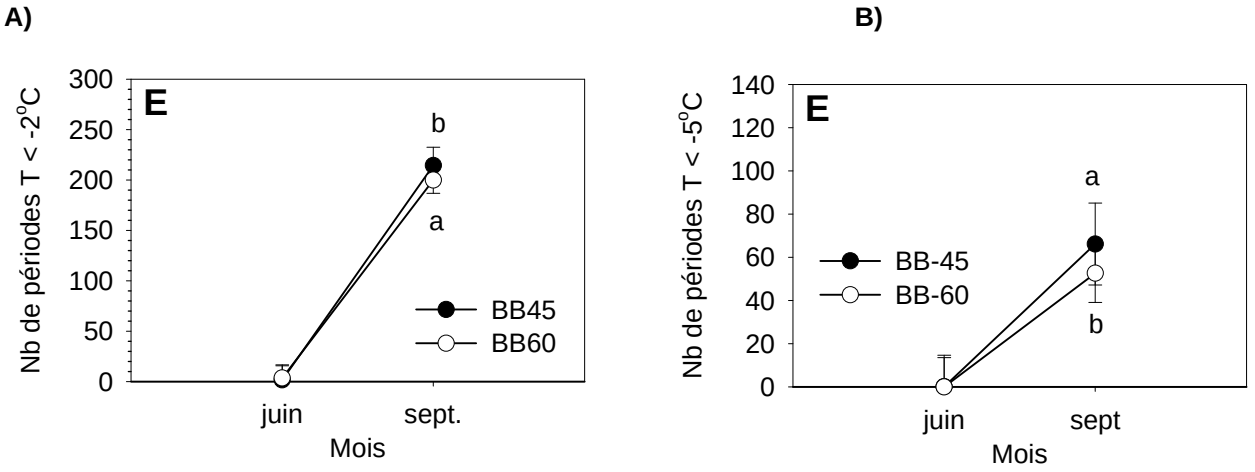


Figure 16. Number of 2008 periods with temperatures below A) -2° C and B) 5° C, relative to blueberry strip width

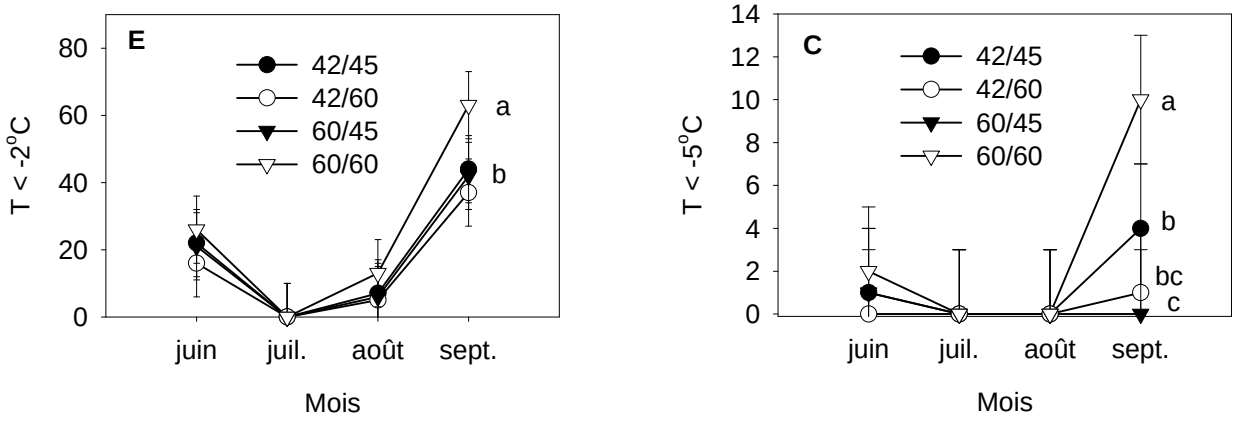


Figure 17. Number of 2009 periods with temperatures below A) -2° C and B) -5° C, relative to month and setup

- In 2007 and 2008, radiation effect from the forest strips was observed for temperatures T° < 0° C, T° < -2° C and T° < -5° C. Freezing temperatures occurred more frequently at the centre of the blueberry strips and decreased in number towards the edges (Figures 29-30). Also, the radiation effect was more pronounced in August and September, a period with higher risk of frost. Moreover, in 2007 the effect for T° < -2° C was more pronounced in the 60 m/45 m and 60 m/60 m strips than the 42 m/45 m and 42 m/60 m strips (Figure 31). Frost occurred more frequently at the centre of blueberry strips combined with 60-metre forest strips.

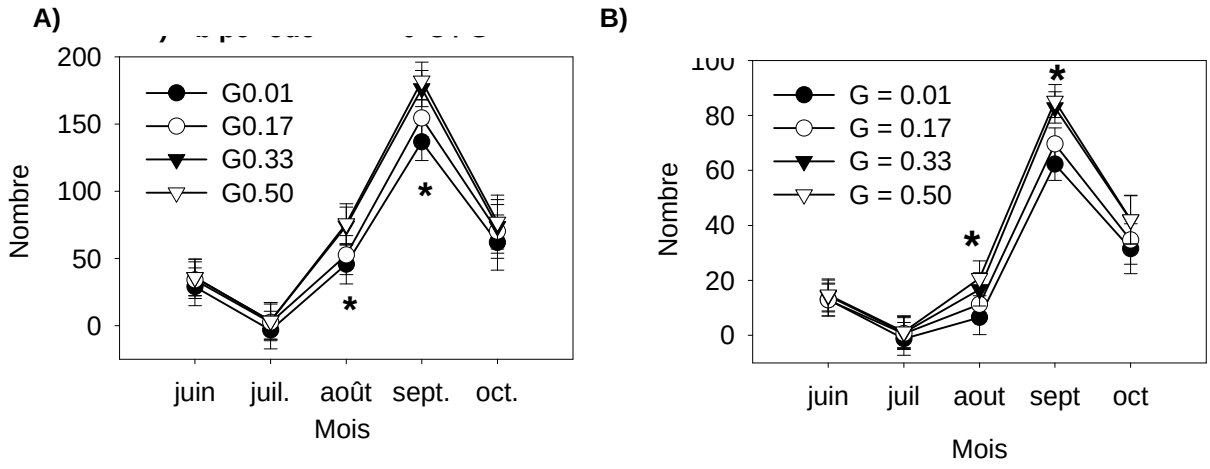


Figure 18. Number of 2007 periods with temperatures below A) 0° C and B) -2° C, relative to the gradient

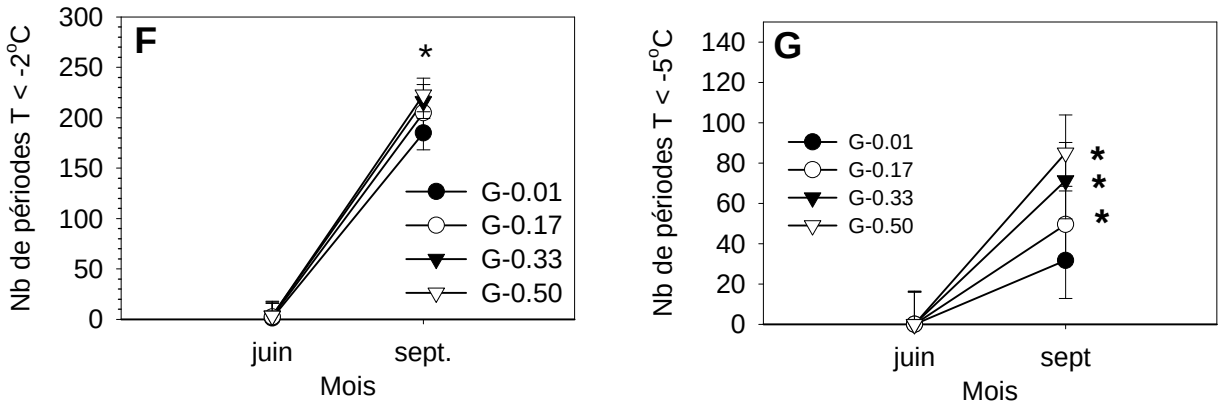


Figure 19. Number of 2008 periods with temperatures below A) - 2° C and B) -5° C, relative to the gradient

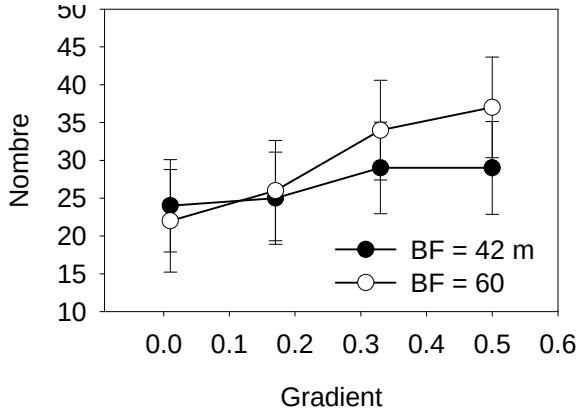


Figure 20. Number of 2007 periods with temperatures below -2° C relative to forest strip width and gradient

- In 2009, radiation effect from the forest strips was observed relative to blueberry strip widths, for September only. September periods with risk of frost seemed to occur more frequently in the 60/60 strips.
- Comparisons with the Saint-Thomas-Didyme conventional blueberry farm show that, in September 2006, when data came only from the 10° strips, there were fewer occurrences of temperatures below -5° C in the forest/blueberry strips than in the conventional farm (Figure 32). In 2007, when data was gathered for all strips, the same observations were made for June and September (Figure 32). The risk of frost exposure was greater in the conventional blueberry grove. In September 2008, temperatures below -5 °C occurred more often in the 10° strips than at the Normandin control field (Figure 33).

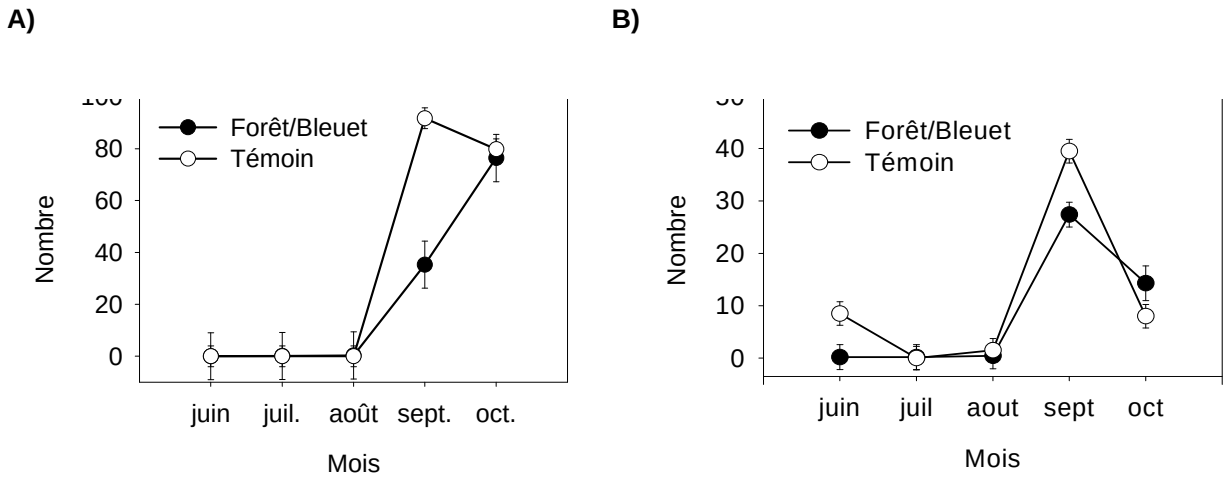
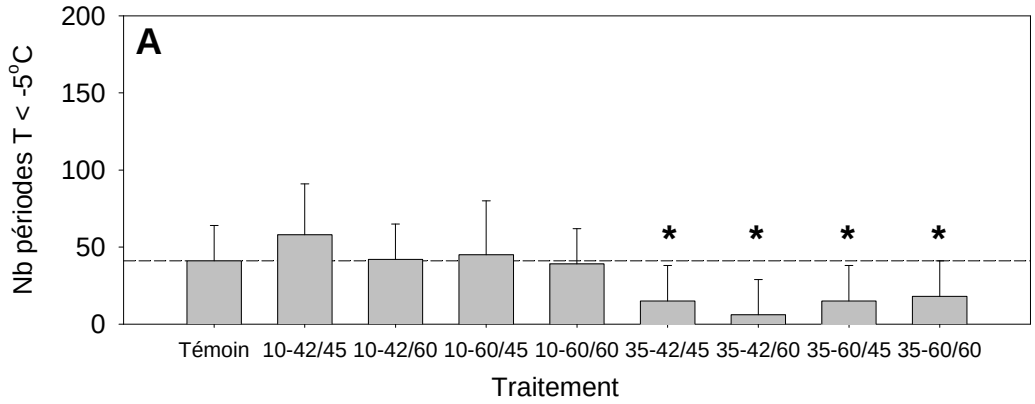


Figure 21. Monthly variations in below -5 °C occurrences in A) 2006 and B) 2007, compared with control values



Note : The number 10 represent the 10° north alignment and 35, the 45° north alignment

Figure 22. Number of below -5 °C occurrences per strip setup in 2008, compared with control values

The **risk of frost** variable was also analyzed relative to date and **time of exposure to early and late frost**, to assess if the periods of killing frost differ from one setup to another. A temperature of -2° C over at least one hour is considered as the damage threshold for blueberry flowers. Late frost occurs in the spring and affects the flowers, while early frost occurs in the fall and affects the fruit harvest. Results show that :

- In 2006, no late frost occurred (very faint presence) and the variable could not be studied. As concerns early frost, no differences were noted between the four strip widths.
- In 2007, the 10° strips were less exposed to the June 7 late frost, but were exposed longer to early frost (varying dates). No differences were noted between the four strip widths for both types of frost.
- In 2008, only the 10° strips were exposed to late frost. Table 8 shows the average exposure to the June 13 late frost for temperature <-2 °C. Moreover, the blueberry strips along the 42-metre forest strips were exposed longer to early frost than those along the 60-metre forest strips (Figure 34).

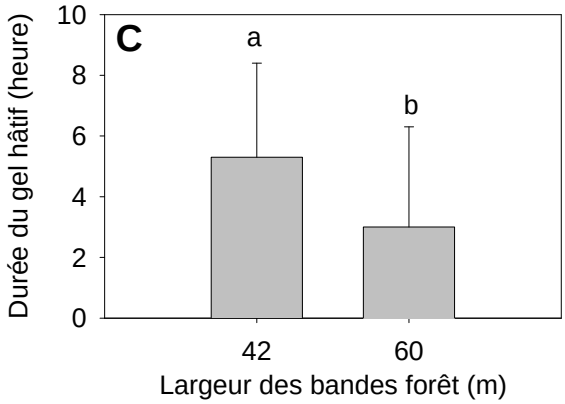


Figure 23. Effect of forest strip width on late frost exposure in 2008

- In 2008, the 45° strips seemed better protected against frost, regardless of width. The frost affecting blueberry groves in the spring and fall are often radiation frost[1], as cold air flows gravitationally along the main slope of a blueberry field (katabatic flow towards the lowest point), and according to the topographic layout of the field. Indeed, landform elements such as microtopography, woody plants, and tree hedges impede the flow of cold air, and hence affect frost intensities during the growing season. The direction of cold airflow is therefore an essential meteorological component to understanding the risk of frost in blueberry fields (Brassard, 2008). In short, the 45° alignment favours radiation frost airflow since the cold air flows in the same direction as the strip setup, which keeps it from getting trapped within the blueberry strips. The 45° alignment could therefore prove to be the best choice.
- Radiation effect originating from the forest strips was also observed in 2008. Exposure to late and early frost increased from the edge of the woods towards the centre of the blueberry strips (Figure 35). In 2009, exposure to late frost was longer with the 60-metre forest strips, particularly in the centre of the blueberry strips (Figure 36).

[1] Radiation frost is caused by the cooling of the earth's surface through radiation loss, meaning that the heat in the soil flows upwards into the air but is not returned to the soil. In such cases, the air near the surface is cooled by contact.

- In 2006, exposure to early frost seemed greater in the conventional blueberry fields.
- In the year 2007, exposure to frost was greater in the 10° forest/blueberry strips, as was the case in 2008, as the 10° showed a propensity to late frost (Table 8).

Table 5. Exposure (average) of June 13, 2008 late frost for temperature <-2 °C

Setup	Late frost exposure (hours)		
Control	0.0	±	1.5
10-42/45	1.6*	±	1.5
10-42/60	2.0*	±	1.5
10-60/45	0.1	±	1.5
10-60/60	1.46*	±	1.5
45-42/45	0.0	±	1.5
45-42/60	0.0	±	1.5
45-60/45	0.0	±	1.5
45-60/60	0.2	±	1.5

Note : The averages with an asterisk (*) significantly differ from control values; the comparisons are valid within each month.

- In 2009, the forest/blueberry plots were more exposed to late frost, particularly in the case of the blueberry strips nestled between 60-metre forest strips (Figure 37).

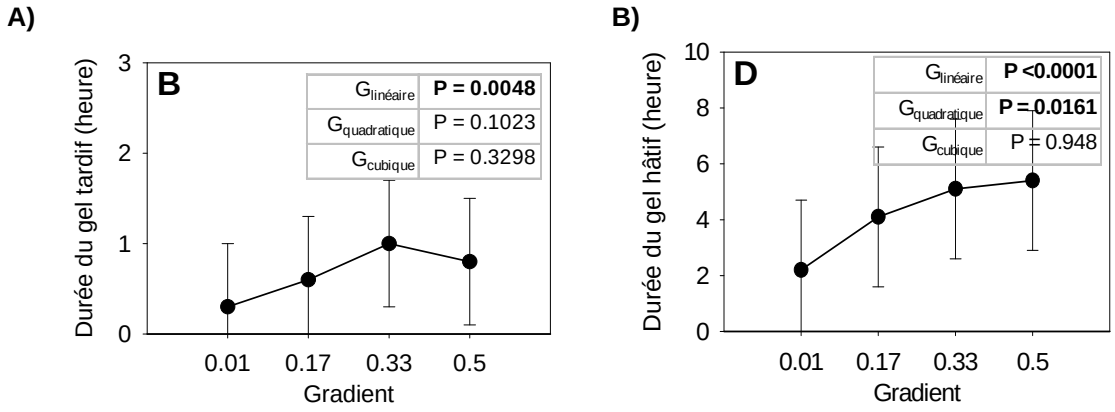


Figure 24. Exposure to 2008 A) late frost and B) early frost relative to gradient

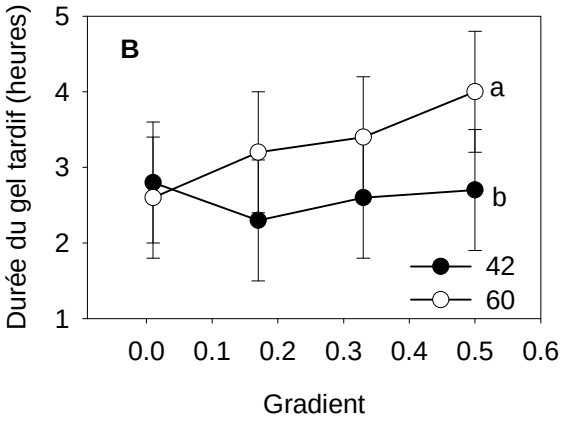


Figure 25. 2009 exposure to late frost relative to gradient and forest strip width

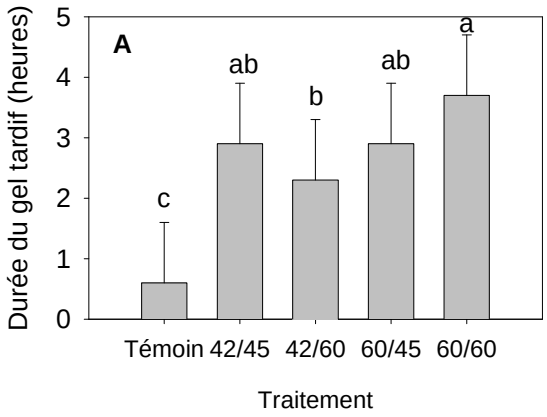


Figure 26. 2009 exposure to late frost per setup compared with control values

As concerns the variable for **temperatures between 10° C and 30° C**, results show that :

- In 2008, the number of occurrences with temperatures between 10° C and 30° C was influenced by alignment, gradient, and month. The 45° strips had the greatest number of these periods, associated with enhanced pollinator activity. The number of occurrences was higher along the edge of the woods, and decreased towards the centre of the blueberry strips. This radiation effect was more pronounced for the 45° strips. However, when correlated with monthly periods in 2008, no differences were noted for June, when flowering occurs.
- In 2009, the number of occurrences with temperatures between 10° C and 30° C was influenced by the gradient, strip width, and month. Again, no differences were noted for June, the month when a positive impact on pollinator activity was expected.

b) Blueberry bush drying index

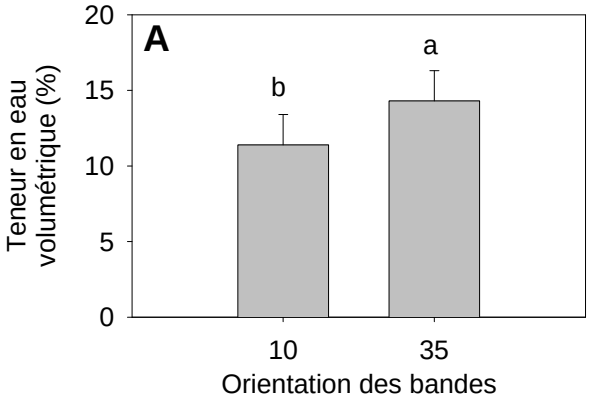
The information gathered from assessments of volumetric water content (%) in the soil, stockwater, and soil textures were used to estimate the drying index of blueberry bushes.

Statistical processing of the soil volumetric water content (%) of soil data for 2008 and 2009 allowed comparing the effects of forest and blueberry strip widths, and determining whether a gradient effect occurs within the blueberry strips, according to monthly data (June and July) and physiological stages. As mentioned earlier, in 2008 data were collected once during the season, in July, which corresponds to the filling/maturing stage of blueberries during the productive year of strips. In 2009 there were two data gathering episodes, as stated above. The ANOVA variance analysis was used to compare volumetric water contents. The 2008 and 2009 data are listed in two tables found in Appendix 3.

The factorial analysis used is called split-plot design. The principal plots were combinations of factors: strip alignment (O) x forest strip width (BF) x blueberry strip width (BB). These experimental units (EU) were repeated three times for a total of 24 EU. Blueberry strip measurements were repeated three times according to perpendicular gradients; the gradient factor was considered as nested in sub-plots.

As concerns the **volumetric water content** variable, the results show that :

- For the July 18, 2008 data, the 45° strips (dormant stage) had higher volumetric water contents that the 10° strips (fruit maturing/filling stage). Figure 38 illustrates that the amount of water drawn by the bushes, as sampled, differed according to production cycles. Water sampling was higher in the 10° strips, as the bushes yielded their first fruits after two dormant years. These results demonstrate the effectiveness of the measurement device and method. No differences were noted between blueberry strip widths and gradients.

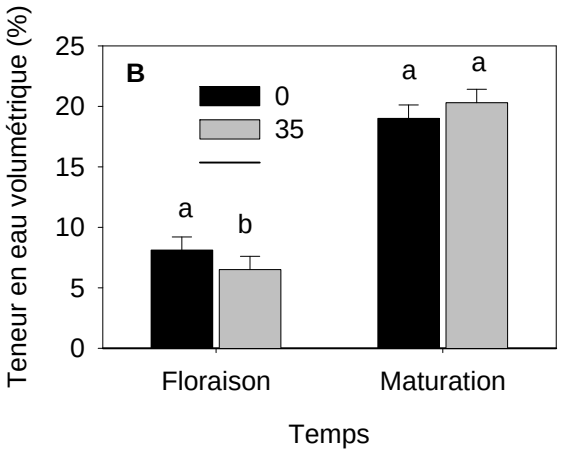


Note : The number 35 represents the 45° north alignment

Figure 27. Effect of physiological stage on volumetric water content in 2008

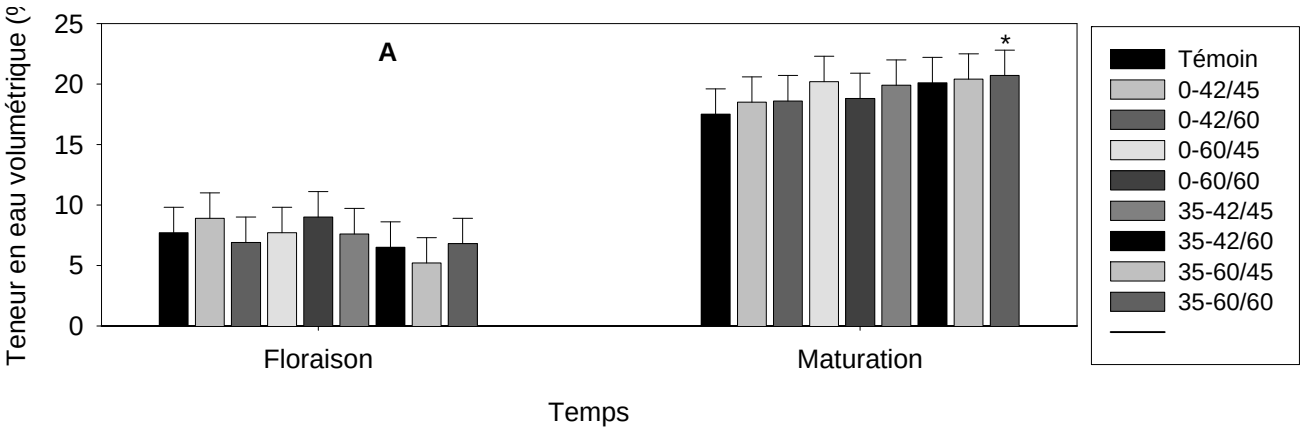
- The 2009 data represent the results of two separate sampling runs during the season. The volumetric water content was clearly higher for the July 21 sampling, compared to June 23 (Figure 39). Soil moisture conditions on June 23, 2009, which is during the flowering period of productive plants, were dryer and possibly ideal for differences to appear in the drying index levels of the various setups. No differences were noted between the four strip widths or strip gradients. Water content was clearly higher on July 21, which favours the fruit maturing process. However, no differences were noted between the four strip widths or strip gradients.

- The volumetric water contents, measured on two occasions for all setups and compared with the conventional blueberry field, show no differences except for the 45° 60/60 strips, which showed significantly higher volumetric water contents on July 21 (Figure 40).



Note : The number 0 represents the 10° north alignment, and 35, the 45° north alignment

Figure 28. Effect of sampling dates on volumetric water contents in 2009

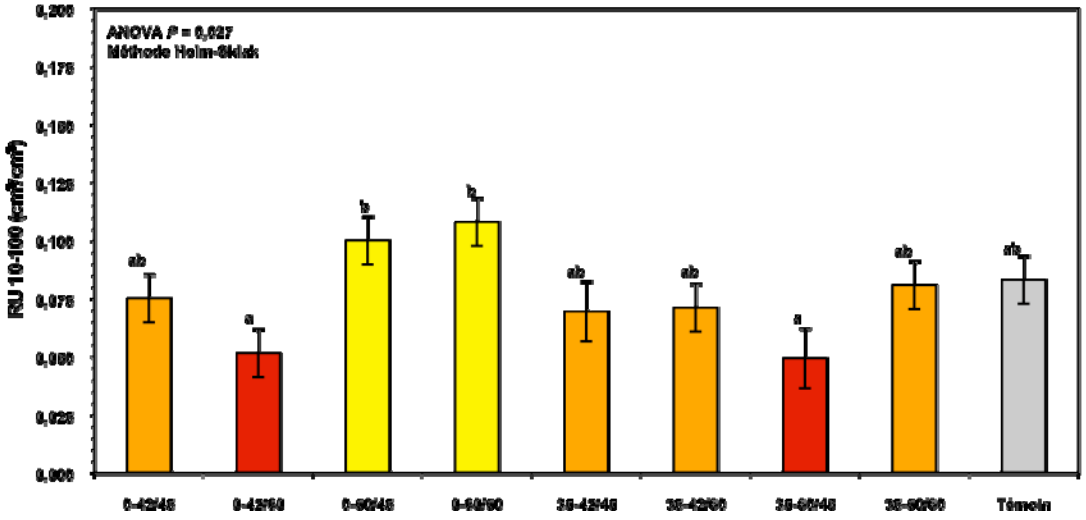


Note : The number 0 represents the 10° north alignment, and 35, the 45° north alignment

Figure 29. Volumetric water contents measured in 2009, relative to sampling dates and setups and compared with the control values

As concerns the **stockwater** variable, the results show that :

- Stockwater estimates of soil samples from the different experimental setups show varying levels (Figure 41). Territorial location could explain this difference. However, several strips showed similar stockwater levels as the control field, or 0.08 cm^3/cm^3. The strips with lower stockwater levels are those with higher macroporosity. Figure 42 compares the water stress curve of the control field with that of sandy soil, which leads to believe that the stockwater assessment technique was suitable. However, no correlations were observed between the volumetric water contents measured in the field during the 2008 and 2009 seasons and the estimated stockwater levels using the *water stress* table.



Note : The number 0 represents the 10° north alignment, and 35, the 45° north alignment

Figure 30. Comparisons between setup and control soil stock water levels

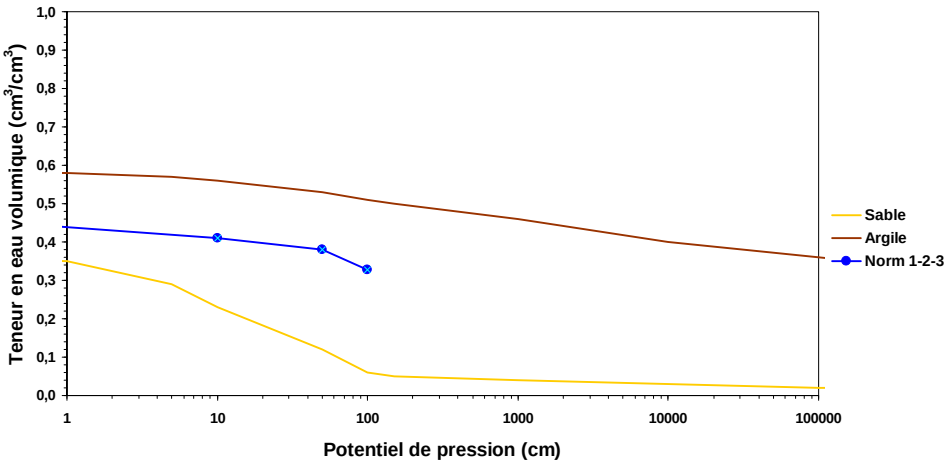


Figure 31. Comparison of the water retention curve from control values with the typical pure-sand and argyle curves

As concerns CAFN and control **soil texture classes**, the results show that sand contents vary from 90 % to 95 %. As a rule, the soils found in the setup strips are sandy.

c) Snow-cover thickness

Snow-cover thickness was assessed using the split-plot design, with repeated measurements. Indeed, the principal plots were combinations of factors: strip alignment (2) x forest strip width (2) x blueberry strip width (2). The month factor was considered as nested in sub-plots (repeated measures). The experimental units (EU) were repeated three times for a total of 24 EU.

As mentioned earlier, snow-cover measurements began in the winter of 2007 and only involved half the experimental units. It should also be noted that the conventional control field was considered as being outside the controlled parameters.

These results were combined with those of the forest/blueberry production model for information purposes. All 24 experimental units were subjected to measurements in 2008.

As concerns the **snow cover** variable, the results show that :

- In 2007, no differences were noted between the four strip widths.
- Starting in February 2007, the snow cover was thicker in the forest/blueberry strips than in the conventional field at Saint-Thomas-Didyme (Figure 43).
- In 2008, no differences were noted between the two strip alignments and four widths. Snow cover was thicker at the centre of strips than on the edges. Snowmelt (April) occurred faster in the 10° strips alongside the 60-metre forest strips. As for the 45° strips, snowmelt (April) occurred faster in strips alongside the 42-metre forest strips (Figure 44).

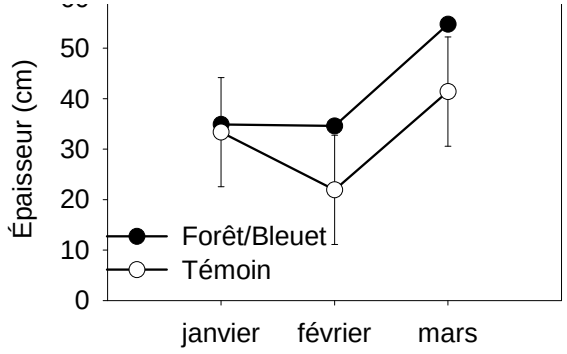


Figure 32. Snow-cover thicknesses measured in 2007, compared to control values

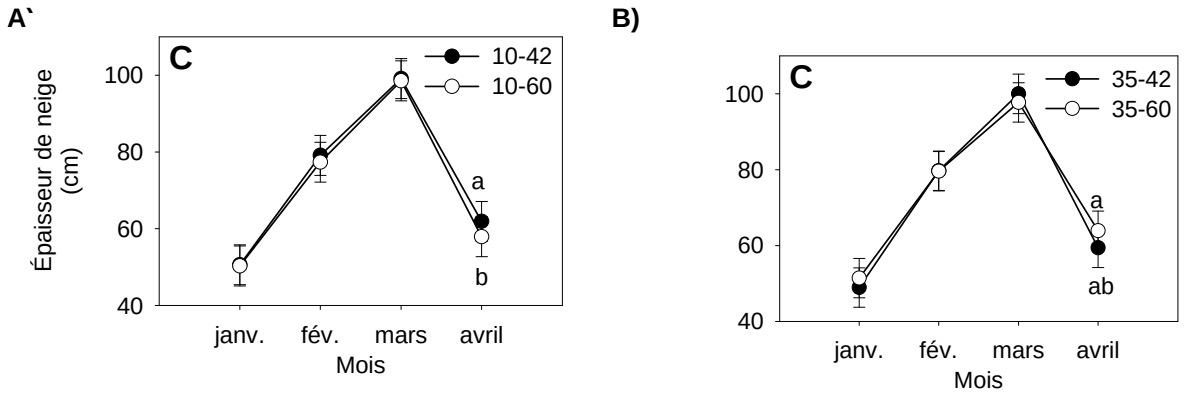


Figure 33. Effect of alignment A) 10° and B) 45° and forest strip width on snow cover in 2008

- In 2008, the snow cover was thicker for all sampling months in the forest/blueberry setups, compared to conventional blueberry field values. Snow cover at the Normandin control field was the lowest of all measured sites (Figure 45). It should be noted that the two conventional blueberry control sites did not benefit from the protection of mature windbreakers; those established at the Normandin site are your trees and the Saint-Thomas tree line is too far from the field to effectively work as a windbreaker. Based on a study conducted by the *Groupe de recherche de la Sagamie*, the average snow cover in flat fields protected by trees is 84 cm (Lemieux et coll., 1992). Maximum snow cover occurs in March. In 2008, snow cover on CAFN lands reached more than 97 cm in March, which constitutes excellent winter protection.

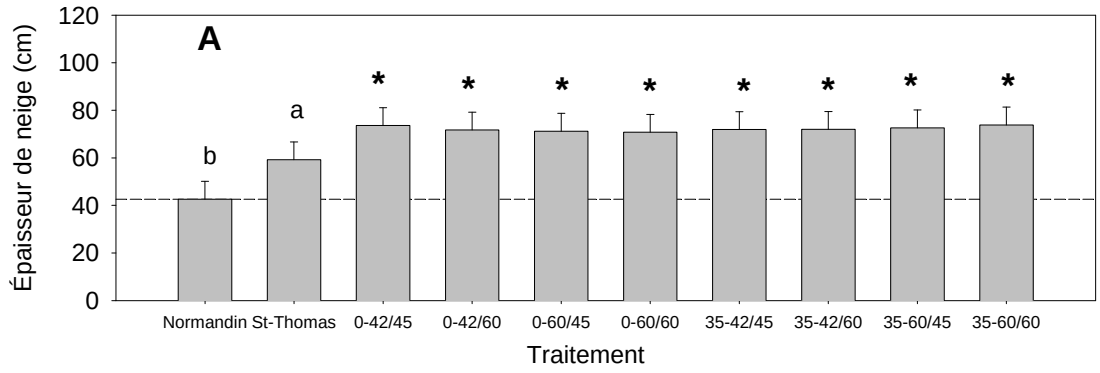


Figure 34. Monthly variation of 2008 snow cover

4.1.2. Assessment of outcome (Objective 2A)

The objective of this research project was to determine which of the forest/blueberry setups provided the best agroclimatic conditions for blueberry production.

The objective was reached as concerns the temperature-within-strips variable, as the results showed that strip alignment, gradient and even in some cases width had an impact on average and extreme (minimum and maximum) temperatures, cumulative degree-days, and the risk of

frost exposure. The 45° alignment showed higher average T° during the growing season, and a larger number of cumulative degree-days. They had higher minimum temperatures and lower risk of frost. That is why the 45° alignment should be the preferred choice for this type of forest/blueberry setup on CAFN lands.

Moreover, the minimum temperatures T° were lower at the centre of blueberry strips than on the edges. The frost periods and time of exposure to early and late frost also increased from the edge of the woods towards the centre of the strips. This radiation effect was in fact more pronounced in August-September 2007 and 2008, at which time the risk of frost is higher. Moreover, in 2007, the radiation effect relative to risk of frost was more pronounced in the 60-metre forest strips than the 42-metre strips. Frost therefore occurred more frequently at the centre of blueberry strips established between 60-metre forest strips. The 2009 results, involving only the 45° strips, corroborate these observations. Indeed, radiation effect from the edge of the woods was noted in 2009, relative to blueberry strip width. Risk of frost temperatures occurred more frequently in the 60/60 strips. Exposure to late frost in 2009 was also longer for 60-metre-wide forest strips, particularly towards the centre of the blueberry strips. These setups seemed to be more at risk than the others.

In 2009, heat accumulation was higher for 42-meter-wide forest strips. This result should however be considered with some discrepancy since the number of cumulative degree-days measured in 2009 may have been affected by the data recorded in the 60-metre-wide strips, which seemed to differ from the other years of the study. The topography of the 45° setups may have influenced some of the results for a number of experimental units. Indeed, although most of the experimental units were flat, some strips were more undulated than others. Hence, temperatures of experimental units located near swales or knolls may have been influence by land topography. The year 2009 was seemingly affected by these exceptional occurrences since correlation between blueberry strips and gradients brought out differences that had not been observed in previous years. These differences are however due to localized conditions, which cannot be generalized over the entire CAFN territory.

As concerns the drying index variable, the objective was partially reached. It was observed that the production cycle, physiological stage, and soil composition have a greater effect on the water requirements and water stress of blueberry bushes than the width of forest strips. The heavy influence of these elements makes it impossible to compare them in relation to the different setups, in terms of strip width and radiation effect.

As concerns the snow-cover variable, the current results do not suffice to determine whether setup alignment or forest strip width can further benefit production, based on snow-cover thickness measurements. However, differences were noted as concerns the effect of strip width and alignment on spring thaw; for the 45° strip alignment, the blueberry fields between 42-metre forest strips thawed faster than those between 60-metre forest strips. This is an interesting interaction that could affect the progression and evolution of the flowering process.

In short, taking into account spring temperatures and production start-up aspects, the 45° alignment and 42-metre forest strips show better potential (better spring thaw and lower risk of frost at the centre of blueberry strips) than the 60-metre forest strips. It should be noted that the interdepartmental committee on the use of State land for the development of the blueberry industry stands behind the use of 42-metre forest strips (MRNF-MAPAQ Committee, 2002).

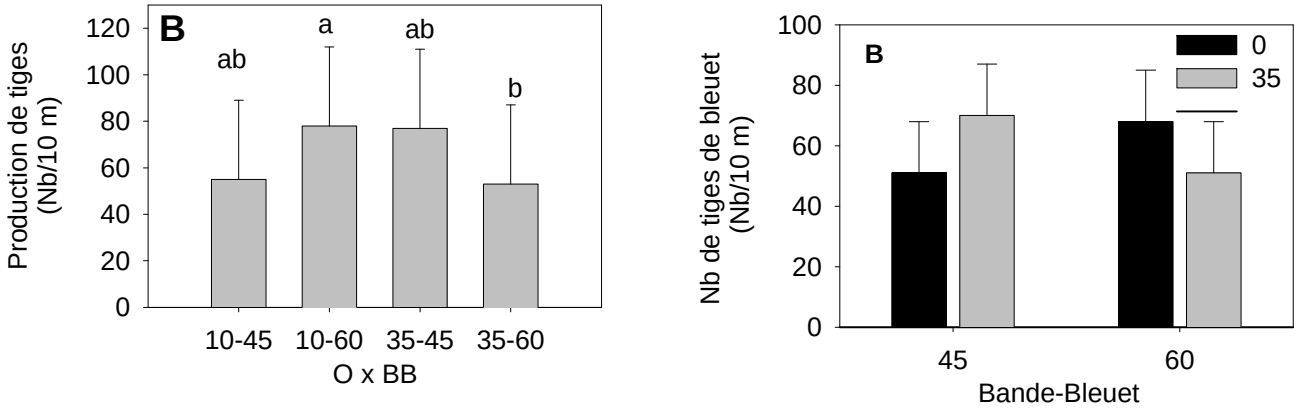
4.1.3. Impact of the different forest/blueberry setups on blueberry yield (2B)

As previously mentioned, the ANOVA variance analysis was used to compare the growth of blueberry stems, flower buds, and fruit yield. The JUMP software was used for data processing. For the three variables, variance uniformity was graphically verified and the findings are described in the following paragraphs.

Stem growth

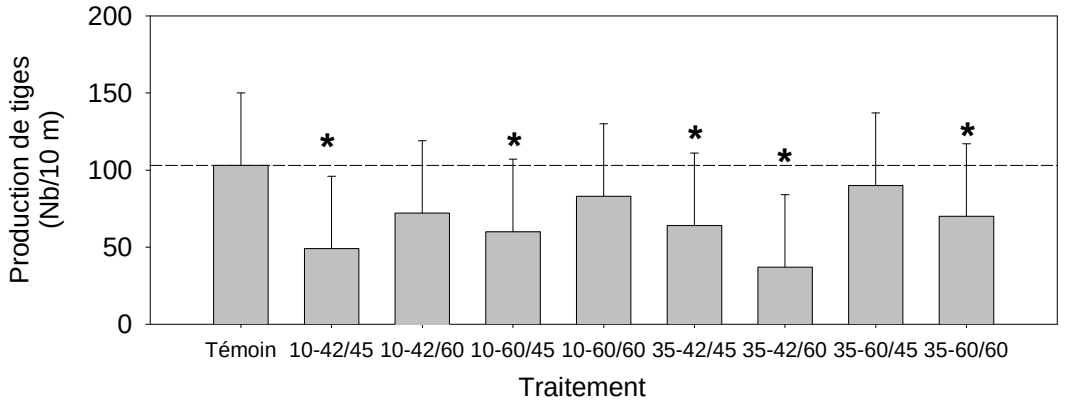
Stem counts were made in 2007, 2008 and 2009, and site-to-site variability was very high for all three years. No alignment or strip width stood out over others. Correlations between alignment and strip width factors do not lead to conclusions. Ten-degree strips aged more than one year did not have better stem densities. Constancy between 2008 and 2009 observations led us to believe that the method used yielded accurate plant densities (Figure 46). For those two years, the 60-metre blueberry strips with 45° alignment had the lowest stem counts. These results can be explained by the fact that process use to set up blueberry fields greatly influences the growth of blueberry bushes and competitive plants as well. Forest-stand type and age also affect undergrowth plants, which can compete with blueberry bushes, and the thickness of forest residue on the ground following wood harvest.

In 2008 and 2009, most strip combinations had lower stem growth than the conventional blueberry control fields (Figures 47-48).



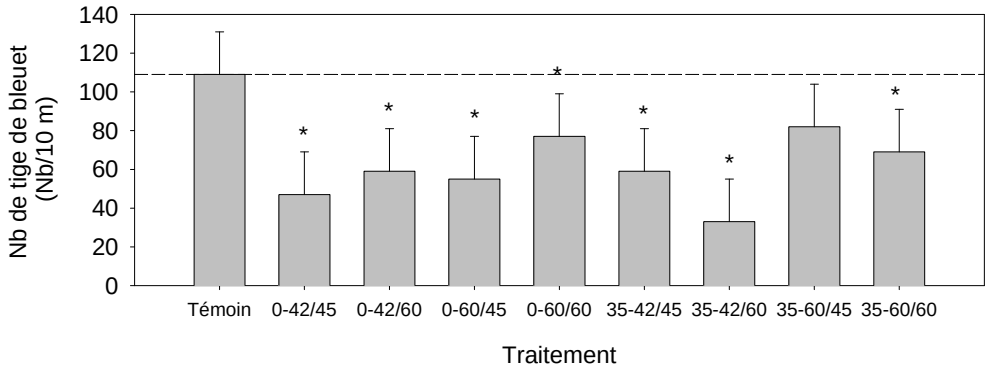
Note : The 0-35 symbol corresponds to the 45° north alignment

Figure 35. Observed correlations A) 2008 and B) 2009 between blueberry strip alignments and widths



Note : The number 0 represents the 10° north alignment, and 35, the 45° north alignment

Figure 36. Comparison of blueberry stem numbers per 10-metre transect, measured in 2008



Note : The number 0 represents the 10° north alignment, and 35, the 45° north alignment

Figure 37. Comparison of blueberry stem numbers per 10-metre transect, measured in 2009

Bud growth

Bud growth data were collected in 2008 for the 45° blueberry strips and in 2009 for the 10° strips. These are not conclusive as to which alignment yields more flower buds. Data processing for 2008 and 2009 does not reveal any differences between the setup strips and control fields (Tables 9-10). The blueberry bushes throughout the various setups all showed similar yield potential to the conventional control fields. In 2009, the average number of buds was slightly higher than that of 2008, due to the fact that the counts were made in strips aged more than one year, and one year following their initial yield (two years' difference between the 45º and 10° strips).

Table 6. Average number of buds for 10 bushes in 2008

Setup	Flower bud yield (average/10 bushes)		
Control	13	±	4
45-42/45	11	±	4
45-42/60	12	±	4
45-60/45	12	±	4
45-60/60	10	±	4

Table 7. Average number of buds for 10 bushes in 2009

Setup	Flower bud yield (average/10 bushes)		
Control	17	±	4
10-42/45	14	±	4
10-42/60	14	±	4
10-60/45	14	±	4
10-60/60	15	±	4

Fruit yield

In 2008, fruit yields were measured in the 10° strips and control fields, this was their initial production year. Performance analysis shows no differences between the different strip widths, and between the experimental strips and control fields. No radiation effects (strip gradients) from the forest strips were noted in 2008. The results of 0.25 m^2 harvests varied greatly. The average fruit weight (large and small) varied from 125 g/m^2 to 222 g/m^2 for the experimental setup, and the control value was 161 g/m^2. The average first-year yield is within the range of 800 kg/ha and 1,000 kg/ha (CRAAQ, 2004), corresponding to 80 g/m^2 to 100 g/m^2 mechanical harvest numbers. Of course, harvest losses for experimental conditions such as these are null, as every blueberry was harvested, which is why the yield numbers are higher than those obtained from mechanical harvesting. The large stem-count variations noted earlier for the strips is probably also reflected in the yield.

In 2009, the 45° strips produced fruit. However, the control field was in dormant stage and could not be used for comparison purposes. The yield of productive strips in 2009 was below that of 2008 and, again, the results of 0.25 m^2 harvests varied greatly. The average fruit weight (large

and small) varied from 126 g/m^2 to 152 g/m^2 for the experimental strips. The quality of setup for the 2006 experimental strips varied greatly and was below the 2005 standard. Some strip sections had very few or no bushes. The fact that the harvest locations were chosen at random explains the variable results for 0.25 m^2 harvest sections. Analysis of the 2009 yield shows no differences between strip widths. However, radiation effects (strip gradients) from the forest strips occurred in 2009. The total weight of harvested fruit increased towards the centre of the strips (Figure 49). On the other hand, comparison with immature fruit shows great variation among the experimental setups. The 45° 42/45 strip combination shows a higher level of ripening (Figure 50).

As mentioned in Section 4.1.1 c) Snow cover, spring thaw in the 45° strips occurred faster with the 42-metre forest strip setup, which could explain why flowering began earlier (Section 4.3.1), and harvesting was done when the fruit were fully ripe; the majority of pollinated fruit would therefore have had time to reach maturity.

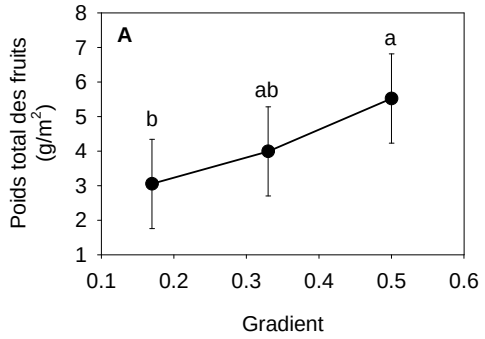


Figure 38. Effect of gradient on total fruit harvest, 2009

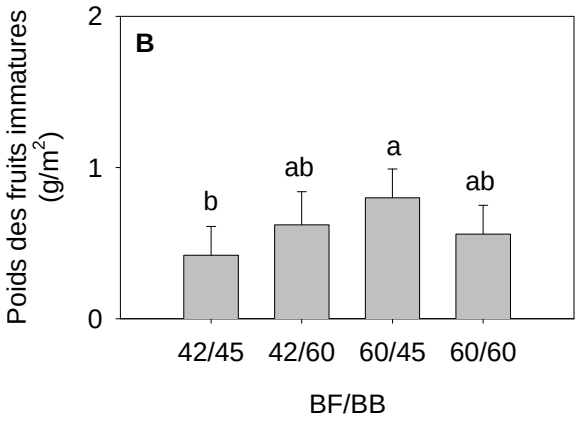


Figure 39. Weight comparisons of immature fruits harvested in 2009 between the different experimental setups

The yield data will be further analyzed and described in Section 4.3.1, where quality of the fruit harvested in the experimental setups will be looked at in greater detail.

4.1.4. Assessment of outcome (Objective 2B)

The objective of this research constituent was to determine which strip alignment and width combinations would produce the best blueberry yields.

The current results do not lead to conclusions as to the productivity of a strip alignment or width over another, based on the yields achieved. The established in 2005 had similar yields to the control field. Considering the number-of-flower-buds variable, the yield potential of all experimental setup strips is similar to that of a conventional blueberry field. The variability of setup quality is clearly illustrated. Repetitive observations of stem growth made in 2008 and 2009 show that establishing blueberry bushes is more difficult in some strips than others. That variability was quite visible in field observations. Section 4.3.1 takes a detailed look at fruit quality within the experimental setups and the effect of indigenous pollinators on harvest.

4.2. Research focus area 3 : Pesticide monitoring for the forest/blueberry cultivation model

The results expected from this research constituent concern pesticide concentrations in water bodies and at resurgence points.

The results of analyses show that hexazinone levels in groundwater evolved according to applications made principally in 2006, 2007, 2008 and 2009. Table 11 lists the hexazinone concentrations derived from the analysis of samples taken from the three piezometers located in the southwest sector of CAFN lands and in *Ruisseau Rouge* (Red brook). As mentioned earlier, hexazinone (Pronone® or Velpar) was used in the springs of 2006, 2007 and 2009.

Table 8. Hexazinone concentrations from the analysis of samples taken from the three piezometers from 2006 to 2009

Date	Hexazinone concentrations (µg/l)				
	Pz-1	Pz-2	Pz-3	Ruisseau Rouge	Control level
Spring 2006	< 0.04	< 0.04	< 0.04	< 0.04	500 (1)
Fall 2006	22	1.4	< 0.04	< 0.04	
Fall 2007	33.56	0.81	< 0.15	0.04	
Spring 2008	16.1	2.7	< 0.15	0.3	
Fall 2008	6.81	0.44	< 0.15	0.39	
Spring 2009	3.9	0.58	0.15	0.97	
Fall 2009	140	3.3	None detected	0.7	

(1) Health Canada, 2005

The 2006 concentrations represent the initial content, or content 0, used to monitor the evolution of hexazinone levels since the first time the herbicide was use in the lowbush blueberry project. Obviously, a sharp increase was noted in piezometer 1 following the initial spraying. It should be noted here that piezometer 1 is located downstream from the groundwater discharge area, while piezometers 2 and 3 are located upstream; this makes it more likely to accumulate hexazinone. On the other hand, piezometer 3 has the lowest risk of accumulation due to its westerly location, at the outer edge of the spraying zone.

In the spring of 2007, the concentrations found in piezometer 1 had increased again after the second Pronone® application made in May of the same year. Then, the hexazinone levels went down progressively until the product was used another time. Because hexazinone degrades slowly, it was still being detected in May 2009, two years after the last use. Photo-degradation and biological decomposition are the principal hexazinone degradation mechanisms; it is generally stable in water. Hence, once it has percolated in the soil and sunk into the water table, it is relatively degradation-free and can persist over long periods. Changeover through the groundwater flow rate contributes to diluting the product and concentrations stabilize over time. But the slower the turnover rate, the more likely is the product to accumulate over time. It should be noted that hexazinone levels in water vary throughout the seasons.

The tendencies generally show reduced concentrations in the spring, followed by a slight increase and stabilization in the fall, which is likely related to dilution from melting snow. Following the use of Velpar in May 2009, concentrations in piezometer 1 went up considerably. Concentrations observed in the fall of 2009 were clearly above the average and maximum values found in other piezometers around the region (Table 12). However, it was still below the hexazinone guideline value for drinking water, or 500 µg/l (Health Canada, 2005).

Table 9. 2009 hexazinone concentrations in piezometer 1, compared with those of the Maria-Chapdelaine regional township.

Organization and date	Hexazinone concentrations (µg/l)
CAFN May 2009	3.9
CAFN September 2009	140
Maria-Chapdelaine regional township February 2009 (average)	9.3
Maria-Chapdelaine regional township February 2009 (average)	30.4

Source : Hexazinone concentration monitoring in groundwater, Maria-Chapdelaine regional township, 2008.
Note : The averages shown were obtained from sampling 10 piezometers in the Maria-Chapdelaine regional township.

Among the factors that may have contributed to groundwater contamination by hexazinone, the weather conditions during or following application (precipitations) may have influenced the probability of contamination. The depth of the water table may also influence the contamination level. The characteristics of the underground water network could also be the reason for the very high level, which is representative of maximum values yielded by an application soon after and cumulative to previous uses. Piezometer 1 is 4.12 m underground (shallow well) and the groundwater therein is 1.3 m deep. It is located downstream of groundwater flow in that sector. The groundwater flow and turnover rates in that area may be low. Lower hexazinone concentrations relative to water table depth have been previously noted in the piezometers (MEQ, 2003). As for surface water, very little or no hexazinone was found in the Ruisseau Rouge.

4.2.1 Assessment of outcome

The objectives of this research constituent were to assess pesticide levels in groundwater and derive a realistic picture of the evolution of hexazinone levels in groundwater and surface water.

The current results allow for determining the conditions that favour the presence of hexazinone in groundwater, that is, the presence of groundwater nearer to the surface. Hexazinone concentrations vary over time, but the product can remain in the groundwater nearly two years after use. Ruisseau Rouge surface water contamination is not a significant hazard. The high concentrations found in piezometer 1, at the end of the project, leads us to recommend continued regular, stringent monitoring in the CAFN piezometers, to make sure accumulations do not occur, and mainly to assess the efficiency of the corrective actions that must be envisioned. Correcting the situation requires that hexazinone application techniques be reviewed and analyzed with agro-environmental club advisers. Using GPS technology to better control the application process should be looked at. The sampling method recommended by the ministère du Développement durable, de l'Environnement et des Parcs must be closely followed (MDDEP, 2006). Sampling twice a year is recommended, in May (just prior to spraying) and in October (6 months after spraying). Given the significant hexazinone levels found in the fall of 2009, sampling in January or February 2010 should also be done to see if concentration levels have gone done in piezometer 1. The results of analyses could be compared to those of the Maria-Chapdelaine regional township, where sampling is done at the same time of year.

4.3. Research focus are 4 : Optimization of the production environment

4.3.1 Impact of the different forest/blueberry experimental setups on pollinator numbers (4A)

These data were collected in 2008 and 2009. The results of statistical data processing as regards indigenous pollinator numbers and diversity are described in this section. The analysis also examines the evolution of flowering as this aspect influences pollinator numbers. The findings of pollination effectiveness and its impact on fruit yields in 2008 and 2009 are also described.

Indigenous pollinator numbers

Indigenous pollinator numbers were assessed by visual count of individuals on blueberry bush flowers. Comparisons were made between blueberry strip widths and gradients, and based on three counting cycles: 1) At the start of flowering; 2) Mid-way through flowering; and 3) At the end of flowering. Flowering evolution was determined by counting the number of open flowers and buds.

As concerns the **evolution of flowering**, interpretation of the results reveals :

- Significant differences between the years 2008 and 2009. The number of open flowers per 10 stems for the three counting and sampling cycles was different (Figure 51). These differences may have influenced pollinator number comparisons, or again yield comparisons for those two years.
- No differences were observed between the alleys and strip widths in terms of flowering evolution. However, comparing the bud ratios of 2009, counting cycle three, reveals differences between strip widths (Figure 52). Flowering evolution in setup 42/60 was more pronounced than in setup 60/45. A closer look at the data showed that the three 45° strips, located in the southwest sector, blossomed earlier.

As for the **number-of-pollinators** variable, interpretation of the results reveals that :

- In 2008 and 2009, positive correlation was found between the number of open flowers and the number of pollinators observed on the flowers (Figure 53). The greater the number of open flowers, the more active were the pollinators.

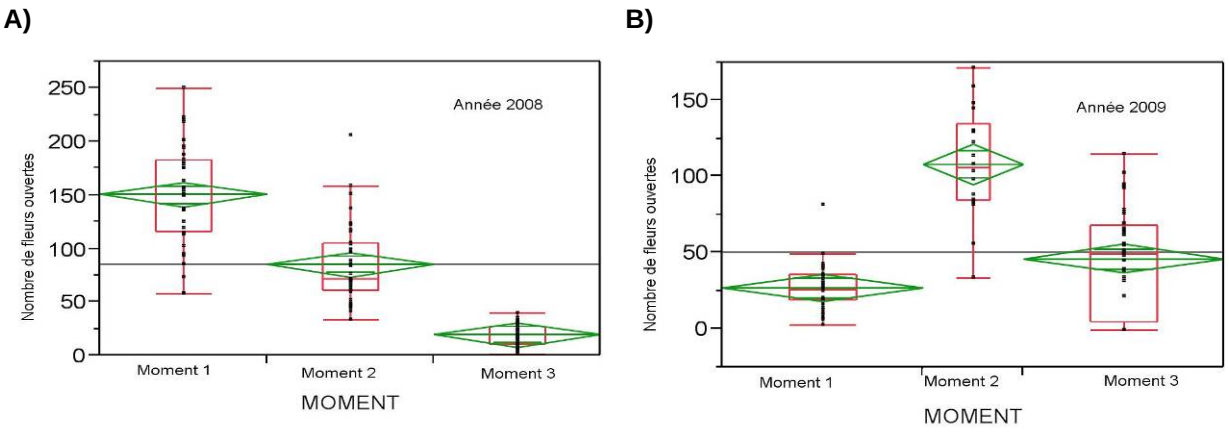


Figure 40. Number of open flowers per 10 stems, for three counting cycles in A) 2008 and B) 2009

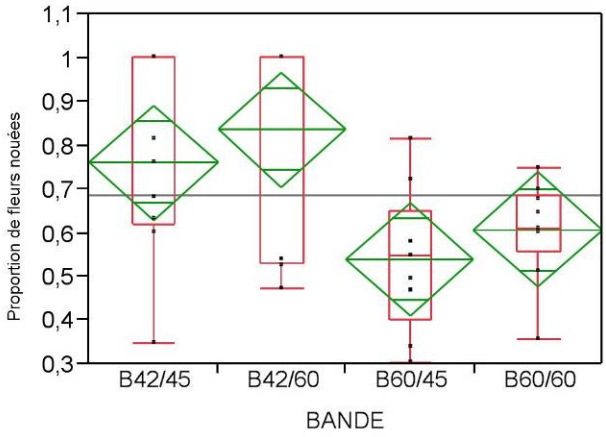
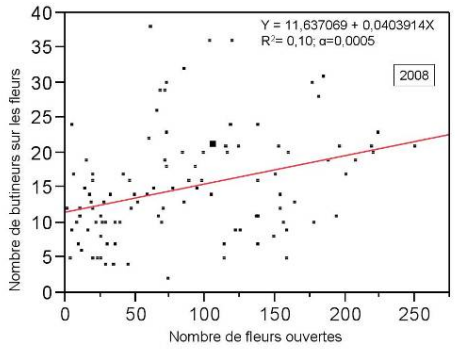


Figure 41. Bud ratio in counting cycle 3 relative to strips, 2009

A)



B)

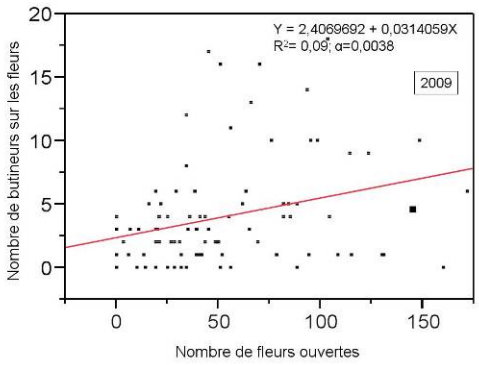


Figure 42. Relation between pollinator numbers and the number of open flowers in A) 2008 and B) 2009

- In 2008, counting began when blossoming was well under way (earlier than in 2009). The results from the three counting cycles allowed determining the movement dynamics of pollinators over time. The overall observations indicate that pollinators do not forage at the centre of the blueberry strips early in the flowering period. Hence, it would seem that they start by foraging along the edges, near the forest strips initially, and then move inward towards the centre of the blueberry strips as flowering progresses. The phenomenon was observed in all experimental setups (Figure 54). Further observations made over the two years yield a complete picture of pollinator movement dynamics, as their behaviour is one of progressive foraging of the resource, starting at the edges of the forest strips. When all the flowers at the edges have been pollinated, the pollinators move towards the centre of the blueberry strips. It should be noted that once a flower has been pollinated, it stops producing

nectar and pollen, and therefore is less likely to attract pollinators. These results also show that weather conditions leading to early flowering enhanced foraging into the centre of the blueberry strips by pollinators that hibernate in the forest strips (Chagnon, 2009).

- In 2009, pollinators were found in larger numbers in the 60/45 experimental setup (Figure 56). This 45° 60/45 setup had a high density of blueberry stems, based on previous observations (Figure 47). In all evidence, denser bushes lead to higher numbers of pollinators. This difference between strips was not observed in 2008, but it should be noted that the quality of the setups for 10° strips was more uniform.

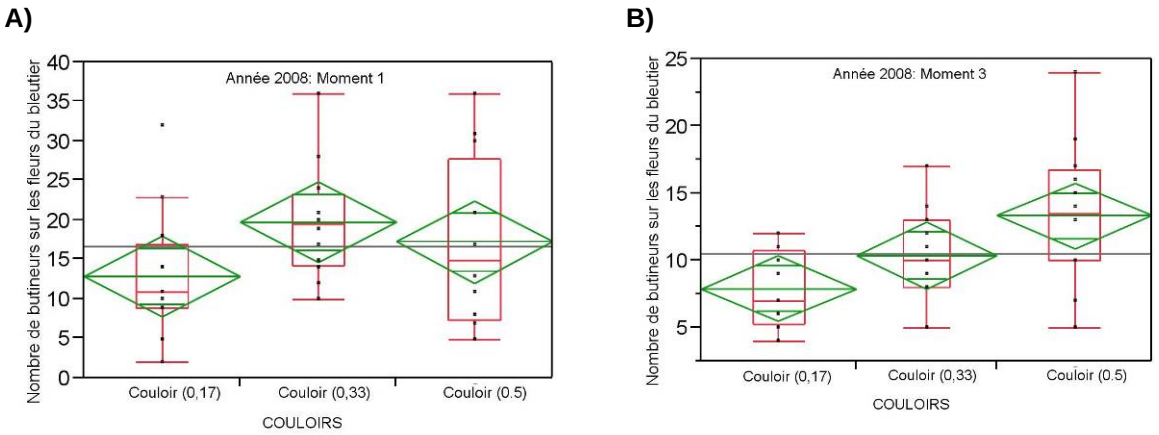


Figure 43. Number of pollinators on open flowers A) counting cycle 1 and B) counting cycle 3, relative to strips, 2008

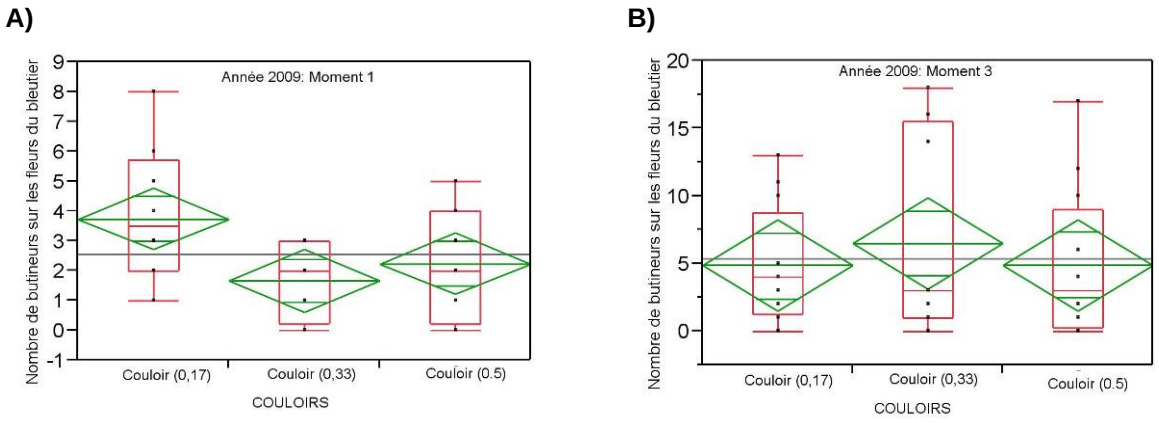


Figure 44. Number of pollinators on open flowers A) counting cycle 1 and B) counting cycle 3, relative to strips, 2009

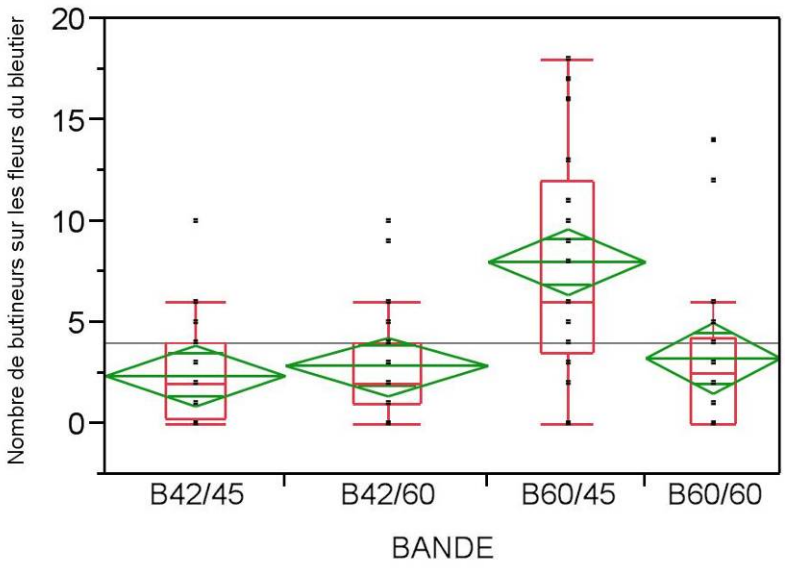


Figure 45. Number of pollinators on blueberry flowers relative to strip width, 2009

Indigenous pollinator diversity

A total of 512 insects distributed among 40 species were sampled over the two-year study, using three separate collecting methods. Table 13 summarizes the large number of specimens. The results of the diversity study are quite similar to those from a Saguenay–Lac-Saint-Jean region blueberry field study, in which 39 species connected to blueberry bush pollination were identified (Gagnon, 2009). It should be noted that, individually, some indigenous pollinators can be up to four times as efficient as domestic bees, particularly *Bombus sp*. and *Andrena sp*. queens (Chagnon, 2009).

Table 10. List of species collected from the forest/blueberry experimental setups (CAFN) in 2008 and 2009, according to three sampling methods

Species	2009		2008	Total
	Trap	Hand capture	Net	
Andrena alleghaniensis	1	0	0	1
Andrena bisalicis	1	0	0	1
Andrena bradleyi	2	0	0	2
Andrena carolina	4	1	3	8
Andrena dunningi	11	1	0	12
Andrena erigeniae	2	0	0	2
Andrena melanochroa	1	0	0	1
Andrena regularis	4	4	0	8
Andrena tridens	5	0	0	5
Andrena vicina	1	0	0	1
Andrena w-scripta	1	1	0	2
Apis mellifera	14	13	12	39
Bombus borealis	3	1	0	4
Bombus fervidus	3	0	0	3
Bombus frigidus	0	4	11	15
Bombus impatiens	0	1	0	1
Bombus insularis	0	3	0	3
Bombus rufocinctus	1	0	0	1
Bombus ternarius	4	6	17	27
Bombus vagans	1	0	0	1
Colletes consors	0	0	3	3
Hylaeus modestus	1	0	0	1
Laisioglossum rufulipes	1	0	0	1
Laisioglossum tenax	1	0	0	1
Lasioglossum athabascense	8	0	0	8
Lasioglossum cinctipes	5	0	0	5
Lasioglossum forbesii	0	0	2	2
Lasioglossum foxii	4	0	7	11
Lasioglossum pilosum	8	0	0	8
Lasioglossum planatum	4	0	0	4
Lasioglossum quebecense	2	1	0	3
Lasioglossum zonulum	1	0	0	1
Megachile rotundata	227	22	32	281
Nomada imbricata	1	0	0	1
Osmia atriventris	1	0	0	1
Osmia inermis	1	0	0	1
Osmia kenoyeri	29	1	0	30
Osmia virga	5	0	1	6
Sphecodes levis	4	0	0	4
Sphecodes solonis	3	0	0	3

Sweeping net catches in 2008 were too low for statistical data processing to determine the effect of strip width on the diversity of wild species foraging on blueberry flowers. Observations lead to the following findings :

- The rainy weather in the summer of 2008 certainly affected the number of insects captured.
- Introduced pollinators (domestic and leafcutting bees) made up 50 % of the captured insects.

The **hand-capture and baited trap** methods used in 2009 were complementary, efficient, and led to improved information on pollinator diversity. Analysis of the data led to the following :

- The large insect species, particularly bumblebees (*Bombus*), were collected by hand only. Inversely, several of the important blueberry pollinators, notably *Lasioglossum* and *Osmia* were captured using baited traps. Trapping was more efficient for sampling abundance and diversity of species (Table 14). The methods used in 2009 were appropriate.
- Analysis of the baited trap results, relative to alleys within the strips, confirms that higher numbers of specimens were found in alleys located at the edges of the forest strips. However, the same tendency was not seen as concerns the diversity of species (Table 15). Some species in fact seemed to clearly avoid the central alleys. Hence, *Andrena regularis* and *Lassioglossum pilosum* were only collected from the outer edges, while *Osmaia kenoyeri* were relatively abundant in the side alleys (86 %) compared to the central alleys of the blueberry strips (14 %). The results of hand capture always showed a lower ratio of individuals harvested from the edges of the forest strips (Table 16) (Chagnon, 2009).

Table 11. Numbers and diversity (number of species) of pollinators in the CAFN blueberry-strip setup in 2008 and 2009

Method	Numbers	Diversity
Baited traps 2009	365	35
Hand capture 2009	59	13
Sweeping net 2008	88	9
Total captures 2008-2009	**512**	**40**

Table 12. Number of specimens and species collected with baited traps in 2009, relative to alleys

	Alley O,17	Alley O,33	Alley O,5
Number of specimens	136	133	96
Number of species	23	20	19

Table 13. Number of specimens and species collected by hand in 2009, relative to alleys

	Alley A O,17	Alley B O,33	Alley C O,5
Number of specimens	6	15	16
Number of species	4	7	6

- The analysis of baited trap results, per cycle, shows greater diversity of species for cycle 1, when the leafcutting bees had not yet been introduced (Table 17). A large number of indigenous pollinators had disappeared by the time cycles 2 and 3 came around. This could mean that there is competition between the leafcutting bees introduced and the wild pollinators, which likely populate the forest strips alongside the blueberry production strips.
- Analysis of the 2009 results, according to alleys and strip widths, and without leafcutting bees, reveals that larger numbers of specimens were found along the edges of the forest strips than at the centre of the blueberry strips, and especially for the 42/60 and 60/60 setups (Figure 57).

Table 14. Number of specimens and species collected with baited traps, per cycle in 2009

	Cycle 1	Cycle 2	Cycle 3
Number of specimens	96	154	115
Number of species	28	14	13

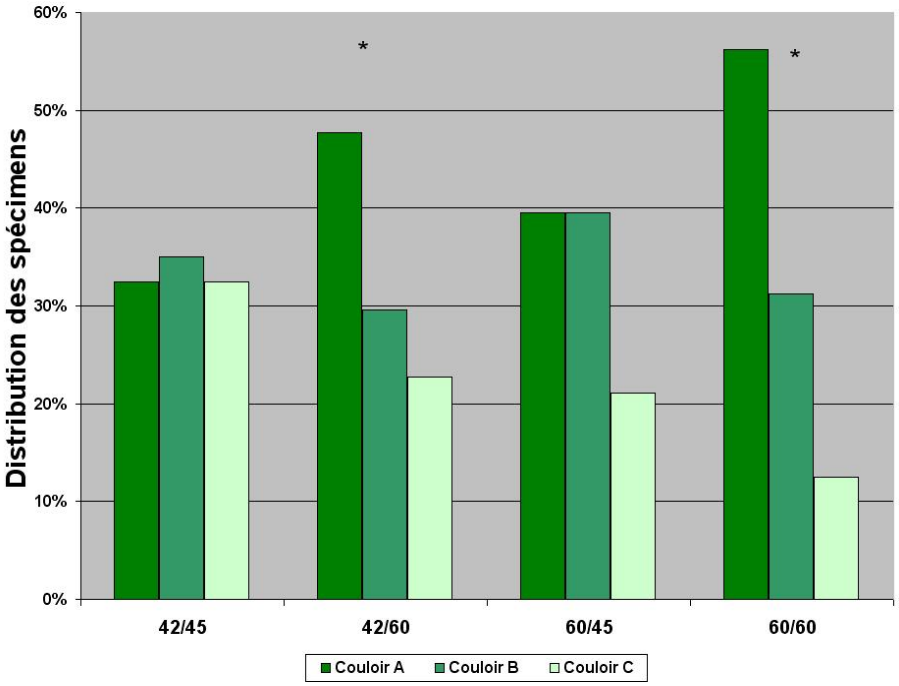


Figure 46. Distribution of baited trap specimens in 2009, according to alleys and strips, leafcutting bees excluded

Pollination effectiveness and effect on fruit yield

Pollination effectiveness and effect on fruit yield were principally studied from the viewpoint of harvest quality. The ratio of large, well-developed fruit was the criterion used to assess harvest quality largely resulting from pollinating insect action. As mentioned earlier, for the two years of the study, no differences were found in total weight of fruit harvested from plots having different strips widths and harvest alley gradients. There were no differences between strip widths in terms of blueberries classed as “large” for the two years of the study. In 2008, the ratio of large blueberries was higher for alleys located near the forest strips than in the centre of the blueberry strips, for all strips. The percentage of large fruit was always above 80 %. This was more pronounced in the 60/45 and 60/60 setups. These data are shown in the histogram of Figure 58. However, in should be noted that only three samples are represented. The tendency was not observed in 2009 (Figure 59). In 2009, the percentage of large fruit was above 80 % for all strips except the 42/60 and 60/45 setups.

Yet, in 2009, flowering came early in the 42/60 setup, and indigenous pollinators had a larger presence in the alleys along the edges. What stands out here is the fact that leafcutting bees had not yet been introduced in these plots when the first captures were made, and setup 42/60 had begun to blossom. The absence of leafcutting bees could be the reason behind the lower fruit quality in every alley of the 42/60 setup.

As concerns the 60/45 setup, flowering occurred significantly late and harvest may have been done before the fruits all had enough time to reach full maturity.

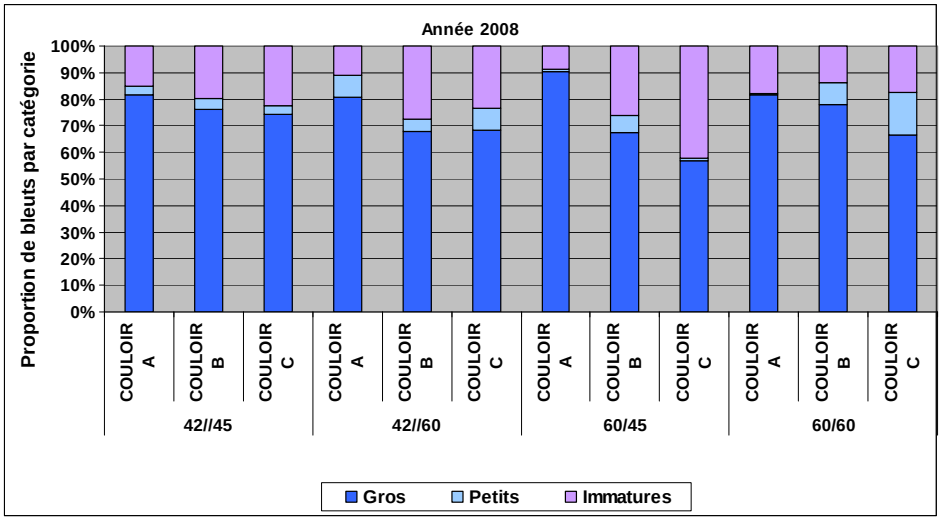


Figure 47. 2008 ratio of blueberry categories in the three alleys, relative to strip width

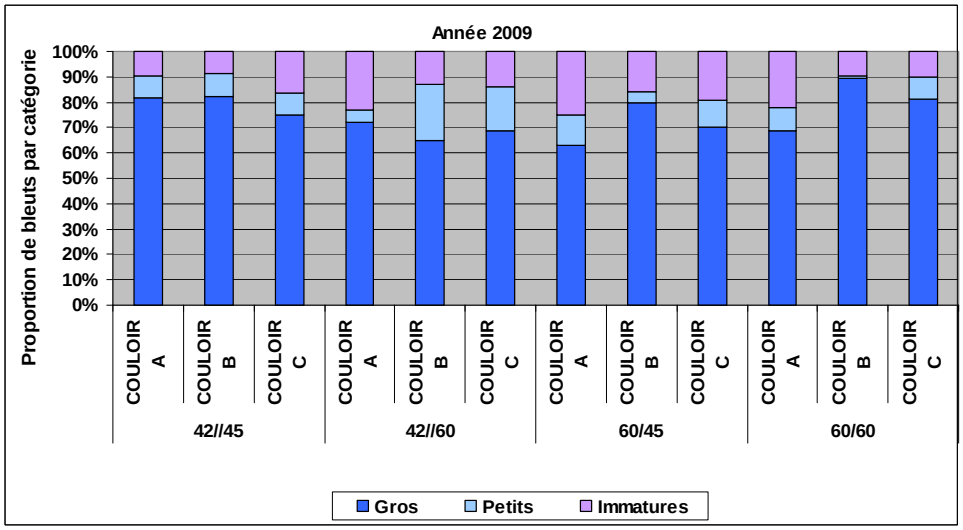


Figure 48. 2009 ratio of blueberry categories in the three alleys, relative to strip width

Pollinating insect foraging was put in parallel with fruit quality to validate observation data. Based on foraging results, better fruit development should have been noted in the alleys bordering the forest strips since a larger ratio of pollinators had been harvested, in 2009, for several experimental setups, at a time when the tendency had not clearly revealed itself. Pollinator action seems to have been fairly evenly distributed among the three alleys in 2009.

The small pollinators, mainly collected in baited traps, seemed to forage in the alleys along the edges at the beginning of flowering, and then extend their territory towards the centre of the blueberry strips over time. This is probably due to the fact that pollinated flowers soon start budding fruit and become useless for pollinators as their resources are depleted. In the wider blueberry strips (60 metres), small pollinators take longer to forage into the centre alleys (Figure 57). The small pollinators are the ones that pollinate the alleys bordering the forest strips. If flowering is delayed by weather conditions (spring thaw), foraging into the centre alley by the small pollinators is also delayed. The larger insects were more abundant in the centre alleys, but generally travel over longer distances. The complementary behaviours of small and large pollinators seem to ensure good pollination across the entire strips. It should be noted that a non-pollinated flower remains open for about eight days. Weather conditions (rain, wind, cold) can also affect pollination efficiency, as they influence pollinator behaviour.

4.3.2 Assessment of outcome (constituent 4A)

The objective of this research constituent was to analyze the effect of the different forest/blueberry experimental setups on indigenous pollinator populations, relative to the different strip widths and alignments.

The results do not allow for determining, based on pollination effectiveness and effect of fruit yield, if a strip width or alignment is better than another. However, since alignment influences spring thaw in some strips widths, it indirectly influences the onset of flowering and, as a consequence, the pollinator foraging period. The largest differences concerned foraging intensity along the edges of the forest strips as opposed to the centre alleys of 60-metre blueberry strips.

The current results confirm that the CAFN experimental setup forest strips contain large natural pollinator populations that are well adapted to the blueberry bush. The complementary behaviours of the different pollinator species found of blueberry flowers seem to ensure good pollination across the entire strips. The overall observations reveal that the weather conditions favouring early flowering, which enhances pollinator foraging in all parts of the blueberry strips, lead to better yield, expressed in ratio of mature, large fruit. However, if weather conditions favour early flowering, leafcutting bees have to be introduced at that point. If the blueberry strip is wider, indigenous pollinators will take more time to reach the centre strip. On the other hand, if flowering occurs later in some of the strips, harvest dates have to be pushed back. As concerns this experimental constituent, all strips were harvested on the same date, but normally the harvest schedule is set according to fruit maturity within the strips in any given area.

4.3.3 Effect of forestry residue management on setup and yield (4B)

As mentioned earlier, variance analysis (ANOVA) was used to compare the thickness of the residue layer, blueberry stem generation, and fruit yield in 2009, the results of which are described below.

Measurement of the residue layer thickness conducted two years following setup showed that the residue layer is effectively thicker in areas where it was left lying on the ground. Based on the stem-count data of 2008 and 2009, the way forestry residue is managed does not seem to significantly affect blueberry stem densities. In 2008, wide data variability was observed. Table 18 shows the average number of stems per 10-metre transect for 2009. Residue management did not significantly influence the 2009 yield. The results of 0.25 m^2 harvests varied widely. The average weight of fruit (large and small) for residue-free plots varied from 163 g/m^2 to 261 g/m^2, and from 120 to 220 g/m^2 for plots with residue.

Table 15. Average number of stems over 10 linear metres for 2008 and 2009

Setup	Stem generation/10 linear metres (average of 16 transects)		
With residue 2009	70	±	5
Without residue 2009	72	±	5

4.3.4 Assessment of outcome (constituent 4B)

The objective of this research constituent was to compare two forestry residue management modes as blueberry strips are being set up. In one the residue was removed from the blueberry plots, and in the other, the residue was left lying on the ground.

Removing the forestry residue before crushing the blueberry strips offers no advantage in terms of blueberry bush density and yield from the first harvest. It engenders unnecessary costs and does not significantly increase income in the end.

5. CONCLUSIONS AND RECOMMENDATIONS

This three-year project was completed in line with the planned objectives and schedule. The overall goal, validating and optimizing the forest/blueberry alternate-strip production model and providing potential users with the data they need to further knowledge, was attained. The forest/blueberry production model was tested and validated by comparing four blueberry and forest strip widths and two strip alignments. The project enabled to :

- Measure the effect of different experimental setups (strip width and alignment) on the agroclimatic conditions within the blueberry strips.
- Determine the effect of the different setups on blueberry yield.
- Understand the environmental evolution of pesticides following their use in a forest/blueberry production design.
- Analyze the influence of the different setups on indigenous pollinator populations.
- Compare two forestry residue management modes used in setting up blueberry strips.

The results of this project, conducted on CAFN land, can be applied to the Normandin site, but cannot be generalized to the entire Saguenay–Lac-Saint-Jean region, or to other Québec regions. Complementary studies are required to be able to apply the model to other blueberry farms in the province.

The final results lead to the following conclusions :

- The **northeast-southwest alignment** (45° north) seemed best for the CAFN site as it **enhances the flow of cold air generated by frost** and keeps it from remaining trapped within blueberry strips. In this experimental setup the average T° were higher, with a larger number of cumulative degree-days during the growing season, minimum temperatures occurred less frequently, and the risk of frost was lower.
- The forest strips generated a radiation effect. The centres of blueberry strips were more at risk of frost than the outer edges, and the risk of frost was higher when forest strips are 60 metres wide. Hence, **42-metre-wide forest strips** seem to provide **better protection against the risk of frost at the centre of blueberry strips**.
- The 45° blueberry strips alongside 42-metre forest strips lose their snow cover earlier in the spring.
- The production cycle, physiological stage, and composition of the soil have a greater influence on the water needs and water stress levels of blueberry bushes than strip width and alignment.

The use of hexazinone led to the following observations :

- The characteristics of the groundwater (turnover rate and depth) and piezometer 1 in the Ruisseau Rouge sector are favourable to the use of hexazinone over several years.
- Hexazinone concentrations vary from one season to the next and are highest during the fall sampling runs.
- Ruisseau Rouge surface water contamination is not a major risk.

To control and reduce the risk of water contamination on CAFN lands, the following recommendations are made for 2010 :

- Conduct regular monitoring (May and October) of hexazinone concentrations in groundwater.
- Conduct an additional analysis in February 2010 to follow up on the evolution of hexazinone concentrations since the last intervention (May 2009), which showed considerable increase in contamination levels.
- Review and analyze the hexazinone intervention techniques in the Ruisseau Rouge sector.
- Consider using GPS technology to better control herbicide applications.

The results of the experimental constituent aimed at pollinator foraging led to the following confirmations :

- Strip alignment and width had no direct impact on pollination effectiveness. As alignment influences spring thaw for some strip widths, it indirectly influences the flowering period of blueberry bushes and, thereby, the pollination period.
- The 60-metre blueberry strips show a greater difference between pollinator numbers along the edges of the forest strips and at the centre of the blueberry strips (radiation effect). Foraging intensity is lower at the centre of the 60-metre blueberry strips, but this has no direct effect of pollination intensity because full pollination of the centre alleys can occur, under the right conditions. Some pollinator species forage progressively across the blueberry strips.
- The forest/blueberry strips established on CAFN lands contain large natural pollinator populations that are well adapted to the blueberry bush.
- If weather conditions are favourable to early flowering, leafcutting bees should be introduced right at the beginning of blossoming. Leafcutting bees have a positive impact on fruit yield and quality. Leafcutting bees and natural pollinators have complementary behaviours that enhance pollination across the entire blueberry strip.

The study of forestry residue management led to the following conclusions :

There seems to be no agronomic advantage to removing forestry residue prior to shredding in blueberry strips. The practice certainly reduces shredding time, but is an additional expense and does not lead to increased income (yield) in the end.

Finally, these experiments also led to the conclusion that the forest/blueberry production model has a yield potential (stems, flower buds, and fruits) that is similar to conventional blueberry fields.

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APPENDIX 1.
T° VARIANCE ANALYSES

ANALYSES DE VARIANCE DE LA VARIABLE TEMPÉRATURE (1)

Tableau A. Analyse de variance (ANOVA) des températures moyennes, minimales et maximales ainsi que du nombre de degrés-jours cumulés mensuellement durant la saison 2006

Source	d.l. num.	Temp. moyenne d.l. dén.	Temp. moyenne F	Temp. moyenne P	Nb de degrés-jours d.l. dén.	Nb de degrés-jours F	Nb de degrés-jours P	Temp. minimale d.l. dén.	Temp. minimale F	Temp. minimale P	Temp. maximale d.l. dén.	Temp. maximale F	Temp. maximale P
Parcelles principales													
Bande-Forêt (BF)	1	8,0	0,09	0,7689	8,0	0,07	0,7925	8,0	0,86	0,3804	8,1	0,91	0,3689
Bande-Bleuet (BB)	1	8,0	0,00	0,9887	8,0	0,00	0,9489	8,0	0,48	0,5087	8,1	4,33	0,0707
BF x BB	1	8,0	0,02	0,8886	8,0	0,02	0,8995	8,0	0,03	0,8638	8,1	0,25	0,6295
Sous-parcelles													
Gradient (G)	3	23,6	0,99	0,4155	23,6	0,97	0,4252	24,2	2,65	0,0715	24,2	1,74	0,1846
BF x G	3	23,6	0,82	0,4944	23,6	0,74	0,5370	24,2	0,55	0,6531	24,2	0,57	0,6427
BB x G	3	23,6	0,96	0,4294	23,6	1,26	0,3123	24,2	0,52	0,6708	24,2	1,21	0,3279
BF x BB x G	3	23,6	0,50	0,6834	23,6	0,43	0,7346	24,2	0,69	0,5697	24,2	2,09	0,1274
Mesures répétées													
Mois (M)	4	123,7	65522,23	**<0,0001**	123,7	87673,26	**<0,0001**	123,7	6516,84	**<0,0001**	124,1	2976,00	**<0,0001**
BF x M	4	123,7	0,44	0,7785	123,7	0,13	0,9723	123,7	1,60	0,1783	124,1	0,32	0,8625
BB x M	4	123,7	3,41	**0,0111**	123,7	2,80	**0,0288**	123,7	2,16	0,0770	124,1	1,34	0,2578
BF x BB x M	4	123,7	1,24	0,2979	123,7	1,06	0,3812	123,7	0,94	0,4437	124,1	1,45	0,2219
G x M	12	123,6	3,99	**0,0000**	123,6	3,35	**0,0003**	123,7	1,02	0,4364	124,1	0,93	0,5196
BF x G x M	12	123,6	0,41	0,9572	123,6	0,31	0,9863	123,7	0,23	0,9966	124,1	0,68	0,7648
BB x G x M	12	123,6	1,22	0,2775	123,6	1,03	0,4228	123,7	0,37	0,9724	124,1	0,54	0,8846
BF x BB x G x M	12	123,6	0,60	0,8377	123,6	0,41	0,9593	123,7	0,27	0,9923	124,1	0,24	0,9957

Tableau B. Analyse de variance (ANOVA) des températures moyennes, minimales et maximales ainsi que du nombre de degrés-jours cumulés mensuellement durant la saison 2007

Source	d.l. num.	Temp. moyenne			Nb de degrés-jours			Temp. minimale			Temp. maximale		
		d.l. dén.	F	P	d.l. dén.	F	P	d.l. dén.	F	P	d.l. dén.	F	P
Parcelles principales													
Orientation (O)	1	17	3.105	0.0964	17	2.186	0.1579	17	0.006	0.9370	19	0.324	0.5756
Bande-Forêt (BF)	1	15	0.035	0.8545	15	0.007	0.9333	16	0.251	0.6233	17	2.563	0.1282
Bande-Bleuet (BB)	1	17	0.236	0.6337	17	0.117	0.7364	17	0.164	0.6909	19	4.996	**0.0376**
BF x BB	1	15	1.142	0.3017	15	0.773	0.3930	16	0.283	0.6018	17	0.140	0.7134
O x BF	1	15	0.019	0.8920	15	0.012	0.9146	16	2.585	0.1271	17	0.238	0.6319
O x BB	1	17	0.017	0.8989	17	0.011	0.9161	17	0.851	0.3694	19	2.227	0.1518
O x BF x BB	1	15	0.275	0.6076	15	0.310	0.5857	16	0.008	0.9288	17	0.770	0.3928
Sous-parcelles													
Gradient (G)	3	51	0.778	0.5115	51	0.781	0.5103	64	15.948	**<.0001**	60	1.821	0.1529
O x G	3	51	0.892	0.4514	52	0.749	0.5280	64	1.367	0.2608	60	0.973	0.4115
BF x G	3	45	1.825	0.1562	45	1.777	0.1652	57	1.329	0.2738	53	0.304	0.8223
BB x G	3	41	0.579	0.6325	41	0.634	0.5972	53	0.520	0.6701	49	1.002	0.3999
BF x BB x G	3	41	1.544	0.2178	41	1.839	0.1554	53	0.472	0.7028	49	2.759	0.0522
O x BF x G	3	44	1.222	0.3130	44	1.249	0.3034	56	0.973	0.4119	52	1.674	0.1839
O x BB x G	3	41	0.254	0.8578	41	0.284	0.8367	53	0.676	0.5709	48	2.194	0.1007
O x BF x BB x G	3	41	1.707	0.1808	40	1.634	0.1966	53	0.340	0.7966	48	2.875	**0.0456**
Mesures répétées													
Mois (M)	4	218	3123.683	**<.0001**	218	4487.200	**<.0001**	229	2177.920	**<.0001**	227	392.282	**<.0001**
O x M	4	218	1.773	0.1354	218	1.979	0.0987	228	28.807	**<.0001**	228	2.473	**0.0453**
BF x M	4	216	1.202	0.3111	215	1.150	0.3338	228	0.336	0.8533	224	0.423	0.7919
BB x M	4	218	0.679	0.6076	218	0.663	0.6186	229	1.054	0.3801	227	1.067	0.3736
BF x BB x M	4	216	1.176	0.3223	215	1.068	0.3734	228	1.253	0.2896	224	2.333	0.0567
O x BB x M	4	218	1.118	0.3489	218	1.003	0.4069	229	0.651	0.6266	228	0.887	0.4726
G x M	12	222	1.441	0.1486	221	1.478	0.1338	233	1.365	0.1837	228	1.494	0.1272
O x G x M	12	222	1.078	0.3798	221	1.087	0.3718	233	0.555	0.8763	228	1.128	0.3381
BF x G x M	12	216	0.828	0.6214	216	0.864	0.5844	229	0.610	0.8331	224	0.945	0.5025
BB x G x M	12	217	0.624	0.8204	216	0.554	0.8770	229	0.370	0.9728	224	0.980	0.4684
BF x BB x G x M	12	217	1.057	0.3984	216	1.049	0.4052	229	0.228	0.9969	224	0.359	0.9759

Tableau C. Analyse de variance (ANOVA) des températures moyennes, minimales et maximales ainsi que du nombre de degrés-jours cumulés mensuellement durant la saison 2008

Source	d.l. num.	Temp. moyenne			Temp. maximale			Temp. minimale			Nb de degrés-jours		
		d.l. dén.	F	P	d.l. dén.	F	P	d.l. dén.	F	P	d.l. dén.	F	P
Parcelles principales													
Orientation (O)	1	16.53	11.766	**0.0033**	16.32	1.307	0.2695	14.53	14.653	**0.0017**	16.64	9.820	**0.0062**
Bande-Forêt (BF)	1	16.53	1.600	0.2234	16.32	0.202	0.6587	14.53	0.179	0.6781	16.64	1.011	0.3290
Bande-Bleuet (BB)	1	16.53	2.477	0.1345	16.32	0.136	0.7172	14.53	1.717	0.2105	16.64	2.674	0.1208
BF x BB	1	16.53	5.179	**0.0365**	16.32	0.335	0.5704	14.53	0.346	0.5656	16.64	2.651	0.1223
O x BF	1	16.53	1.319	0.2671	16.32	0.138	0.7152	14.53	3.836	0.0697	16.64	1.212	0.2866
O x BB	1	16.53	0.009	0.9259	16.32	0.454	0.5099	14.53	1.525	0.2365	16.64	0.090	0.7681
O x BF x BB	1	16.53	0.299	0.5920	16.32	0.294	0.5949	14.53	0.013	0.9099	16.64	0.000	0.9881
Sous-parcelles													
Gradient (G)	3	49.2	2.338	0.0850	48.41	14.929	**<0.0001**	48.43	21.923	**<0.0001**	49.7	2.408	0.0782
$G_{linéaire}$	1	-	-	-	47.8	43.261	**<0.0001**	161.79	4492.947	**<0.0001**	-	-	-
$G_{quadratique}$	1	-	-	-	48.39	9.120	**0.0040**	157.05	15616.705	**<0.0001**	-	-	-
$G_{cubique}$	1	-	-	-	49.05	9.962	**0.0027**	155.6	378.024	**<0.0001**	-	-	-
O x G	3	49.2	0.966	0.4163	48.41	0.324	0.8079	48.43	2.723	0.0544	49.7	0.845	0.4758
BF x G	3	49.2	0.689	0.5634	48.41	0.309	0.8185	48.43	0.305	0.8218	49.7	0.804	0.4976
BB x G	3	49.2	0.870	0.4632	48.41	1.618	0.1973	48.43	0.752	0.5266	49.7	0.749	0.5282
BF x BB x G	3	49.2	0.978	0.4107	48.41	1.797	0.1603	48.43	0.606	0.6141	49.7	0.862	0.4668
O x BF x G	3	49.2	0.784	0.5089	48.41	0.254	0.8580	48.43	1.486	0.2302	49.7	1.019	0.3924
O x BB x G	3	49.2	0.157	0.9248	48.41	0.447	0.7205	48.43	0.434	0.7294	49.7	0.162	0.9215
O x BF x BB x G	3	49.2	1.035	0.3852	48.41	0.694	0.5603	48.43	0.224	0.8789	49.7	1.134	0.3442
Mesures répétées													
Mois (M)	3	165.4	17816.860	**<0.0001**	160.4	13.723	**<0.0001**	158.1	5955.480	**<0.0001**	166.1	18862.070	**<0.0001**
O x M	3	165.4	7.210	**0.0001**	160.4	5.296	**0.0017**	158.1	29.498	**<0.0001**	166.1	10.215	**<0.0001**
BF x M	3	165.4	1.213	0.3067	160.4	1.514	0.2129	158.1	1.012	0.3892	166.1	1.351	0.2596
BB x M	3	165.4	1.427	0.2368	160.4	3.862	**0.0106**	158.1	3.755	**0.0122**	166.1	1.318	0.2705
BF x BB x M	3	165.4	2.434	0.0668	160.4	1.625	0.1856	158.1	0.037	0.9906	166.1	3.461	**0.0177**
O x BF x M	3	165.4	0.848	0.4696	160.4	5.923	**0.0007**	158.1	3.666	**0.0137**	166.1	1.366	0.2549
O x BB x M	3	165.4	0.763	0.5165	160.4	1.074	0.3617	158.1	0.126	0.9447	166.1	0.821	0.4843
O x BF x BB x M	3	165.4	0.287	0.8346	160.4	0.579	0.6299	158.1	0.273	0.8448	166.1	2.750	**0.0445**
G x M	9	168.6	2.585	**0.0081**	164.9	1.078	0.3820	165.3	3.023	**0.0023**	169.8	2.035	**0.0382**
O x G x M	9	168.6	0.365	0.9505	164.9	1.592	0.1212	165.3	0.714	0.6953	169.8	0.252	0.9858
BF x G x M	9	168.6	0.542	0.8427	164.9	1.291	0.2450	165.3	0.514	0.8629	169.8	0.472	0.8921
BB x G x M	9	168.6	0.212	0.9925	164.9	0.448	0.9072	165.3	0.276	0.9805	169.8	0.235	0.9890
BF x BB x G x M	9	168.6	0.370	0.9481	164.9	0.562	0.8268	165.3	0.222	0.9911	169.8	0.399	0.9345
O x BF x G x M	9	168.6	1.056	0.3978	164.9	0.517	0.8612	165.3	0.313	0.9699	169.8	0.870	0.5535
O x BB x G x M	9	168.6	0.488	0.8816	164.9	0.641	0.7607	165.3	0.360	0.9524	169.8	0.436	0.9141
O x BF x BB x G x M	9	168.6	1.338	0.2208	164.9	2.211	**0.0237**	165.3	0.238	0.9884	169.8	1.201	0.2975

Tableau D. Analyse de variance (ANOVA) des températures moyennes, minimales et maximales ainsi que du nombre de degrés-jours cumulés mensuellement durant la saison 2009

Source	d.l. num.	d.l. dén.	Temp. Moyenne		Temp. Maximale		Temp. Minimale		Nb de degrés-jours	
			Rapport F	Prob. > F	Rapport F	Prob. > F	Rapport F	Prob. > F	Rapport F	Prob. > F
Parcelles principales										
Bande-Forêt (BF)	1	8	6.253	**0.0368***	0.935	0.3624	1.460	0.2614	7.288	**0.0282***
Bande-Bleuet (BB)	1	8	0.120	0.7376	0.233	0.6422	0.665	0.4385	0.431	0.5308
(BF) x (BB)	1	8	3.054	0.1186	0.047	0.8342	2.211	0.1753	2.494	0.1546
Sous-parcelles										
Gradient (G)	3	23	3.291	**0.0383***	4.920	**0.0085***	6.444	**0.0023***	3.087	**0.0469***
BF x G	3	23	0.753	0.5319	0.869	0.4708	0.391	0.7608	0.646	0.5934
BB x G	3	23	4.396	**0.0136***	7.355	**0.0012***	3.278	**0.0382***	3.945	**0.0206***
BF x BB x G	3	23	0.416	0.7431	1.885	0.1597	0.281	0.8384	0.502	0.6848
Mesures répétées										
Mois (M)	3	93	2250.481	**<.0001***	63.364	**<.0001***	1777.964	**<.0001***	30216.420	**<.0001***
BF x M	3	93	3.868	**0.0118***	0.053	0.9840	1.316	0.2737	0.217	0.8843
BB x M	3	93	0.380	0.7676	0.946	0.4219	3.662	**0.0151***	0.745	0.5282
BF x BB x M	3	93	3.375	**0.0217***	0.633	0.5953	1.427	0.2398	0.662	0.5777
G x M	9	93	1.271	0.2632	0.888	0.5391	0.349	0.9557	1.307	0.2444
BF x G x M	9	93	0.245	0.9867	0.262	0.9830	0.411	0.9264	0.496	0.8736
BB x G x M	9	93	1.338	0.2285	1.918	0.0588	1.279	0.2587	1.602	0.1263
BF x BB x G x M	9	93	0.112	0.9993	0.621	0.7764	0.426	0.9183	0.447	0.9058

APPENDIX 2.

RISK OF FROST VARIANCE ANALYSES

Tableau A. Analyse de variance (ANOVA) du nombre de périodes où les températures étaient inférieures à 0 °C , -2 °C, -5 °C ou variaient entre 10 et 30 °C durant la saison 2006

Source	d.l. num.	Nb périodes T < 0°C			Nb périodes T < -2°C			Nb périodes T < -5°C			Nb période 10°C < T < 30°C		
		d.l. dén.	F	P	d.l. dén.	F	P	d.l. dén.	F	P	d.l. dén.	F	P
Parcelles principales													
Bande-Forêt (BF)	1	8,1	0,803	0,3962	8,0	0,388	0,5506	8,0	0,775	0,4041	8,0	0,040	0,8471
Bande-Bleuet (BB)	1	8,1	0,006	0,9402	8,0	0,137	0,7210	8,0	0,059	0,8146	8,0	1,552	0,2481
BF x BB	1	8,1	0,010	0,9236	8,0	0,000	0,9870	8,0	0,004	0,9498	8,0	0,007	0,9338
Sous-parcelles													
Gradient (G)	3	23,9	1,178	0,3388	22,5	1,981	0,1455	23,0	0,644	0,5947	23,7	2,271	0,1064
BF x G	3	23,9	0,159	0,9229	22,5	0,249	0,8612	23,0	0,438	0,7281	23,7	0,073	0,9737
BB x G	3	23,9	0,574	0,6378	22,5	0,776	0,5196	23,0	0,622	0,6081	23,7	1,316	0,2927
BF x BB x G	3	23,9	0,682	0,5718	22,5	0,753	0,5322	23,0	0,510	0,6795	23,7	0,949	0,4326
Mesures répétées													
Mois (M)	4	124,1	1413,007	**<0,0001**	123,5	747,317	**<0,0001**	124,1	142,066	**<0,0001**	123,5	11417,865	**<0,0001**
BF x M	4	124,1	1,814	0,1304	123,5	0,786	0,5365	124,1	2,153	0,0782	123,5	0,652	0,6264
BB x M	4	124,1	0,279	0,8908	123,5	1,003	0,4089	124,1	0,427	0,7889	123,5	1,332	0,2618
BF x BB x M	4	124,1	0,407	0,8030	123,5	0,238	0,9162	124,1	0,031	0,9982	123,5	0,239	0,9157
G x M	12	124,1	0,819	0,6304	123,5	0,583	0,8527	124,1	0,209	0,9978	123,5	1,885	**0,0423**
BF x G x M	12	124,1	0,142	0,9997	123,5	0,040	1,0000	124,1	0,103	0,9999	123,5	0,197	0,9984
BB x G x M	12	124,1	0,347	0,9782	123,5	0,205	0,9980	124,1	0,167	0,9993	123,5	0,476	0,9256
BF x BB* x G x M	12	124,1	0,319	0,9849	123,5	0,206	0,9980	124,1	0,160	0,9994	123,5	0,290	0,9901

Tableau B. Analyse de variance (ANOVA) du nombre de périodes où les températures étaient inférieures à 0 °C, -2 °C, -5 °C ou entre 10 et 30 °C durant la saison 2007

Source	d.l. num.	Nb périodes T < 0°C d.l. dén.	F	P	Nb périodes T < -2°C d.l. dén.	F	F	Nb périodes T < -5°C d.l. dén.	F	P	Nb période 10ºC < T < 30ºC d.l. dén.	F	P
Parcelles principales													
Orientation (O)	1	16	0.450	0.5116	16	1.073	0.3154	16	0.064	0.8029	15	2.692	0.1215
Bande-Forêt (BF)	1	16	0.697	0.4162	16	0.540	0.4732	15	0.333	0.5726	15	2.672	0.1233
Bande-Bleuet (BB)	1	16	0.088	0.7704	16	0.000	0.9953	16	0.000	0.9964	15	2.184	0.1599
BF x BB	1	16	0.876	0.3635	16	1.043	0.3226	15	0.008	0.9292	15	0.031	0.8630
O x BF	1	16	2.096	0.1674	16	2.535	0.1314	15	1.377	0.2591	15	0.871	0.3659
O x BB	1	16	0.530	0.4769	16	0.155	0.6991	16	0.536	0.4747	15	0.619	0.4435
O x BF x BB	1	16	0.021	0.8880	16	0.163	0.6922	15	0.080	0.7813	15	0.037	0.8503
Sous-parcelles													
Gradient (G)	3	75	10.070	**<.0001**	78	14.042	**<.0001**	97	4.370	**0.0062**	53	4.585	**0.0063**
O x G	3	76	0.975	0.4089	78	1.492	0.2232	98	0.470	0.7042	53	1.749	0.1682
BF x G	3	66	1.208	0.3140	67	2.756	**0.0491**	96	0.768	0.5145	48	1.239	0.3061
BB x G	3	58	1.124	0.3468	59	1.091	0.3601	75	1.164	0.3293	45	2.834	**0.0487**
BF x BB x G	3	58	1.824	0.1529	59	2.280	0.0887	76	0.115	0.9513	45	2.610	0.0629
O x BF x G	3	65	1.667	0.1828	66	2.117	0.1063	95	2.035	0.1142	47	3.836	**0.0154**
O x BB x G	3	58	0.814	0.4915	59	1.017	0.3919	76	0.559	0.6436	45	1.363	0.2661
O x BF x BB x G	3	58	0.221	0.8818	59	0.429	0.7331	76	0.456	0.7138	45	1.967	0.1325
Mesures répétées													
Mois (M)	4	230	530.612	**<.0001**	230	604.201	**<.0001**	105	205.384	**<.0001**	221	5382.944	**<.0001**
O x M	4	230	0.699	0.5937	231	4.122	**0.0030**	106	1.042	0.3562	221	2.464	**0.0461**
BF x M	4	229	0.682	0.6049	229	0.694	0.5966	104	0.668	0.5149	220	0.761	0.5515
BB x M	4	230	1.526	0.1955	230	1.098	0.3585	105	0.548	0.5796	221	0.820	0.5138
BF x BB x M	4	229	1.754	0.1390	229	1.366	0.2467	104	0.414	0.6623	220	2.197	0.0704
O x BB x M	4	230	3.129	**0.0157**	231	0.782	0.5380	106	2.238	0.1117	221	1.844	0.1214
G x M	12	235	2.329	**0.0078**	236	3.084	**0.0005**	112	1.235	0.2938	224	0.739	0.7125
O x G x M	12	235	0.594	0.8461	236	0.579	0.8582	112	0.773	0.5930	224	0.802	0.6479
BF x G x M	12	229	0.153	0.9996	230	0.323	0.9848	104	0.648	0.6914	221	1.290	0.2255
BB x G x M	12	230	0.181	0.9990	231	0.200	0.9984	106	0.147	0.9893	221	1.137	0.3313
BF x BB x G x M	12	230	0.325	0.9843	231	0.546	0.8830	106	0.139	0.9907	221	0.582	0.8558

Tableau C. Analyse de variance (ANOVA) du nombre de périodes où les températures étaient inférieures à 0 °C, -2 °C, -5 °C ou entre 10 et 30 °C durant la saison 2008

		Nb périodes T < 0°C			Nb périodes T < -2°C			Nb périodes T < -5°C				Nb périodes 10°C < T < 30°C		
Source	**d.l. num.**	**d.l. dén.**	**F**	**P**	**d.l. dén.**	**F**	**P**	**d.l. dén.**	**F**	**P**	**d.l. num.**	**d.l. dén.**	**F**	**P**
Parcelles principales														
Orientation (O)	1	16.7	6.006	**0.0256**	17.49	19.935	**0.0003**	18.33	58.990	**<0.0001**	1	15.31	8.143	**0.0119**
Bande-Forêt (BF)	1	16.7	1.176	0.2936	17.49	0.592	0.4520	18.33	0.044	0.8368	1	15.31	0.401	0.5359
Bande-Bleuet (BB)	1	16.7	0.230	0.6381	17.49	2.344	0.1437	18.33	2.649	0.1207	1	15.31	0.044	0.8371
BF x BB	1	16.7	1.146	0.2996	17.49	1.345	0.2618	18.33	1.946	0.1797	1	15.31	0.399	0.5368
O x BF	1	16.7	3.776	0.0691	17.49	2.037	0.1711	18.33	2.748	0.1144	1	15.31	2.283	0.1512
O x BB	1	16.7	0.120	0.7331	17.49	1.105	0.3075	18.33	0.921	0.3497	1	15.31	0.000	0.9991
O x BF x BB	1	16.7	0.019	0.8912	17.49	0.027	0.8710	18.33	0.012	0.9145	1	15.31	0.128	0.7254
Sous-parcelles														
Gradient (G)	3	57.3	9.874	**<0.0001**	59.87	15.641	**<0.0001**	58.52	19.164	**<0.0001**	3	46.28	19.894	**<0.0001**
O x G	3	57.3	0.453	0.7164	59.87	1.194	0.3197	58.52	1.020	0.3905	3	46.28	3.538	**0.0217**
BF x G	3	57.3	0.252	0.8596	59.87	0.419	0.7400	58.52	0.295	0.8287	3	46.28	0.704	0.5543
BB x G	3	57.3	1.195	0.3200	59.87	0.710	0.5497	58.52	0.887	0.4531	3	46.28	0.315	0.8144
BF x BB x G	3	57.3	1.614	0.1962	59.87	1.681	0.1807	58.52	2.072	0.1138	3	46.28	2.109	0.1120
O x BF x G	3	57.3	0.757	0.5228	59.87	1.703	0.1760	58.52	1.581	0.2035	3	46.28	0.601	0.6177
O x BB x G	3	57.3	0.294	0.8293	59.87	0.719	0.5449	58.52	0.233	0.8730	3	46.28	1.900	0.1428
O x BF x BB x G	3	57.3	0.089	0.9659	59.87	0.648	0.5875	58.52	0.717	0.5460	3	46.28	1.763	0.1674
Mesures répétées														
Mois (M)	1	65.09	5774.991	**<0.0001**	68.06	4706.643	**<0.0001**	68.7	315.874	**<0.0001**	3	159.4	5699.291	**<0.0001**
O x M	1	65.09	1.062	0.3067	68.06	19.910	**<0.0001**	68.7	91.859	**<0.0001**	3	159.4	4.300	**0.0060**
BF x M	1	65.09	2.056	0.1564	68.06	3.027	0.0864	68.7	0.073	0.7881	3	159.4	1.176	0.3209
BB x M	1	65.09	3.267	0.0753	68.06	7.563	**0.0076**	68.7	4.080	**0.0473**	3	159.4	0.095	0.9628
BF x BB x M	1	65.09	0.834	0.3645	68.06	1.462	0.2308	68.7	3.057	0.0849	3	159.4	1.406	0.2430
O x BF x M	1	65.09	1.920	0.1706	68.06	1.618	0.2077	68.7	4.232	**0.0435**	3	159.4	12.802	**<0.0001**
O x BB x M	1	65.09	1.286	0.2610	68.06	3.898	0.0524	68.7	1.454	0.2321	3	159.4	0.865	0.4606
O x BF x BB x M	1	65.09	0.109	0.7425	68.06	0.003	0.9558	68.7	0.021	0.8851	3	159.4	1.089	0.3554
G x M	3	70.48	6.658	**0.0005**	69.27	8.819	**<0.0001**	69.3	14.733	**<0.0001**	9	166	7.866	**<0.0001**
O x G x M	3	70.48	0.050	0.9851	69.27	0.342	0.7952	69.3	0.782	0.5080	9	166	0.929	0.5016

BF x G x M	3	70.48	0.446	0.7207	69.27	0.359	0.7827	69.3	0.232	0.8735	9	166	1.322	0.2287
BB x G x M	3	70.48	0.761	0.5199	69.27	0.253	0.8588	69.3	0.696	0.5578	9	166	0.449	0.9061
BF x BB x G x M	3	70.48	1.134	0.3413	69.27	0.896	0.4480	69.3	1.611	0.1947	9	166	0.988	0.4517
O x BF x G x M	3	70.48	0.584	0.6277	69.27	0.904	0.4437	69.3	1.202	0.3154	9	166	0.594	0.8011
O x BB x G x M	3	70.48	0.229	0.8760	69.27	0.403	0.7514	69.3	0.175	0.9132	9	166	0.458	0.9011
O x BF x BB x G x M	3	70.48	0.085	0.9680	69.27	0.296	0.8281	69.3	0.555	0.6467	9	166	0.840	0.5808

Tableau D. Analyse de variance (ANOVA) du nombre de périodes où les températures étaient inférieures à 0 °C, -2 °C, -5 °C ou entre 10 et 30 °C durant la saison 2009

Source	d.l. num.	d.l. dén.	Nb période T < 0ºC		Nb période T < -2ºC		Nb période T < -5ºC*		Nb période 10ºC < T < 30ºC	
			Rapport F	Prob. > F	Rapport F	Prob. > F	Rapport F	Prob. > F	Rapport F	Prob. > F
Parcelles principales										
Bande-Forêt (BF)	1	8	1.285	0.2897	1.630	0.2373	4.6766	0.0625	0.511	0.4950
Bande-Bleuet (BB)	1	8	0.453	0.5199	0.327	0.583	0.2988	0.5995	0.007	0.9376
(BF) x (BB)	1	8	2.835	0.1306	2.375	0.1616	1.3937	0.2716	1.135	0.3176
Sous-parcelles										
Gradient (G)	3	25	4.429	**0.0127***	3.260	**0.0386***	7.7354	**0.0010***	7.909	**0.0008***
BF x G	3	25	0.234	0.8718	0.408	0.7486	1.1793	0.34	1.698	0.1943
BB x G	3	25	4.503	**0.0119***	3.757	**0.0238***	2.74	0.0673	8.627	**0.0005***
BF x BB x G	3	25	0.291	0.8314	0.070	0.9753	2.4322	0.0917	1.016	0.4031
Mesures répétées										
Mois (M)	3	95	403.675	**<.0001***	212.294	**<.0001***	46.3721	**<.0001***	16174.420	**<.0001***
BF x M	3	95	2.745	**0.0473***	3.179	**0.0275***	2.1158	0.1035	0.035	0.9911
BB x M	3	95	3.079	**0.0312***	1.541	0.209	0.4347	0.7286	0.452	0.7165
BF x BB x M	3	95	5.936	**0.0009***	4.628	**0.0046***	3.4472	**0.0198***	0.319	0.8113
G x M	9	95	1.188	0.3117	1.276	0.2601	0.1638	0.997	0.735	0.6756
BF x G x M	9	95	0.172	0.9964	0.171	0.9965	0.1	0.9996	0.691	0.7155
BB x G x M	9	95	2.064	**0.0404***	1.684	0.1035	0.1954	0.9942	1.887	0.0633
BF x BB x G x M	9	95	0.121	0.9991	0.087	0.9998	0.0852	0.9998	0.333	0.9620

*** Les données ont été transformées en rangs avant l'analyse**

APPENDIX 3.
VOLUMETRIC WATER CONTENT VARIANCE ANALYSES

ANALYSES DE VARIANCE DE LA TENEUR EN EAU VOLUMÉTRIQUE

Tableau A. Analyse de variance (ANOVA) des mesures de la teneur en eau volumétrique du sol pour la saison 2008

Source	d.l. num.	d.l. dén.	F	P
Parcelles-principales				
Orientation (O)	1	16	18.286	**0.0006**
Bande-Forêt (BF)	1	16	0.131	0.7222
Bande-Bleuet (BB)	1	16	0.030	0.8651
O x BF	1	16	1.797	0.1988
O x BB	1	16	0.243	0.6284
BF x BB	1	16	0.046	0.8334
O x BF x BB	1	16	3.424	0.0828
Sous-parcelles				
Gradient (G)	2	32	1.580	0.2217
O x G	2	32	0.286	0.7531
BF x G	2	32	0.739	0.4856
BB x G	2	32	1.141	0.3322
O x BF x BB	2	32	0.207	0.8140
O x BB x G	2	32	3.328	**0.0486**
BF x BB x G	2	32	0.589	0.5606
O x BF x BB x G	2	32	0.263	0.7704

Tableau B. Analyse de variance (ANOVA) des mesures de la teneur en eau volumétrique du sol pour la saison 2009

Source	Mesures mesures en eau volumétrique du sol			
	d.l. num.	d.l. dén.	Rapport F	Prob. > F
Parcelles-principales				
Orientation (O)	1	16	0.114	0.7402
Bande-Forêt (BF)	1	16	0.167	0.6882
Bande-Bleuet (BB)	1	16	0.029	0.8663
O x BF	1	16	0.652	0.4311
O x BB	1	16	0.382	0.5455
BF x BB	1	16	0.930	0.3491
O x BF x BB	1	16	0.050	0.8261
Sous-parcelles				
Gradient (G)	2	32	1.903	0.1656
O x G	2	32	1.831	0.1766
BF x G	2	32	1.452	0.2492
BB x G	2	32	0.111	0.8951
O x BF x G	2	32	2.340	0.1126
O x BB x G	2	32	0.002	0.9978
BF x BB x G	2	32	1.817	0.1789
O x BF x BB x G	2	32	1.023	0.3709
Mesures répétées				
Temps (T)	1	48	728.353	**<.0001***
O x T	1	48	9.552	**0.0033***
BF x T	1	48	1.322	0.2559
BB x T	1	48	0.045	0.8323
O x BF x T	1	48	0.393	0.5339
O x BB x T	1	48	0.011	0.9181
BF x BB x T	1	48	4.031	0.0503
O x BF x BB x T	1	48	0.341	0.5619
G x T	2	48	1.249	0.2961
O x G x T	2	48	0.549	0.5812
BF x G x T	2	48	0.092	0.9120
BB x G x T	2	48	2.671	0.0795
O x BF x G x T	2	48	0.036	0.9645
O x BB x G x T	2	48	0.381	0.6854
BF x BB x G x T	2	48	2.052	0.1396
O x BF x BB x G x T	2	48	2.765	0.0730