Cultivation Of Melliferous (Honey) Plants To Improve Honeybee Colony Health And Productivity While Providing Valuable Crops For The Development Of Short Food Chains And Rural Development

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ABSTRACT

A lack of floral quality and diversity is among the multiple factors causing health problems to honeybees. Small areas of flowered managements bordering industrial faming systems are often considered to offer more nectar and pollen resources to honeybees. Instead, we propose to use these plants as full crops, thus increasing their availability to honeybees and providing small market opportunities for rural development. Annual and perennial plants were selected for their potential value as a crop for culinary, aromatic, medicinal or agronomic use. Plants trails were done in 20M X 50M plots in two low revenue agricultural environments of the Lanaudière region (Québec, Canada). Control sites were established in a conventional industrial agricultural region. A total of 30 hives were monitored. Plant attractivity to honeybees and the impact of their proximity to hives on colony health was followed tree times a week. Brood development was assessed and bee mortality in front of hives was registered. Pollen in honey was identified, honeybee visits to flowers were recorded and standing crop nectar sugar concentrations (BRIX) were measured. Regional agronomic success of the 90% of the selected plant species shows a high potential for cultivation of these crops. Results show a 48% higher development of brood and an average 30% increase in honey yield in colonies placed near melliferous plant plots compared to hives placed in an industrial agriculture landscape. In order to evaluate public appreciation of experimental crops, aromatic plants were harvested, integrated into dark chocolate and cheese recipes, or transformed into pesto, and offered for tasting to visitors during four regional harvest and field day events. These types of foods could a have a significant presence in short food chain distribution and the strengthening of these chains could eventually offer new large-scale opportunities for rural development while providing healthier resources for Honeybees.

INTRODUCTION

Significant losses of honeybee colonies (Apis mellifera) have been reported in several parts of the world. In Quebec (Canada), as elsewhere in North America, a yearly 30% (or more) loss of honeybee colonies has been recorded over the last ten years. A decline in the overall health of colonies and a significant reduction in honey yields per hive have been observed over this decade. One potential cause could be a poor floral diversity around the hives.

Agricultural landscapes have greatly changed over the last decades, due to the intensification of major crops, now covering large areas. (Brodschneider and Crailsheim 2010). This loss of floral diversity and the pollination of large monocultures can create food shortages and nutritional deficiencies for honeybees as well as nutrient imbalances (Glare and O'Callaghan 2008; Kevan and Ebert 2005; Oldroyd 2007). Both adults and the brood can be affected. This can be added to other stress factors that could be affecting honeybees, such environmental stresses (Porrini et al., 2003) as well as parasites, pathogens and pesticides.

Access to a rich diversity of flowering plants is thus very important for the development of honeybee colonies introduced in crops for pollination. According to Westerkamp and Gottsberger (2000) and Decourtye et al. (2010), growing a diversity of plants is the best way to provide a natural and complete source of proteins and essential nutrients for honeybees. Many perennial plant species are known to attract honeybees and contribute to higher honey yields. These plants can be used to build habitat managements to attract bees to farmlands. Unfortunately, few incentives are available to encourage the farming community to grow these types of plants with high nectar potential that could provide multiple benefits.

Many honey plants have interesting properties regarding their aromatic, medicinal and agronomic properties. Plants with aromatic and medicinal properties could be used as rural development tools by strengthen local food markets. Furthermore, many green manure plants also have interesting nectar producing properties. This aspect of honey plant production could gains to be valued. Fertile soils with good physical properties to support root growth are essential for sustainable agriculture, but, since 1945, approximately 17% of vegetated land has undergone human-induced soil degradation and loss of productivity, often from poor fertilizer and water management, soil erosion and shortened fallow periods.

To address this issue, this study aims the selection and cultivation plants species that can be grown, as a crop, to attract honeybees, procure higher honey yields and enhance honeybee health, while offering local benefit for farmers.

Specifically, this study also looked at the impact of different levels of sugar concentration (BRIX index) and the attractiveness they aroused in terms of number of honeybee visits to the flowers. Using two well-known honey plants (Phacelia tanacetifolia and Agastache foeniculum), this part of the study aimed to examine comparative flower attractivity in a context where floral supply and hives distance between were different. Impact honey plant foraging on colony health was also examined.

MATERIAL AND METHODS

Study regions, sites and plots

The study was conducted in three localities of the Lanaudière region of the province of Quebec, Canada. Sites were in 1) an agroforestry landscape, 2) diversified agricultural landscape and 3) a conventional industrial agricultural landscape. In each of these localities, a honey plant site and a control site were established. Three plots of 20M X 50M were planted or sown in the experimental sites (Fig. 1). Each plot cultivated with honey plants was composed of a variety of seasonal species based on agronomic and nectar secretion criteria. The control sites were used only for data regarding honeybee health.

Figure 1: Localisation of different study sites in the Lanaudière region

Forested : Saint-Damien (M) / Sainte-Béatrix (T)
Agroforested : Saint-Félix-de-Valois (M) / Sainte-Mélanie (T)
Conventionnal Industrial : Saint-Thomas (M et T)
M = Melliferous experimental / T = Control site

Honey (melliferous) Plants

Plants were chosen for different proprieties that could have either an alimentary or medicinal purpose or again if they could be used as green manure plants for crop rotation.

Honeybee mortality and brood surface evaluation

The honeybee colonies came from the Centre de recherche en sciences animales de Deschambault (CRSAD), Quebec, Canada. Colonies were *Apis mellifera ligustica* hybridized with *Apis mellifera primorsky*. Data were collected on fives hives per site, for a total of 30 hives.

Parameters indicating the health of colonies were followed for each of the hives: honeybee mortality, weight of the hive and brood development. The entrance to each hive was weeded, and a white sheet was fixed with nails in this zone in order to better see the dead honeybees. There were three visits to the hives per week. Because honeybees frequently clean the hive leaving debris, including dead bee bodies, sheets were cleaned after each bee count. Changes in weigh were monitored every week and number of dead bee in from of the hives was counted. The surface area occupied by total brood (eggs + larva + capped brood) was evaluated 3 times during the study, by measuring width and length of the brood surface on each side of every brood frame. For statistical analysis, only comparison of the final versus the initial brood was assed, giving the differences in brood development between the sites, during the summer. The presence cells royal cells and any other discrepancies were also noted.

The fives hives at each site were considered as pseudo replicates. It was important to have pseudo-replicates given the extreme variability between colonies. Wilcoxon and Mann-Whitney tests as well as Kruskal-Wallis tests were performed to assess the different relationship between these variables. A Pearson correlation was also made (JMP, version 10, SAS institute Inc.). Non-parametric tests were preferred because of the distribution that did not follow the normal distribution and the small sample size.

Pollen and honey sampling

Pollen harvested by foragers was collected using a pollen trap (Shaparew model) installed on selected hives. Drawers were emptied twice a week and pellets were frozen for further analysis. Honey samples were taken after major blooms.

Nectar sampling

At each site, 20 m x 50 m plot was grown with two seasonal plants, Agastache (Agastache foeniculum) and Phacelia (Phacelia tanacetifolia). Three times more Agastache than Phacelia was sown (6 rows vs 2 rows), but this latter crop was three times closer to the hives than Agastache. The data collection was done over a period of two weeks from 10h to 15h, on average and when weather permitted. Sugar concentration (BRIX index) in nectar secretion of standing crop was measured following advices of Corbet (2002), using a Bellingham + Stanley low volume hand held refractometer and Drummond Scientific Microcap capillary tubes. A new microcap was used for every sample. Sampling was done every hour from 10AM to 5PM.

Honeybee foraging

Number of foragers on flowers was counted every hour, as for the nectar sampling. Bee visits on flowers were counted by two methods: either by walking along the rows (1MX30M) in a given amount of time (3 minutes) at a regular pace or by observing 1m^2 of a given plot for 10 minutes. Observed insects on flowers were classified into three categories: Honeybees, Bumblebees and other pollinators. Foragers were photographed and filmed using a Pentax Optio camera to assess foraging time on flowers.

RESULTS

Honey plants

Several plants in the study were sown and grown in the greenhouse in April before being transplanted into the plots to the beginning of June. Around this same time, the seeds of some of the remaining floral varieties were sown directly into the ground. Only lupine and phacelia were sown earlier (from the end of May). Flowering plants began in mid-July. The first year of the study, flowering began in mid July. This late flowing date was expected because the summer was exceptionally dry. The second year, perennial plants were well established and sowing was done earlier, offering more timely resources to honeybees.

A good honey plant cover was obtained in plots. It was important to manage last minute plant substitutions based on species provided, ensuring a succession of good resources and land use. The invasion by weeds caused major problems at the begging of the season and intensive hand weeding was necessary. Table 1 gives the list of plants examined in our study and the functional reason for which they were chosen. The plantation scheme is presented in Annexe 1.

Nectar production and composition are understood to be crucial factors influencing flower visitation and consequently pollinator preferences for particular plant species (e.g. Baker and Baker, 1982). The BRIX degree (°B) indice indicates the percent of different sugar composition (% saccharose) in nectar were found in Centaurea (52,1°B) Dandelion (51,2 °B) Agastache 50°B, Phacelia (38°B), Borrago officinalis 29,6 °B, Alfafa (31,2 °B), White clover (30,2 °B).

Table 1. List of plants evaluated for their attractivity for honeybees and their potential use

Annual plants	
Ammi visnaga	Medicinal
Borago officinalis	Aromatic
Carum roxburghianum	Spice, Medicinal
Coriandrum sativum	Alimentary
Desmodium canadense Leguminosae	Medicinal
Dracocephalum moldavicum	Aromatic
Ocimum basilicum « Citriodorum »	Alimentary
Ocimum sanctum	Alimentary
Ocimum basilicum « Trisiflora »	Alimentary
Ocimum sp. « Thai »	Alimentary
Origanum majorana	Alimentary
Matricaria recutita	Medicinal
Monarda citriodora	Medicinal
Nigella damascena	Aromatic, medicinal
Shizonepeta japonica	Medicinal
Silphium	Medicinal
Phacelia tanacetifolia	Green manure
Lupinus albus (Amiga)	Green manure
Lupinus angustifolius	Green manure
Perrenials	
Agastache rugosa	Alimentary, aromatic
Agastache foeniculum	Alimentary, aromatic
Bocopa monnieri	Medicinal
Flowers	
Helianthus Arikara	Alimentary,medicinal
Helianthus Taiyo	Alimentary,medicinal
Helianthus Grand primerose	Alimentary,medicinal
Cosmos sulphurecum	Aromatic

Honeybee visits

First plants to flower were *Lupinus* spp. Honeybee visits to these crops were scarce. Bumblebees visited this species at a preferential rate of 90%. From all sites, the plots that received most pollinator (and honeybee) visits were those that supported a seasonal succession of forage plants with abundant Phacilia and Agastache.

Significant number of visits began only in late July and was mostly observed on Phacelia, followed by Agastache later in August. Visiting rates varied from 1 to 11 honeybee/m^2/min.

Plant competition for honeybees and nectar reward

Honeybee behaviour and plant attractivity according to nectar reward was estimated by trails using Phacelia and Agastache. The histogram in Figure 1 shows the "switch" that is rapidly taking place between the two plants. On day 1, the honeybee was more on Phacelia than on Agastache and while bumblebees were mainly recorded on Phacelia. From day 2 to day 5, the situation is reversed and Agastache attracts more bees and bumblebees. Variability is explained by the 71% trend of the honeybee towards Agastache.

For further analyzes, bumblebees were set aside the analysis was focused on the honeybee. Two tables of data were been created for the analysis. A first table where the number of bees recorded was done individually by rank and every hour and another table where the number was recorded as the total rows per hour. Data transformation was necessary to assure the normal distribution for each table. The first table required a cube root transformation of the data while for the other, a logarithmic transformation was necessary. The Shapiro-Wilk test confirmed the normality of distributions (Table 3). The normality of the residuals of the model was also tested.

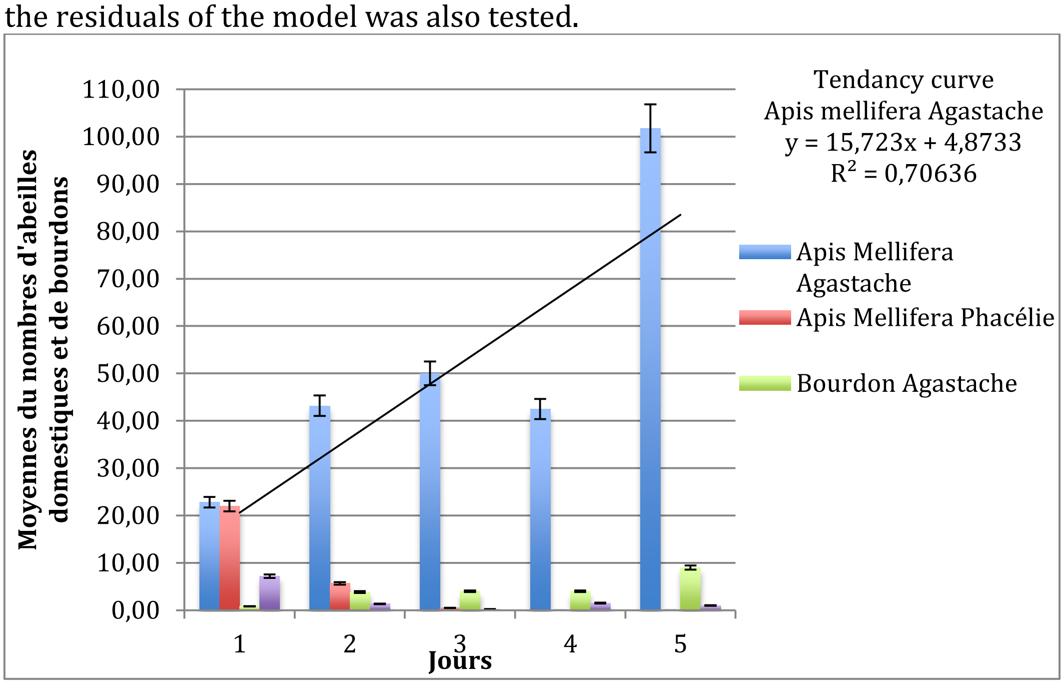

Figure 2: Histogram of recorded daily average number of honeybees and bumble bees on Phacelia tanacetifolia and Agastache foeniculum.

Table 2: Shapiro-Wilk test performed on the distribution of the cube root of the number of bees recorded on Agastache and Phacelia. Note: Ho = data from the Normal distribution. Small p-values reject Ho

Plants	W	Prob,<W
Agastache	0,98	0,18
Phacélie	0,924	0,12

Table 3: Shapiro-Wilk test performed on the logarithmic distribution of the number of bees recorded of all ranks. Note: Ho = data from the Normal distribution. Small p-values reject Ho

W	Prob.<W
0,96	0,60

A first ANOVA was performed to see if the BRIX index was closely related to the number of visits of bees. The assumptions for the application of ANOVA were met and confirmed by the Shapiro-Wilk test on the residuals and the Brown-Forsythe test of equality of variances. With 48% of the variability explained, the model is highly significant (Table 4). Table 5 shows the t-test the level of differences between the rates of BRIX. Surprisingly, high levels of BRIX do not seem different at low levels although the highest level is alone in its class with a substantially higher visits than any other observation.

Table 4: One-way ANOVA of the cube root of the number of honeybees based on the BRIX index (in% sugar concentration) of the two plants without distinction.

Source	Degrés de liberté	Somme des carrés	Rapport F	R^2
BRIX	6	15,751269	20,8598	0,477
Résidus	137	17,241461	Prob. > F	$R^2_{ajusté}$
Total	143	32,992730	<,0001*	0,455
		Rapport F	Prob. > F	
Brown-Forsythe	6	1,0177	0,48	

Table 5: Comparison for each pair by the Student t BRIX levels depending on the number of visits of honeybees two plants without distinction. Numbers that are not connected by the same letter are significantly different.

Niveau						Moyenne
25	A					2,53
6		B				1,95

Niveau						Moyenne
11		B				1,94
21		B	C			1,85
9				D		1,55
17			C	D	E	1,5496007
7,5					E	1,0000000

t	Alpha
1,98	0,05

By isolating Agastache, the model is slightly more accurate and remains highly significant (R2 = 58%, p = <.0001 *). Student's t test indicates that the extreme levels of BRIX index are widely different from all others. The index 17 is also connected to 21 to 9.

Table 6: one-way ANOVA of the cube root of the number of honeybees based on the BRIX index (in%) of Agastache only.

Source	Degrés de liberté	Somme des carrés	Rapport F	R^2
BRIX	5	15,721000	26,5918	0,583
Résidus	114	13,479317	Prob. > F	$R^2_{ajusté}$
Total	119	29,200317	<,0001*	0,518
		Rapport F	Prob. > F	
Brown-Forsythe	5	0,98	0,43	

Table 7: Comparison for each pair by the Student t BRIX levels depending on the number of visits of bees of Agastache. Numbers that are not connected by the same letter are significantly different.

Niveau						Moyenne
25	A					2,53
11		B				1,94
21		B	C			1,85
9				D		1,55
17			C	D		1,55
7,5					E	1,00

t	Alpha
1,98	0,05

After logarithmic transformation of the total number of visits per hour of honeybees, one-way ANOVA of log (n honeybees) depending on the type of plants BRIX was measured index. Assumptions application were always respected and this for the two types of plants. The Shapiro-Wilk and Bartlett for Agastache confirmed while Shapiro-Wilk and Brown-

Forsythe did for Phacelia. The model on Agastache now accounts for almost 78% of the variability and is highly significant (Table 7). Student's t test still shows that the highest rate of sugar concentration is largely different from other levels, the levels 6, 11 and 21 are connected together and the level 9 is isolated. Figure 3 shows this situation graphically.

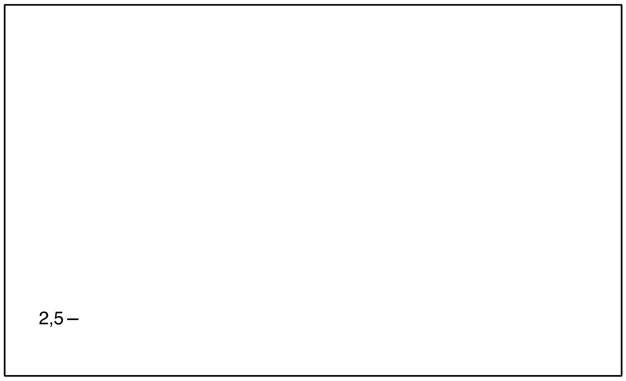

Figure 3: One-way ANOVA of the log of the number of visiting honeybees based on the BRIX index on Agastache

Table 8: One-way ANOVA of the cube root of the number of honeybees based on the BRIX index (in%), for Agastache only

Source	Degrés de liberté	Somme des carrés	Rapport F	R^2
BRIX	4	5,2239809	13,8420	0,776
Résidus	16	1,5096023	Prob. > F	$R^2_{ajusté}$
Total	20	6,7335831	<,0001*	0,720
	Num., Dén.	Rapport F	Prob. > F	
Bartlett	4, 16	2,08	0,081	
Shapiro-Wilk		W= 0,96	Prob.<W = 0,60	

Table 9: Comparison For Each pair by the Student t test BRIX levels DEPENDING on the number of visits of bees of Agastache. Numbers that are not connected by the same letter are significantly different.

t		Alpha		
2,11991		0,05		
Niveau				Moyenne
25	A			4,6211230
6		B		3,8215595
11		B		3,7439067

t		Alpha		
21		B		3,7290931
9			C	3,0905439

The model explains 80% for Phacelia and variability remains significant (Table 10). Student's t test clearly shows the differences between the different levels of BRIX in phacelia (Table 11). Figure 4 presents this visually.

Figure 4: One-way ANOVA of the log of the number of visiting honeybees based on the Phacelia BRIX index.

Table 10: one-way ANOVA of the cube root of the number of honeybees based on the BRIX index (in%) of Phacelia.

Source	Degrés de liberté	Somme des carrés	Rapport F	R^2
BRIX	2	12,610931	16,8849	0,808
Résidus	8	2,987509	Prob. > F	$R^2_{ajusté}$
Total	10	15,598439	0,0013*	0,761
	Num., Dén.	Rapport F	Prob. > F	
Brown-Forsythe	2, 8	1,53	0,27	
Shapiro-Wilk		W= 0,92	Prob.<W = 0,30	

Table 11: for each pair comparison by Student's t test BRIX levels depending on the number of visits of honeybees on Phacelia. Numbers that are not connected by the same letter are significantly different.

Niveau				Moyenne
11	A			2,9650303
17		B		1,9752518
7,5			C	0,0000000
t				Alpha
2,30600				0,05

A clear “switch” from one plant to the other thus was observed within a few days despite an overlap in nectar availability. Honeybees were the most abundant pollinators on Agastache (90%) and Phacelia (70%) but overall, Bumblebees preferred Phacelia to Agastache.

The intensity of visitation was significantly higher ($p<0.05$) on *Agastache foeniculum* than on other foraging sources. The highest percent of sugar measured in standing crops were 29% for Phacelia and 27,5% for Agastache. A high variation in sugar content was found between flowers of a same crop, but overall data was significantly correlated to number of honeybee visits on flowers (r=0,65; p=0,01). Pollen collection on Agastache was observed when humidity was higher than 80%. Compared with other bees, honeybees appear to have high levels of constancy.

Honeybee health

A marginally significant difference in weight gain can be observed (Figure 5) between the different treatments in the industrial zone (Wilcoxon and Mann-Whitney, DF = 1, KHI2 = 3.1527, p = 0.0458). As for honeybee mortality, numbers were significantly different between the two treatments, (Wilcoxon and Mann-Whitney, DF = 1, KHI2 = 4.8109, p = 0.0283). Mortality was, on average, five times higher at the honey plant site (Figure 6) while brood development was similar between both treatments (Figure 7).

No significant treatment-related differences (honey plant or control sites) could be demonstrated by statistical tests, for these three same parameters examined in agroforestry area. The planting honey plants near hives had not seem to have an impact on honeybee colonies in our agroforestry area. In forested area, one relationship came out different. A higher mortality was observed in hives from the honey plant sites than those from the control site (Wilcoxon and Mann-Whitney, DF = 1, KHI2 = 3.1527, p = 0.0458).

The large radius of action of honeybees (Spurgin , 2010) gives foragers the opportunity to access many regional floral resources. The colonies probably had had access to more floral diversity in these agroforestred areas, offering a variety of both wild and cultivated species. This was show statistically by a higher average weight gain in hives from this area.
The significant difference in the weight gain of forested and agroforestred, versus industrial environments can be explained by modern farming techniques used in industrial environment, which promote monocultures and thus, a nutrient supply of lower quality for honeybee colonies (Naug , 2009). Moreover, some cultivated plants used in monoculture have a deleterious impact on honeybee health. For example, take the case of soybeans, where 40 % of the sugars found in flowers as toxic to honeybees (Barker, 1977). Thus, according to the literature and the results obtained in the study, cultivation of honey plants would be valued mainly industrial zones with lacking of floral diversity, and be less useful for honeybees in areas such as regions characterized by agroforestry, which provide richer foraging resources.

Significant differences in weight gain have been found following the introduction of honey plant in an industrial environment. This could be explained by considering the poor nutrient intake provided by monocultures (Naug, 2005). Thus, it could be assumed that the introduction of honey plants in hostile environments as industrial environments allow apiaries have a better development of a given nutrient supply better quality.

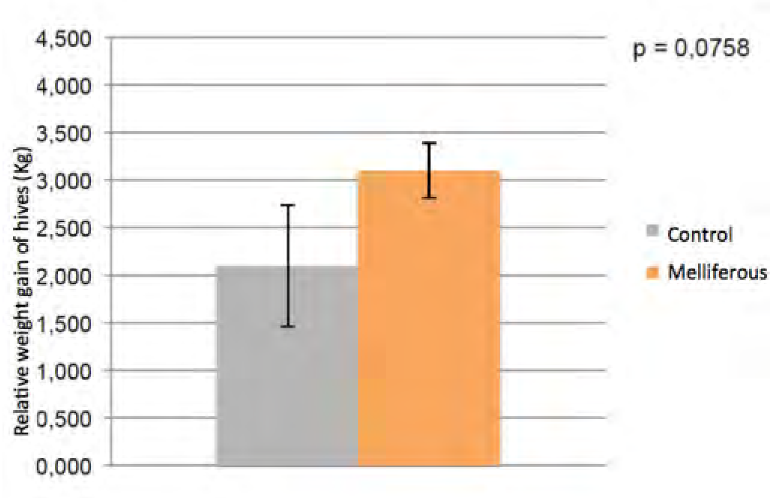

Figure 5: Relative weight gain (kg), means and standard deviations for apiaries in Honey plant treatment and control, in the industrial sites after the summer

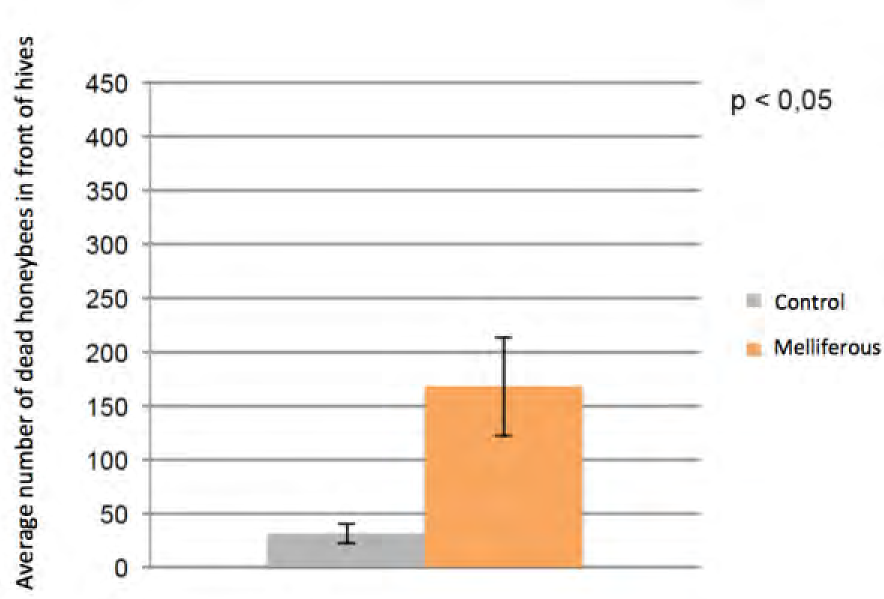

Figure 6: Average number of dead honeybees in front of hives (standard deviations) in apiaries for Honey plant and control treatments in the industrial sites during summer (6/07/12 to 26/08/12) [Wilcoxon and Mann-Whitney test].

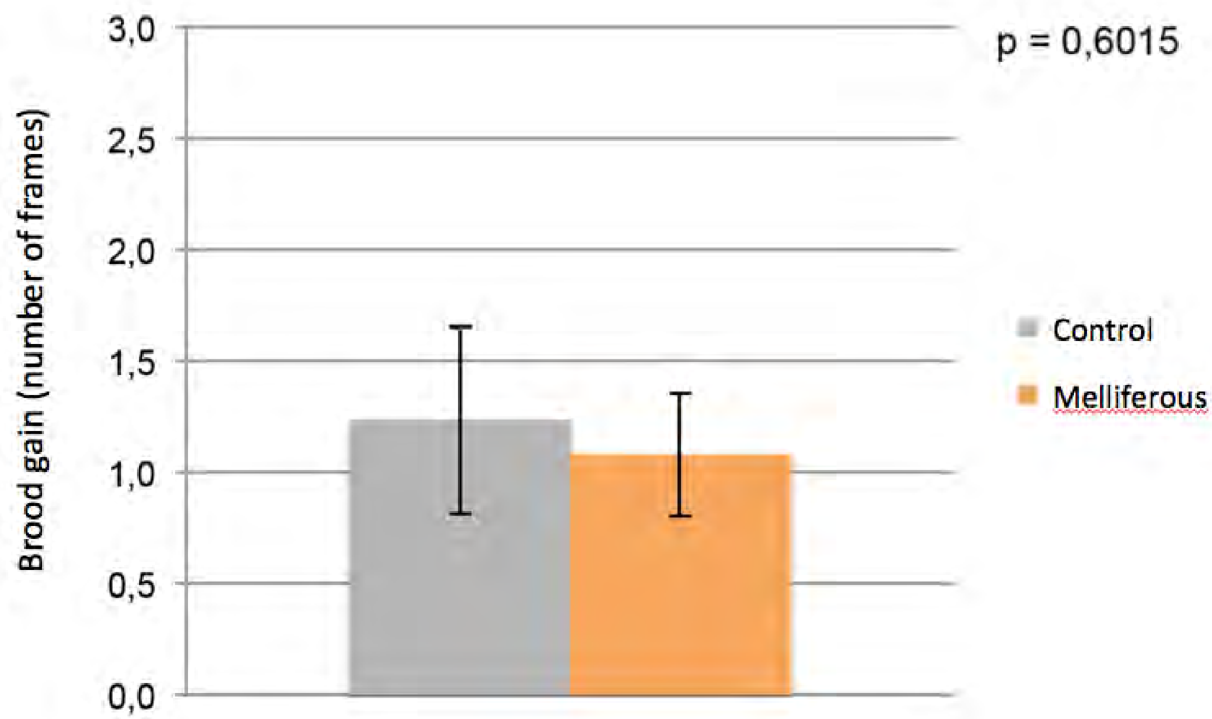

Figure 7: Brood gain (number of frames) means and standard deviations , of hives from the honey plant and control treatments in the industrial site (18 June 2012 and August 3, 2012) [Wilcoxon Mann-Whitney test].

We could hypothesis that honeybee poisoning in the industrial honey plant site could have been avoided because of the proximity of resources that would have spared the honeybees from foraging in environmentally hazardous fields. In fact, the high quality of the closely accessible honey plant food sources probably narrowed their range of action, maximizing their cost/benefits budget (Spurgin, 2010; Giraldeau and Dubois,2009; Chauvin, 1999). In the control site, foragers had no choice to expand their range in order to find a viable food sources. Thus, honeybees were more vulnerable to nearby environmental hazards in the environment, such as the pesticides or other chemicals.

If a significantly higher dead honeybee counts was observed in the honey plant site from the forested area, it is probably because of circumstantial and local conditions at this site. Indeed, although our honey plant site was an organic farm situated in a forested environment, this farm had closely distant neighbours who used pesticides at different times during the season, explaining the high mortality observed. We must not forget that stresses affecting honeybee health are multifactorial and are only not related to reduced floral diversity in agricultural environments. Considering the impossibility of controlling the whole agricultural neighbourhood, cultivation of honey plants could, at that time, allow better resilience in hives by access to richer floral level environments. Indeed, for the forest site, despite greater bee mortality in the honey plant site, a similar weight gain was shown for both treatments. In the sites from the industrial area, the inverse situation was found.

Public appreciation of plants

In order to evaluate public appreciation of experimental crops, aromatic plants were harvested, integrated into dark chocolate and cheese recipes, or transformed into pesto, and offered for tasting to visitors during two regional harvest and field day events. Public was asked to respond and a 100% level of appreciated was expressed. One of our organic growers introduced Agastache into her baskets and had very high appreciation of its tatste. This plant was used mainly as tea and mixed with alcool drinks (Vodka and Gin).

DISCUSSION

Honey plants

For green manure plants, the priorities of the new organic farming and precision farming, guided our plantation choices. It is important to consider new agricultural avenues comprising direct seeding without herbicides in order to better target the usefulness of honey plants for crop rotations. In organic farming, tillage is really a matter of managing ground cover, because this type of management uses the ground cover to suppress weeds.

Honeybee health

Observed bee mortality did not differ between melliferous and control sites (10 to 300 bees/day), but colonies from the control sites in the conventional industrial landscape locality harvested 30% less honey, showed a 48% lower brood development and thus weighed 36% less that hives in the paired melliferous site. This difference was not observed in other localities showing a more diversified landscape.

There was a recurrent observation of dead bees in front of hives in all sites. However, very few dead bees were observed in front of the control hives in our industrial site, located near intensive monocultures using high loads of pesticides. Yet this site offered limited nectar and pollen resources for bees. In addition, the honey input in these hives was very poor compared to other sites. This could explain why the colonies of this site showed a weak development of their brood, despite the fact that very few dead bees were observed. We could hypothesis that honeybees might have been dying off in the fields, rather than in front of the hives, dues to specific sub-lethal poising by certain agrochemical.

On the other hand, in front of other hives placed in the honey plants sites, a large number of dead bees were observed. These yet gave the highest yields in honey at the end of the season. This demonstrates that a well-fed colony can remain productive, despite the various stresses that can cause high mortality.

Plant attractivity and nectar resources

Clearly, there was a marked increase in honeybee visits on Agastache at the expense of visits to Phacelia, as their respective BRIX indices were varying. A first ANOVA (Table 4) indicates that in almost 50% of cases, the number of visits of bees is influenced by the levels of BRIX , regardless of whether these visits were on Phacelia or Agastache . Student test then indicates that the average visits will be higher for a 25% level of BRIX only. At this concentration, the attractive energy takes over regardless of the floral offering or distance, at least regarding this experiment. By adjusting the model by keeping only the Agastache , variability explained rises to 58% and is highly significant. Student's test now indicates that the highest and lowest levels of BRIX are widely different from the other levels. Median levels are always interconnected. So within the same species of plant, BRIX index appears to influence the number of visits to plants. By removing the effect Phacelia from the model, the analysis two levels of concentration are removed (7.5 and 17) permitting the model to focus solely on rates found in Agastache only .

This way, if the total time for a visit is always analyzed in terms of the BRIX index by the type of plant, the model now explains 78 % of the variability, is highly significant, and the Student test always draw the same conclusions. Almost 80 % of the time, the bees will be more attracted by the Agastache when it has a high index of BRIX and much less when it is low. However, in this model, a BRIX level of 6, the lowest registered, still receives many bee visits. It is also possible that the rate of sugar concentration was particularly low in the selected flowers and did not represent the average floral reward found in reality. One drop of water can dilute the concentration and vary greatly when the measurements are affected by µl. The model developed on Phacelia explains 81% of the variability is significant too. Student's t test indicates that each level of BRIX is widely different from each other. Strangely, the level where the number of visits is the highest is found in a median of BRIX . This could be explained by the fact that when the average BRIX of Phacelia was 11 (median), the supply of nectar Agastache was 9, so lower than that of Phacelia. Considering the proximity of the Phacelia, it seemed more optimal for honeybees to visit this plant.

CONCLUSION

Nectar sampling showed that all bees were indeed attracted by the Agastache foeniculum and Phacelia tanacetifolia. This study found that levels of BRIX were the determining factor influencing the number of honeybee visits to flowers. It was found that despite similar or lower rates of BRIX and despite greater distance to travel, floral offers by Agastache seemed to be more profitable and less risky for the honeybees. It would be interesting to have more threshold levels influencing decision making by honeybees, to better estimate the average visiting rate of honeybees on a given plant, at given time. A greater abundance of data, however, is essential to improve the robustness of the statistical model.

Constant honeybee mortality in front of hives was observed at all sites. Conventional agricultural fields using high loads of pesticides were present within a flying rang of all colonies in this study. However, in the control site of our industrial conventional locality, these crops were to only accessible nectar and/or pollen resources for the honeybees. This could explain why the colonies from this site showed a weaker development than those from the honey plant sites. In other sites, a greater variation was found between colony developments. Honeybee colonies from a single apiary placed within the same habitat do not forage exactly the same flora. The results of this work will provide a better understanding of the contribution of quality plants on overall honeybee colony health, while promoting their cultivation for different economic uses including green manure, catch crops and agronomic, aromatic and medicinal uses.

Our study also underlines the importance of testing the adaptability of different honey plant to local environmental conditions and resources. It also shows that plant competition, the impact of density and distance of the resource for honeybees, transition of honeybees between species and attractiveness are not well understood.

In accordance with the original objectives of our study, it is important to underline that economic and viable plant choices should be made while selecting honey plants for a local rural project.

Moreover, these genuine agronomic realities must be pointed out: the cultivation of honey plants is farming with all its complexities, comprising pest control, fertilisation and degree day previsions. Honey plant choices must take into account regional needs and their cultivation must be adapted to regional realities encompassing soil properties, climatic conditions and regional market demand.

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