UNIVERSITÉ DE NEUCHÂTEL

The use of honey bee dance communication to link bee-friendly agroecological measures with colony monitoring.

Master thesis 2020-2021

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Content

Abstract

The master thesis takes place in the “agriculture & pollinators" project framework by Swiss Federal Office for Agriculture (OFAG), aiming to see if agroecological measures taken to save domestic and wild bee populations are useful for the bees. It aims to see if it is possible to use the bees’ dances (1) to see where the foraging honey bees are going to forage or already have found their resources and (2) to determine if the agroecological measures are useful resources for the bees.

During the master thesis, we want to see if it is possible to use a waggle dance decoding system directly on the field to be able to link what is happening in the hive and where the bees are going to collect resources. We also want to analyse the constraints of the adapted protocol of Couvillon (2012) directly on the field. For this study, our design is mainly inspired by Okubo et al. (2019)’s experimental design with some addition of Couvillon et al. (2012) in order to analyse the dance manually.

22 waggles dances were recorded and 46 round dances on three apiaries of the project. Waggle dances were recorded on two of the three apiaries, while the round dances were recorded in the three of them.

It is clear to me that further research is needed to determine if the honey bees use the agroecological measures resources. However, thanks to the honey bees waggle dance, we were able to know that the environment with meadows, pastures and forests are attractive for them.

Acknowledgments

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Thanks to the three partner beekeepers of AGRIPOL's project for the provision of their hive, their shared knowledge and their time.

My grateful thanks go to Benjamin Délèze for his daily support and for putting up with me during the hardest parts of this thesis.

And a big thank to the honey bees for inviting me to discover a little bit of their wonderful world!

Introduction

Bees are essential for food security as they pollinate a major part of crops (Klein et al. 2007). In particular, honeybee *Apis mellifera* (Hymenoptera: Apidae) (Linnaeus, 1758) provide an efficient pollinization's service. Furthermore, as wild bees decline, they are not sufficient to provide alone pollicization's services (Batra 1995; J. C. Biesmeijer 2006; Free, J.B. 1993; Volz, Tustin, and Ferguson 1996). Beekeepers selected the bees on five main criteria: colony survival during dearth periods and when nectar flow is poor, resistance to diseases, honey production, tendency to sting, and ease of pacification by smoke (Crane 2013). In addition to these five main criteria, beekeepers aimed to reduce the natural mechanism of swarming (Oldroyd 2012). This reproduction mechanism occurs in spring. The old queen leaves the hive with a part of the colony to establish a new colony. Weber (2012) has speculated that all the adaptations may have weakened some natural defences of the bees and increase their exposure to diseases such as the infection of *Varroa destructor* (Mesostigmata: Varroidae) (Anderson & Trueman, 2000) because the colony does not swarm as often as before. Unfortunately, nowadays, bees are declining (Cox-Foster et al. 2007; Oldroyd 2007). The major cause is the degradation of their habitat such as its reduction, which is caused by urbanization, agricultural intensification (Wojcik et al. 2018), the use of pesticides (Blacquière et al. 2012; Straub et al. 2019) and the ectoparasite *V. destructor* (Rosenkranz, Aumeier, and Ziegelmann 2010; Dietemann et al. 2012). For example, the intensification of monocultures plays an important role in the decline of bees because it degrades their habitats (Goulson et al. 2015) by simplifying the landscape, which is linked with the loss of floral resources (Senapathi et al. 2015). There are also other factors responsible for the decline of bees, for example invasive species such as the hornet *Vespa velutina* (Hymenoptera: Vespidae) (Lepeletier, 1836), climate change, pathogens, pesticides, and other contaminants (Wojcik et al. 2018).

Before 1940, the Varroa was only present in Eastern honey bees *Apis cerana* (Hymenoptera: Apidae) (Fabricius, 1793) (Rosenkranz, Aumeier, and Ziegelmann 2010). VanEngelsdorp et al. (2008) said that *V. destructor* represents the main beekeeping problem for different reasons: (1) since the Varroa is a new parasite for *Apis mellifera sp.*, the host-parasite equilibrium is lacking, (2) the dispersal of the parasite occurs almost all around the world very rapidly, (3) it is said that a colony cannot survive more than three years without treatment, (4) the treatment increases the cost of apiculture, (5) Varroa increases the number of beekeepers that stop apiculture, which increases the loss of pollinators throughout the world (Rosenkranz, Aumeier, and Ziegelmann 2010), and (6) Varroa causes 20 to 90% of annual mortality rate in the colonies of managed honey bees (vanEngelsdorp et al. 2008). The hemophagous parasite kills honey bees by weakening them (Rosenkranz, Aumeier, and Ziegelmann 2010; Dietemann et al. 2012), reducing their learning capabilities (Kralj et al. 2007) and prematuring foraging and death (Janmaat and Winston 2000). Recent research by Straub et al. (2019) suggests that varroa also decreases the detoxifying ability of honey bees and makes them more sensitive to pesticides.

The Swiss Federal Office for Agriculture (OFAG) founds a resource project called "agriculture and pollinators" (AGRIPOL) (Sutter, Louis and al. 2019). The project is run by the canton of Vaud, Prométerre and the Fondation Rurale Interjurassienne in collaboration with UNINE

and Agroscope. It aims to test the effect of the agroecological measures on honey bees *A. mellifera* and wild bees. The project is conducted by a PhD student. The measures this project analyses try to achieve the following objectives: (1) the improvement of food resources for pollinating insects; (2) the reduction of the mechanical and chemical disturbance for pollinators; (3) and the addition of habitats for wild pollinators (Table 1). The aim of this project is to see the agroecological measures' effect on the honey bees colony over the years (Hernandez, J. 2020). The project will be conducted for six years in the cantons of Jura and Vaud, and its effects will be monitored on 300 honeybee colony hives managed by 30 beekeepers. The honeybee colonies are monitored for four years. The honey bee population is evaluated with a method called ColEval (Colony Evaluation) (Hernandez et al. 2020). It is an estimation method that consists of an evaluation of the colony by evaluating on all hives frames the percentage of bees present on the frames, closed brood cells, the stocks of pollen and honey (Hernandez et al. 2020). The ColEval is done four times per year on each hive in April, June, August and October (Hernandez, J. 2020). The ColEval aims to describe the evolution in the size of the colony during the years. At the same time, samples of honey bees are taken in each hive to analyse virus and pathogens levels and calculate the Varroa mite infestation rates at the colony level. The colony's level of health is also determined with natural mites fall and counting of the mites (Hernandez, J. 2020). These analyses can tell the health and the evolution of the honey bees' colonies.

In addition, the pollen is collected by pollen trap during 24 to 72 hours on three out of the ten hives by apiary three time along the beekeeping season. The goal here is to evaluate honey bees' floral resources by performing palynological analysis and residues of pesticides on this pollen.

Another crucial part of this project is to know in which specific field the honey bees collect their food resources, because we want to find out if they use the agroecological measures (Hernandez, J. 2020). Knowing what type of fields are visited can indicate which agricultural practices have a significant impact on bees. Then, we can set up a list of experience-based practical advice for farmers willing to promote pollinators. However, this is precisely the missing knowledge in the project: where are really going the honey bees? Thanks to the ColEval methods, it is possible to know what is happening in the hive at the moment of the colony evaluation. We get real-time information about the population and their food supply. Thanks to the analyses of the pollen, we have information about the different plants honey bees visited and, on the presence, or absence of pesticides on the pollen. Nevertheless, we do not know where the bees went and if they are going on the field with agroecological measures. Analysing the honey bees waggle dances allows us to try to link what is happening in the hive, the landscape and the agroecological measures.

Honey bees' dances

The honeybee waggle dance was first described by Karl von Frisch in 1973. He found that honey bees communicate interesting foraging sources to other bees by waggle dance (von Frisch K. 1946). Von Frisch received the Nobel prize in 1973 for its discovery highlighting for the first time that insects communicate with each other.

When a forager bee returns to the hive and wants to communicate an interesting location with useful resources such as pollen, nectar, propolis, water or a new nest site (von Frisch K. 1946; 1967; Dyer 2002), she does this waggle dance. She quickly vibrates her abdomen side to side and advances linearly in the main time. It can last from 1 to 11 second. Then, she comes back to the start of the waggle and can repeat the run from 1 to 100 times. The number of time depends on the quality of the resource (Seeley et al.2000). With the waggle dance, it is possible to determine the distance to the location thanks to the duration of the run and the direction to this place thanks to the orientation relative to the vertical (von Frisch K. 1967; 1946).

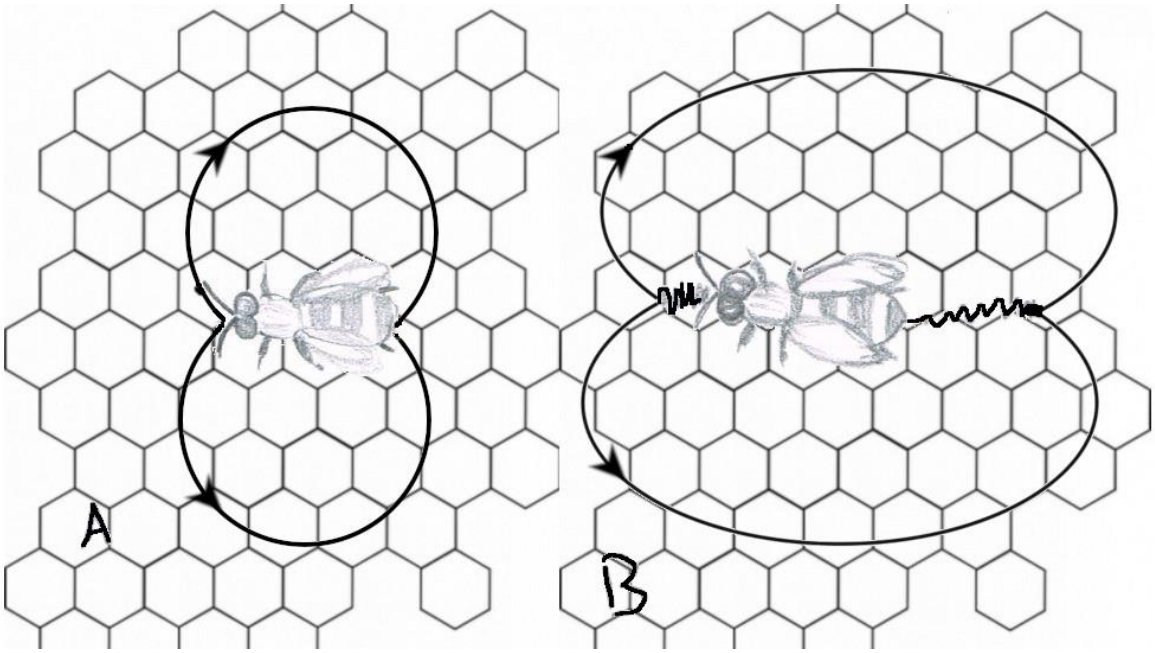

Illustration 1: A the round dance, this dance is used by the bees to communicate a foraging location at less than 100m; B the waggle dance, this dance is used by the bees to communicate a foraging location at more than 100m. The illustrations are inspired by Gardner et al. (2008).

Two types of dances were described: the round and the waggle dance (Tautz J., Sandeman D.C., and Rohrseitz K. 1996) (Illustration 1a). It seems that the round dance is for the resources located at less than 100m, whereas the waggle dance is used to give information for further away resources (von Frisch K. 1967; 1946).

In addition to the dance, the dancer gives up nectar to their nestmates during the waggle dance (Jürgen Tautz and Martin Lindauer 1997). Tautz and Lindauer (1997) found out that there are some chemical markers to locate the “dance floor” and the dancing bees reinforced them. It helps the dancers and the other foraging to meet in the same place.

The waggle dance is important for novice foragers as 60% use the waggle dance information to find resources (Jacobus C. Biesmeijer and Seeley 2005). When they become older, the foragers pay less attention to the dances or simply use them to reactivate their memory for foraging (Jacobus C. Biesmeijer and Seeley 2005), but they still use it when they discover richer food (Seeley 1983; Seeley and Visscher 1988).

Aims of the master project

Decoding honey bee waggle dances might be useful to link the landscape ecology aspects of AGRIPOL to describing what is going on colony population and stocks. During the master thesis, we want to see if it is possible to use a waggle dance decoding system directly on the field in this big project and what are the constraints of the adapted protocol of Couvillon (2012) directly on the field.

The master project aims to analyse (1) if the adapted design of Couvillon (2012) and Okubo et al. (2019) is applicable to the AGRIPOL project context on relevance of agroecological measures as a resource for honeybee colonies, or more generally for future fields studies about honeybee's resources. (2) Furthermore, it wants to assess what decoded dances can bring to a project such as AGRIPOL attempting to link the colony dynamic with the research of resources. Currently, the AGRIPOL team does not know exactly where the bees are going. With the analyses of pollen, they know on which species of plants the bees went to forage. However, we do not know from which field this pollen comes if this field is close or far away from the apiary and if there is an agroecological measure on it or not. We are interested to know where the bees are going and if they are going on fields where there is the agroecological measure.

Materials and Methods

Study area

3 of the 30 apiaries studied in the AGRIPOL project were studied for the master thesis. These three hives are located in three different apiaries. Although the project took place both in the cantons of Jura and of Vaud, the three sites are located in the canton of Jura. The reason for this is that the agroecological measures taken by farmers are denser around the Jura's apiaries than around the Vaud's apiaries. Therefore, if the effect of the agroecological measures taken for the honey bees is not visible in Jura where the conditions are, then there is no reason that the results would be different in the canton of Vaud.

The three apiaries were chosen from AGRIPOL's project volunteers' beekeepers of Jura. The PhD student contacted three beekeepers in the canton of Jura to discuss with them the possibility of putting an additional hive for the waggle dance experiment. We needed to contact some beekeepers with more hives than the ten already involved in the project in order to not disturb them. For the study of the dance, the colony hive needs to be open and recorded every week for two months. We took an extra hive to avoid affecting the "AGRIPOL" monitoring system, which has hives with traps, scales and ColEval. From a technical point of view, we also had to transfer the hives into glass hives, as it was during the ColEval monitoring period, we could not have any bias in measurements of this study.
In the different apiaries, the colony of bees are in different stages. For the apiary R05, it is a colony that is recorded for the experiment. In the apiary R06, it is a nucleus. For the last apiary R07, it is a nucleus, and the beekeeper did a lot of changes in the hive during the experiment.

Landscape variables

The three areas around the apiaries are in a region of mixed farming and mainly cattle breeding. The apiaries are mostly surrounded by agricultural landscape, which is composed of meadows, pastures, cultures and forests. The grasslands are for mowing and fanned with conditioner. The meadow fields may have agroecological measurements. The pastures have animals on them, which is often cattle. There are no agroecological measures for pastures. Meadows and pastures have generally the same botanical composition but differ in their use. The former is used for mowing and the latter for grazing cattle. The crops are composed of cereals, mainly winter and autumn cereals, rape, beetroot and sunflower. There are also urban zones and water bodies. The agroecological measures are applied at a circle with a radius of 2 kilometres around the apiary (Hernandez, J. 2020). The 2km is an average for the bees' foraging radius (Steffan-Dewenter and Kuhn 2003). All these distances were calculated thanks to maps. Maps and lands distribution are represented in the results section.

Agroecological measures

The area of each crop is known for all the agricultural lands. In the project, the farmers have nine agroecological measures (Table 1). These measures have "three main objectives: (1) the improvement of food resources for pollinators; (2) the reduction of the chemical and mechanical disturbance known to be disruptive to pollinating insects; (3) and the increase in the supply of habitats for pollinators." (Hernandez, J. 2020) Besides, another goal of these

agricultural measures is to promote biodiversity, which may have a positive impact on honey bees population (Hernandez, J. 2020).

Agroecological measures	
1. Foraging resources for pollinators	a. Sowing of fodder legumes under cover of the main crop
	b. Floral resources for pollinators in temporary meadows
	c. Delayed mowing of temporary meadows
2. Agricultural practices respectful of pollinating insects	d. Renouncing the use of neonicotinoids as seed treatments
	e. Renouncing the use of insecticides on the flowering crops on the farm
	f. Mowing without conditioner on meadows
3. Creating habitats for pollinating insects	g. Provision and maintenance of one or more sites for an apiary all year round
	h. Creation and maintenance of open soil areas in vineyards with high natural biodiversity
	i. Installation and maintenance of nesting structures for wild bees

Table 1: The nine agroecological measures that the farmers can choose to do on their fields during the project and the three aims of the measures ('Brochure de Description Du Projet Agriculture et Pollinisateurs' 2018). *The measure a. is flowering at the end of July. As the last recording was made on the 22nd of July, we did not cover this measure with the recording. The measures b. and c. are interesting for the honey bees. The second category of measures is interesting for the honey bees but cannot be apprehended for them, as the measure is not on the field but happen at one moment. The third category of measures is not useful for the master project. The agroecological measures that are interesting for the honey bees are: 1. Foraging resources for pollinators and f. Mowing without conditioner on meadows.*

Hive design

The Dadant hives system were modified so that there was glass on both sides (27x39cm), through which we could see and record the waggle dances that occurred on the frame. Wood panels were made of the same dimensions. They were made in order to avoid that bees put wax on the glass when we are not filming. The wood panels replaced the glass when we were not recording. The beekeeper installed a colony in each of these modified hives. The hives were minimum 30cm away from the other hives on the apiary, which made it possible to record images with a camera.

Data collection

Before the recording

The hives were opened, and each modified frame was numbered in order to be able to put them back at the right place after the recording. Then, each frame was observed to select

the frame where the most waggles occurred. There are some frames where the bees dance more because they lay pheromones on them. Such frames are called dancefloors (Jürgen Tautz and Martin Lindauer 1997), and the aim was to put one of these dancefloors in front of the camera. In each hive, the frame selected was put in front of the glass in order to be able to record the activities on it.

The entrance of the hive was partially blocked with a 2cm thick foam. The foam was arranged such that most of the bees would enter the frame filmed. The goal was to force bees to perform their dances on the frame facing the camera and therefore increase the number of observations.

Field notes

Notes were taken about the recording hour, the orientation of the hive, the GPS coordinates of the apiaries, some observations such as the weather and differences of the lands around, an indication of the number of flying bees in front of the hive, the fact that foragers came back with pollen, the kindness of the bees and if waggle dance were easy to see on the frames. In addition, the beekeepers gave me sometimes some indications about the resources.

An interview was made with the three beekeepers to ask them how the experiment was perceived for them, as I went on their apiary every week for two months.

Recording

Each hive was recorded once a week depending on the weather from the 28th of May 2020 to the 22nd of July during 30 minutes with a camera (Sony, HDR-CX450) at 29.97 images per second. To avoid reflections on the glass, a black tissue was used behind the camera and a Pavatex plate on the top of the hive (Figure 1). The camera was on a tripod at around 20cm from the glass (Figures 2 and 3). On the side of the glass a plumb bob was added to detect the vertical of the hive and a small clock on the glass in order to know the exact hour of the waggle dance (Figures 2 and 3).

Figure 1: recording infrastructure: the picture shows the Pavatex and the black tissue used to have shadow on the glass in order to avoid the reflection.

Figure 2: recoding infrastructure: the picture shows the camera recording on the tripod, the black tissue, the hive with the glass and a small clock on the glass in order to know the exact hour of the waggle dance. On the side of the glass a plumb bob was added to measure the inclination of the hive.

Figure 3: recording infrastructure: the picture shows the 2 cm thick foam that obscures the entrance in order to force the bees to go on the filmed frame.

After the recording

The frames were put in the same order as at the beginning. The foam was taken away, and the entrance was put back in place.

Data analysis

Waggle dance

I watched the videos until I saw honey bee dancing. I noted all the waggles in an Excel file. Then, I used the software Shortcut to decode the waggle dances. I used Couvillon's protocol (2012) to analyse the waggle dances.

Two pieces of information are needed to decode the waggle dances: (1) the duration of the waggle run (von Frisch K. 1967; T. D. Seeley, *et al.* 2000), which is used to determine the distance of the location indicated and (2) "the direction of the waggle run relative to vertical, which gives the direction from the nest relative to the solar azimuth" (M. J. Couvillon et al. 2012).

The duration was determined by the start of each waggle run and its end. The software provides the precision by the temporal resolution of 0.04 sec, which is one frame. The waggle dance is easy to see with this temporal resolution. I estimate my maximum error at 0.08 sec. Then the duration is transformed to distance thanks to Von Frisch (1967).

To determine the direction of the waggle dance, we determine "the angle of the dancer's body relative to vertical during the waggle run" (M. J. Couvillon et al. 2012). I put an acetate sheet on my computer screen in order to be able to mark with two dots the centre of the dancing bee's thorax during the waggle run. Then, I drew a line to connect the dots and extended it to cross the vertical line made by the plumbline. Then, with a protractor, I determined the degree of the angle. I estimate my maximum error at 1 degree.

To determine the azimuth for each waggle run, I used a website (http://solartopo.com/orbite-solaire.htm). I put the apiary's location and the time of the waggle dance known thanks to the clock.

Finally, I added the azimuth and the angle of the dancer to have the direction.

Round dance

I counted and reported all the round dances seen on the video in an Excel file per video.

Maps

All the maps are produced with the software QGIS (Orthophotos 2017 du Canton du Jura mises à disposition par le Système d'Information du Territoire du Canton du Jura (SIT Jura) via la Fondation Rurale Interjurassienne (FRI). Projet Ressources selon LAgr art. 77a, Agriculture et Pollinisateurs, 2018-2025, FRI-DGAV-ProConseil, Cantons de Vaud, Jura, Berne, OFAG.)
The waggle dances were added on the maps using the direction and the distances obtained.

Statistics

Round dance

I used a general linear mixed-effects model (GLMM; 'glmer' function in the R package 'lme4') to know if an apiary has significantly more round dances than the other. This will allow us to understand if the number of round dances is linked to the diversity of resources around the apiary. The diversity of the resources is determined in function of the number of different fields present in the 100m around the apiary. The response variable is the number of round dances. The explanatory variable is the apiary. The random effect is the day and the month of the video recording. However, as there are only a few data, the statistics are not very strong. To be able to have enough data, it would have been interesting to record dances on 10 to 15 apiaries different. For this reason, I did more descriptive statistics.

The histograms were created with the software "RStudio" (Version 1.1.456 – © 2009-2018 RStudio, Inc). The surfaces of each field were calculated to obtain theses graphs. Then, the percentage was calculated depending on the categories of fields. I used the same categories as the project AGRIPOL to keep unity. The areas were previously calculated by the mapping data made for the project.

Waggle dance

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Results

Landscape variable

There are two different categories of landscapes around the apiaries in the project. The first category, forests and grasslands, is mostly composed of forest and pasture with a large proportion of grasslands. The second one is the cereals and various crops, which contain mostly cereals, various crops and few grasslands.

To determine the category of the landscape of the different apiaries as well as the variety and difference between the different landscapes around the apiaries, I made histograms.

We can see that the apiary R05 (figure 4) has 47.1% of forests, 19.75% of meadows, 12.4% of cultures, 10% of pasture and 8.2% of urban zones. This apiary is therefore in the category forests and grasslands.

The apiary R06 (figure 5) is composed of meadows at 53.2%, cultures at 26.5%, forests at 22.4%, urban zones at 14.5%, pastures at 5.7%, and flowering crops at 1.6%. This apiary is in the category cereals and various crops.

The apiary R07 is composed of 54% of meadows, 30.2% of forests, 21% of cultures, 8.5% of pastures, 7.2% of urban zones and 1.6% of flowering crops. It is part of the category cereals and various crops, even if there are only very few cereals. This apiary has however a lot of temporary meadows. For this reason, we can say that it is intermediate between cereals and various crops and forest and grasslands.

The following histograms show the distributions of the different landscape variables around the 2km of each apiary.

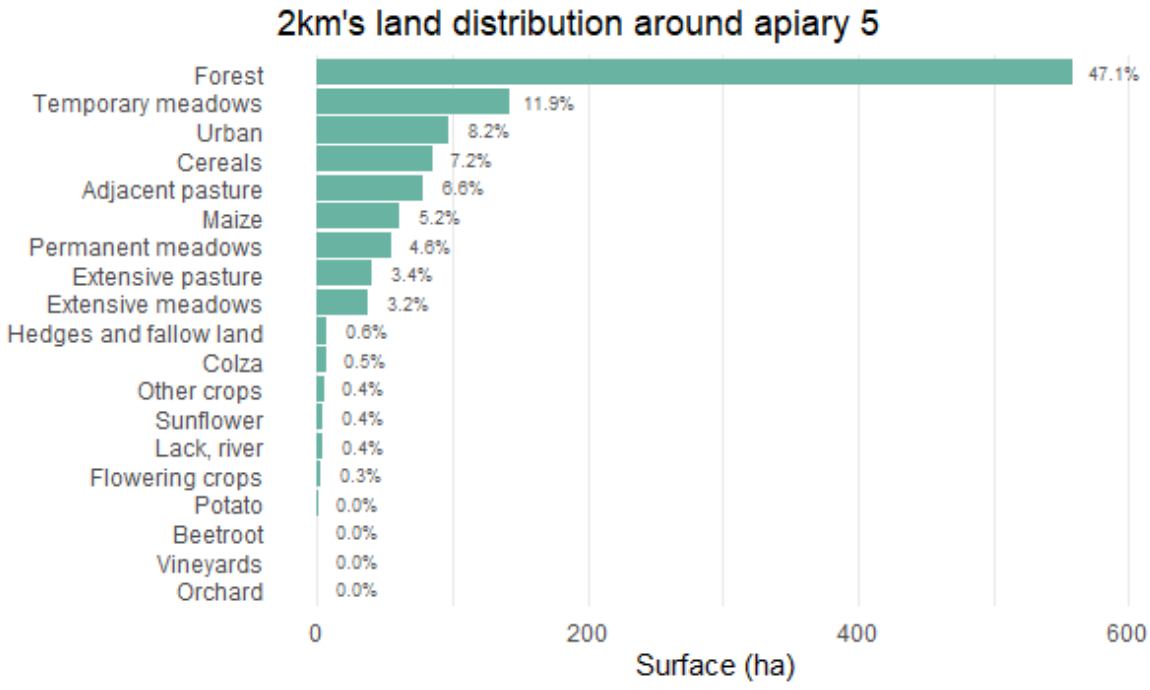

Figure 4: histogram with the proportion of the composition inside the 2km radius around apiary 5.

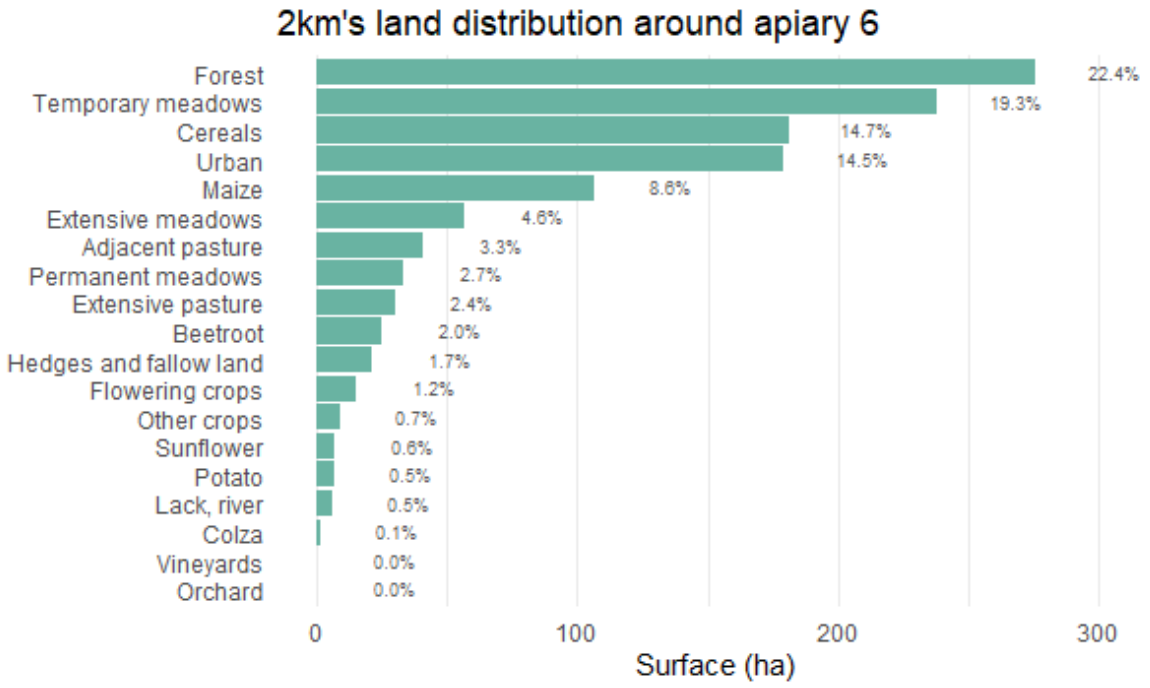

Figure 5: histogram with the proportion of the composition inside the 2km radius around apiary 6.

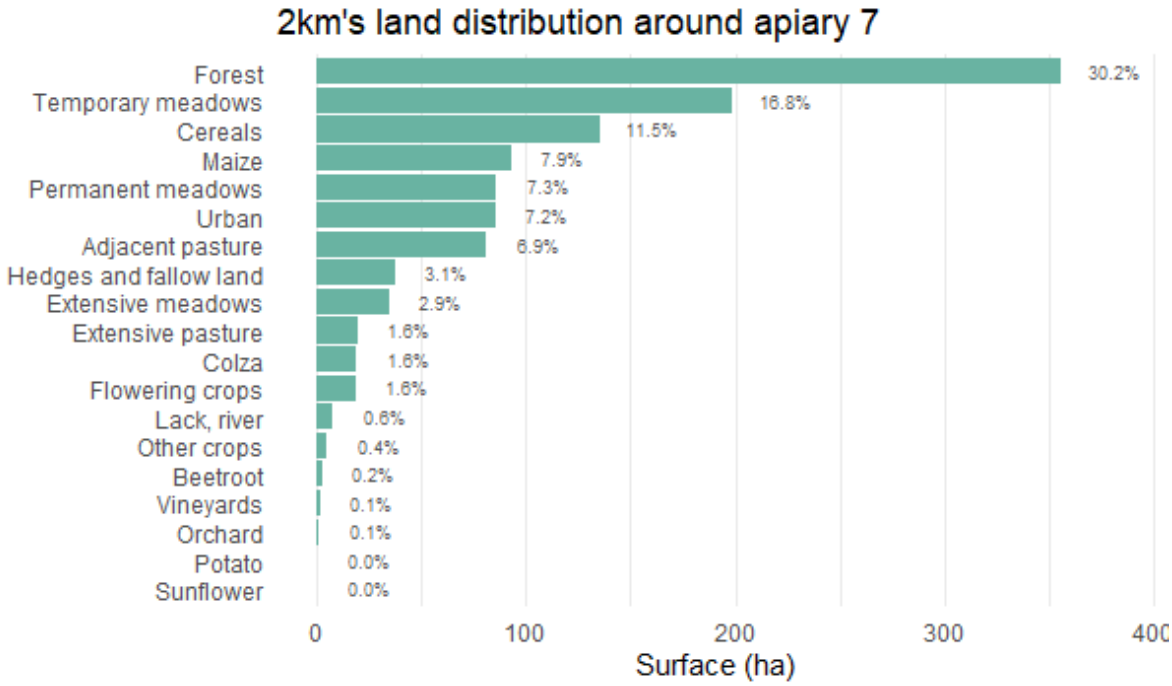

Figure 1: histogram with the proportion of the composition inside the 2km radius around apiary 7.

Waggle dance

All the waggle dances were recorded for each apiary and each month (Table 2).

Number of waggle dances per month and apiary				
Apiary	May	June	July	Total
R05	0	6	9	15
R06	0	6	1	7
R07	0	0	0	0

Table 2: Number of waggle dances per apiary and per month. The apiary R05 has 15 dances recorded, and the apiary R06 has in total 7 dances, whereas the last apiary (R07) has not any waggle dances recorded.

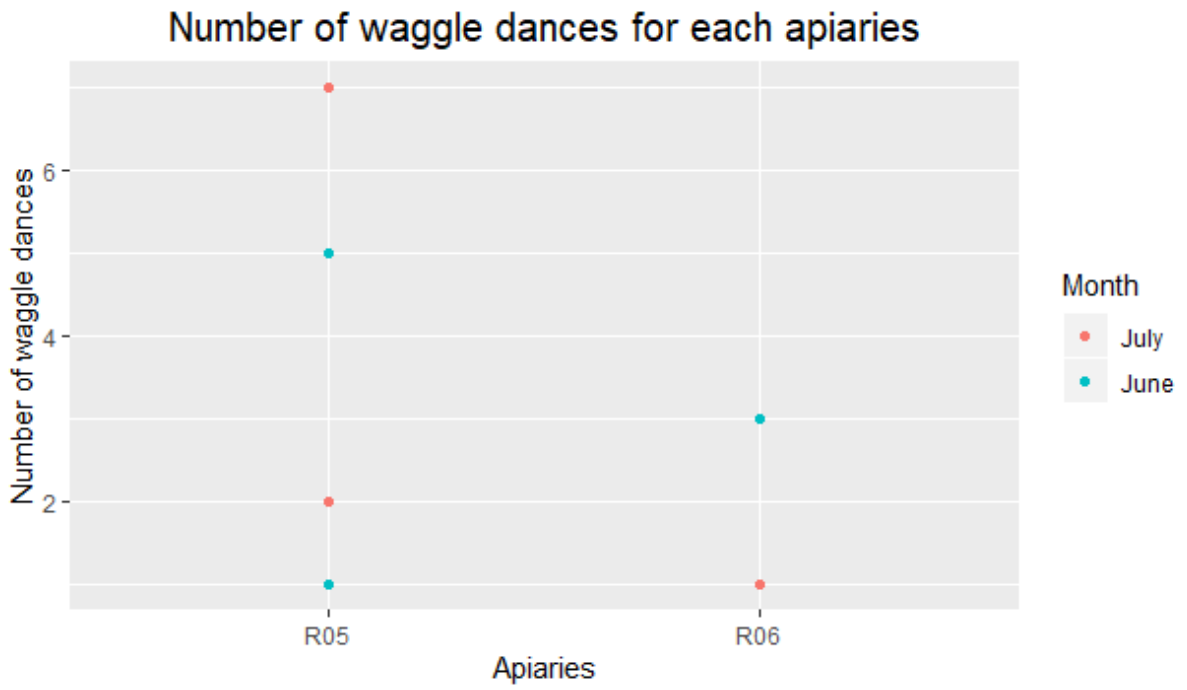

Figure 7: Number of waggle dances for each apiary. The apiary R07 is not on the graph as no waggle dance was recorded in it. The x-axis represents the apiary numbers, the y-axis represents the number of waggle dances and months are identified by colors. There are two points at different dates of the month when some waggle dances were recorded.

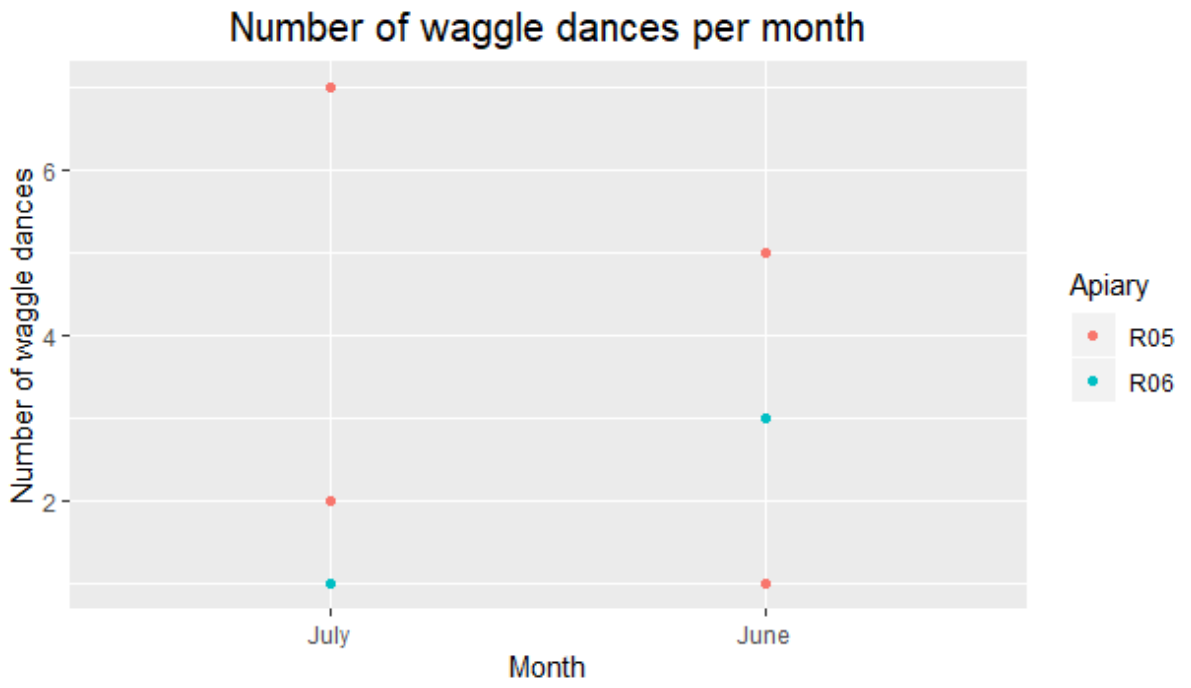

Figure 8: Number of waggle dances for each apiary. The apiary R07 is not on the graph as no waggle dance was recorded in it. The x-axis represents months, the y-axis represents the number of waggle dances and the different apiaries are identified by colors. There are two points at different dates of the month when some waggle dances were recorded.

On the maps (Figures 9 and 10), we can see the 22 waggle dances detected on the recording. The different colours are linked to the date of the dance's recording.

Waggle dance of the R05 apiary

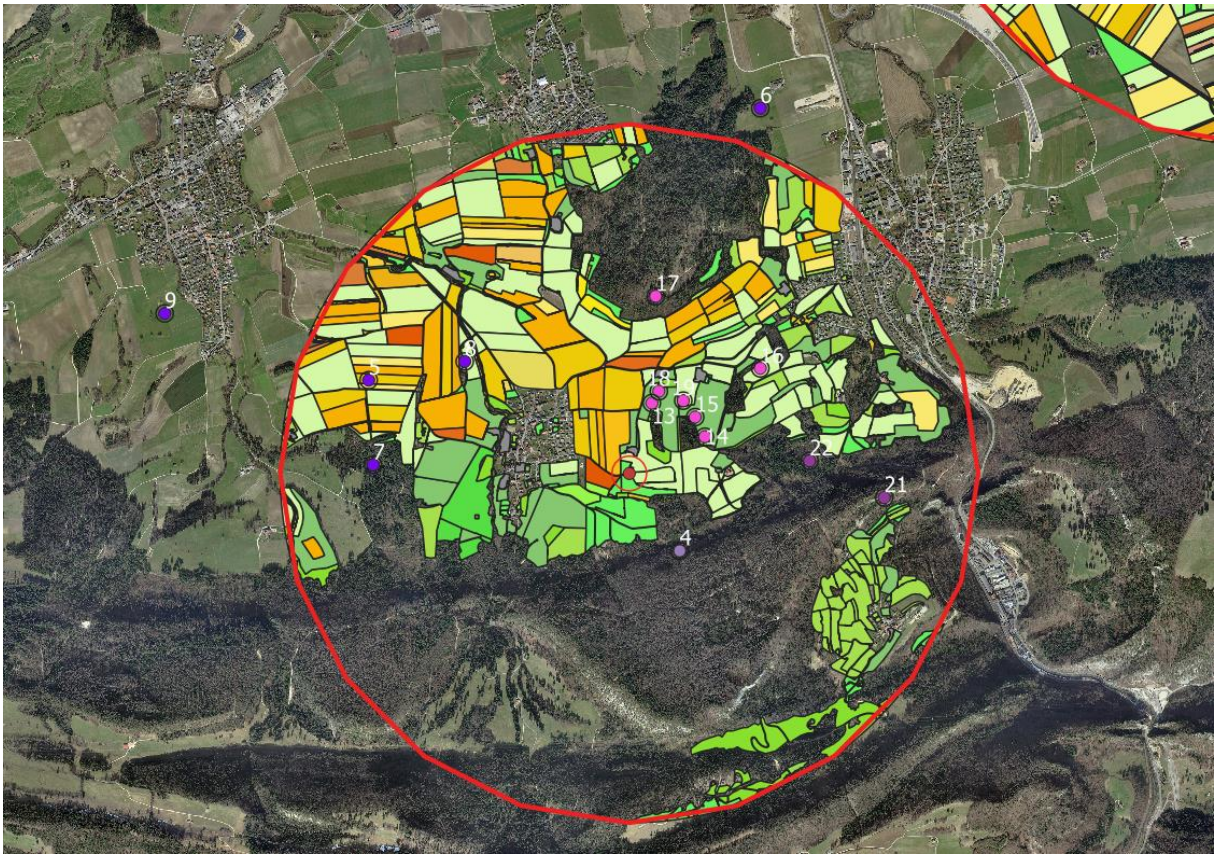

Figure 9: map with the 15 waggle dances, illustrated by the coloured dots, with their 50m radius black circle, which represent the error. Dance 4 in pink was recorded on the 12th of June. The dances 5 to 9 in dark purple were observed on the 23rd of June. The dances 13 to 19, in pink purple, were recorded on the 14th of July. The dances 21 and 22 in purple were observed on the 22nd of July. The red point is the apiary. The first red circle is the 100m circle, where the round dances occur. The second red circle is at 2km radius. Inside that circle, the agroecological measures are taken. The fields coloured on this map are the fields that have, at a moment of the project, interesting resources for the bees. The meadows and pastures are in shade of green, and the different crops in shade of orange. The legend is in the appendices (appendix 1).

Waggle dance of the R06 apiary

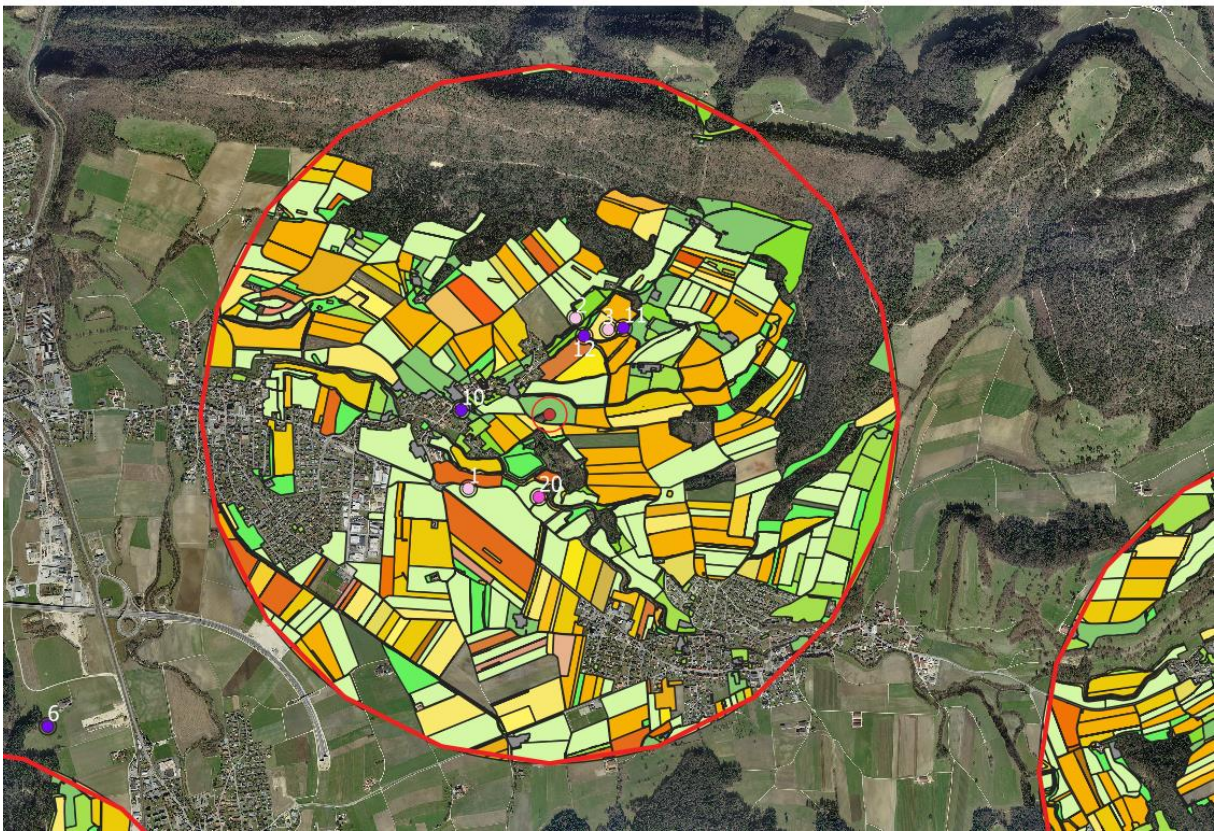

Figure 10: map with the 7 waggle dances, illustrated by the coloured dots, with their 50m radius black circle, which represent the error. The dances 1, 2, and 3 in pale pink were observed on the 3rd of June. The dances 10, 11, and 12 in dark purple were filmed on the 23rd of June. Dance 20, in pink purple, was recorded on the 14th of July. The red point is the apiary. The first red circle is the 100m circle, where the round dances occur. The second red circle is at 2km radius. Inside that circle, the agroecological measures are taken. The fields coloured on this map are the fields that have at a moment of the project, interesting resources for the bees. The meadows and pastures are in shade of green, and the different crops in shade of orange. The legend is in the appendices (appendix 1).

Waggle dance of the R07 apiary

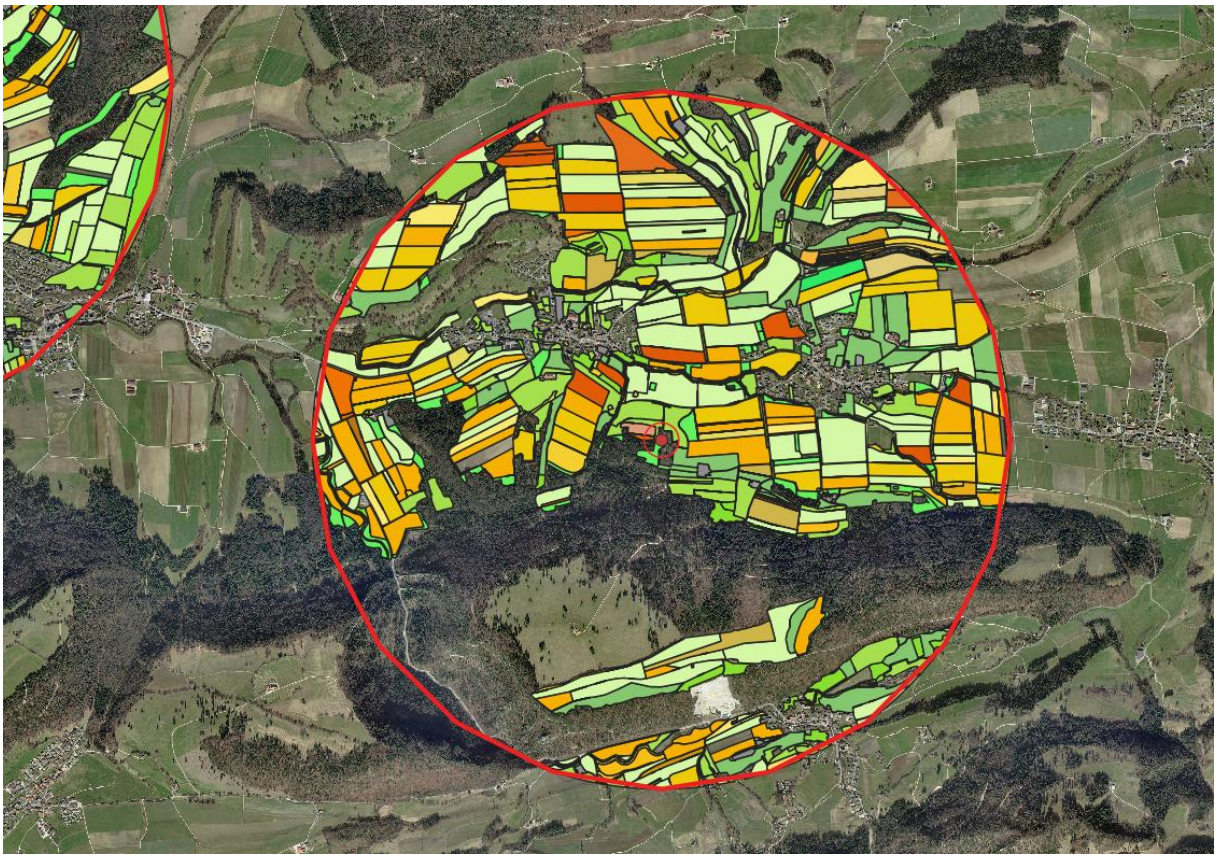

Figure 11: map of the 7th apiary, no waggle dances were observed. The red point is the apiary. The first red circle is the 100m circle, where the round dances occur. The second red circle is at 2km radius. Inside that circle, the agroecological measures are taken. The fields coloured on this map are the fields that have at a moment of the project, interesting resources for the bees. The meadows and pastures are in shade of green and the different crops in shade of orange. The legend is in the appendices (appendix 1).

With their margins of error, the waggle dances have indicated 63 fields, 12 of which have agroecological measures, so 19% of the time. The 63 fields indicated by the waggle dances were 53.2% of the time pastures and meadows, then 16.1% the forest was indicated. In the third position, the different fields of cereals were indicated with 11.3% (Figure 14). In details, for the apiary R05, the waggle dances indicated 58.8% of the time the pastures and the meadows, while within the 2km around the apiary, there is only 29.7% of pastures and meadows. Then the forest was indicated 26.7% and represent 47.1% of the fields within the 2km radius of the apiary (Figures 4 and 12). For the apiary R06, pastures and meadows were the most indicated with 46.4%, while within the 2km around the apiary there is only 32.3% of pastures and meadows. The hedges and fallow land with 17.9%, while it is only 1.7% of the filed around the apiary (Figures 5 and 13).

There are 4 agroecological measures on 33 fields for the R05 apiary, so 12.1%. For apiary R06, there are 8 fields with measures indicated out of 30 or 26.6% (Table 3).

With the margin of error of 50m radius around the dances, one dance indicates an area of 7854.9m^2, naturally, the honey bee did not visit all this area. Some of the fields visited have measures that are not of interest to honey bees such as: (1) "Nesting structure" for wild

pollinators. (2) "Renounce the use of foliar insecticides for beetroots". Beetroots is not a resource for bees as it is a biennial plant that is harvested in the first year and flowers in the second year. However, in these fields, poppies or other flowers may have grown (Chauvel et al. 2018). These are flowers that are of interest to bees (see Discussion). (3) "Mowing without conditioner", the honey bees cannot know whether the mowing is done with or without a conditioner. The fields, which are meadows, with this measure were visited 6 times or 9.5%. The meadows are very interesting for the bees because of their diversity of resources (Senapathi et al. 2015, Carr-Markell et al. 2020). The measure "Delayed mowing of temporary meadows and mowing without conditioner" is interesting for bees because they are resources for a longer time in a field before mowing. In apiary R06, two fields with this measure were indicated, so 6.6% for the apiary. "Delayed mowing of temporary meadows" is also of interest for the reasons mentioned above. A dance indicated a field of apiary R05. Finally, a dance from apiary R05 indicated the measure "Floral resources pollinators on temporary meadows" which is interesting for the bees.

Simplified table of the waggle dances and the fields indicated with the agroecological measures

Waggle dance	Apiary	Category	Flowering	Ressources	If a measure, which one?
1	R06	Cereals	No	Yes	
1	R06	Temporary meadows	Yes	Yes	
2	R06	Extensive meadows	Yes	Yes	Mowing without conditioner on meadows
2	R06	Extensive meadows	Yes	Yes	
2	R06	Temporary meadows	Yes	Yes	
2	R06	Hedges and fallow land	Yes	Yes	
2	R06	Extensive pastures	Yes	Yes	
2	R06	Beetroot	No	No	Renounce the use of foliar insecticides for beetroots
3	R06	Cereals	No	Yes	
3	R06	Hedges and fallow land	Yes	Yes	
4	R05	Forest	Unsure	Yes	
5	R05	Maize	No	Yes	
5	R05	Cereals	No	Yes	
5	R05	Cereals	No	Yes	
6	R05	Forest	Unsure	Yes	
6	R05	Adjacent pastures	Yes	Yes	
6	R05	Extensive pastures	Yes	Yes	

7	R05	Forest	Unsure	Yes	
8	R05	Adjacent pastures	Yes	Yes	
8	R05	Temporary meadows	Yes	Yes	Floral resources pollinators temporary meadows
8	R05	Temporary meadows	Yes	Yes	Delayed mowing of temporary grassland
8	R05	Cereals	No	Yes	
9	R05	Maize	Yes	Yes	
9	R05	Extensive meadows	Yes	Yes	
9	R05	Permanent meadows for mowing	Yes	Yes	
9	R05	Bedding surfaces	Yes	Yes	
10	R06	Urban	No	No	
10	R06	Adjacent pastures	Yes	Yes	Nesting structures for wild bees
11	R06	Adjacent pastures	Yes	Yes	
11	R06	Maize	No	Yes	
11	R06	Maize	No	Yes	
11	R06	Cereals	No	Yes	
11	R06	Extensive meadows	Yes	Yes	Mowing without conditioner on meadows
11	R06	Hedges and fallow land	Yes	Yes	
12	R06	Extensive meadows	Yes	Yes	Mowing without conditioner on meadows
12	R06	Extensive meadows	Yes	Yes	Mowing without conditioner on meadows
12	R06	Cereals	No	Yes	
12	R06	Hedges and fallow land	Yes	Yes	
12	R06	Extensive pastures	Yes	Yes	
12	R06	Sunflower	No	Yes	
13	R05	Forest	Unsure	Yes	
13	R05	Extensive pastures	Yes	Yes	
13	R05	Adjacent pastures	Yes	Yes	
14	R05	Forest	Unsure	Yes	
14	R05	Extensive pastures	Yes	Yes	
14	R05	Adjacent pastures	Yes	Yes	
15	R05	Forest	Unsure	Yes	

15	R05	Adjacent pastures	Yes	Yes	
16	R05	Adjacent pastures	Yes	Yes	
16	R05	Temporary meadows	Yes	Yes	
16	R05	Temporary meadows	Yes	Yes	Mowing without spacers on meadows
17	R05	Forest	Unsure	Yes	
18	R05	Extensive pastures	Yes	Yes	
18	R05	Adjacent pastures	Yes	Yes	
19	R05	Adjacent pastures	Yes	Yes	
19	R05	Adjacent pastures	Yes	Yes	
19	R05	Temporary meadows	Yes	Yes	Mowing without spacers on meadows
20	R06	Forest	Unsure	Yes	
20	R06	Temporary meadows	Yes	Yes	Delayed mowing of temporary meadow and mowing without conditioner
20	R06	Temporary meadows	Yes	Yes	Delayed mowing of temporary meadow and mowing without conditioner
20	R06	Hedges and fallow land	Yes	Yes	
21	R05	Forest	Unsure	Yes	
22	R05	Forest	Unsure	Yes	

Table 3: Table of the waggle dances and the fields indicated with the agroecological measures. The culture indicates the field where the honey bees waggle dances indicated. It is used in the discussion to analyse the waggle dances. The category categorised the field to better understand of the different graphs. The resource category includes nectar, pollen, aphid honeydew and propolis, which are useful to honey bees. A table with the date, the exact culture is in the appendices (appendix 3).

Percentage of the different fields indicated by the waggle dances

Some histograms were made to illustrate the percentage of the different types of fields indicated by the waggle dances: one for each apiary and then one featuring all the apiaries (Figures 12, 13 and 14).

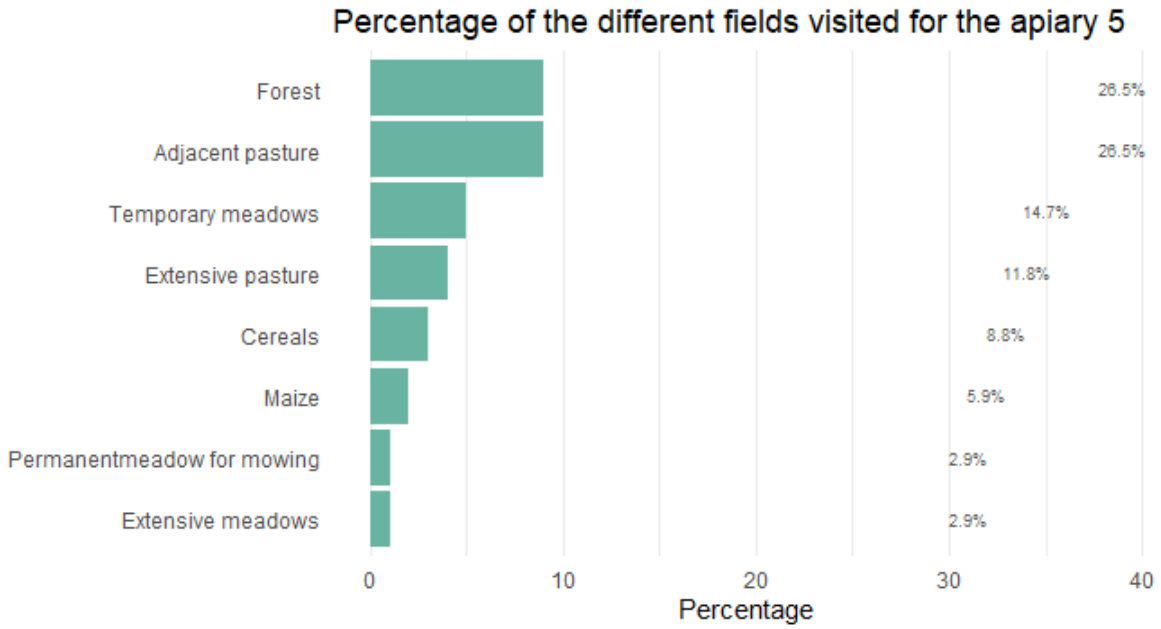

Figure 12: Percentage of the different fields indicated by the honey bees waggle dances for the apiary R05. For this apiary, the waggle dances indicated 58.8% of the time the pastures and the meadows, then the forest was indicated 26.7%. Each field visited count as one.

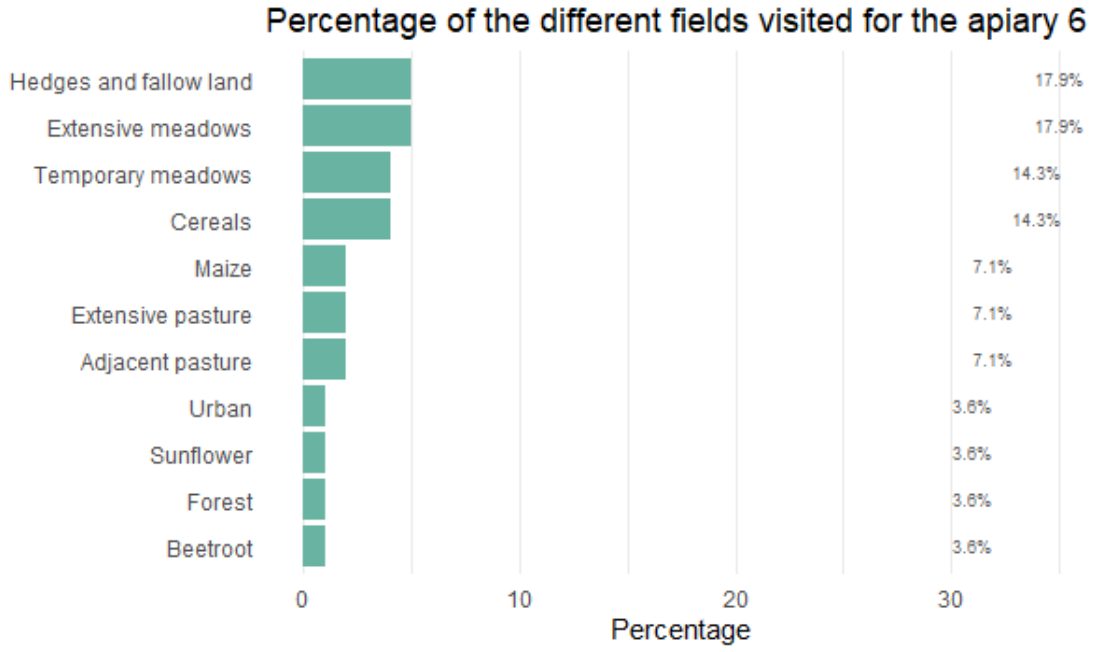

Figure 13: Percentage of the different fields indicated by the waggle dances of the honey bees for the apiary R06. For this apiary, pastures and meadows were the most indicated with 46.4%, then the hedges and fallow land with 17.9%. Each field visited count as one.

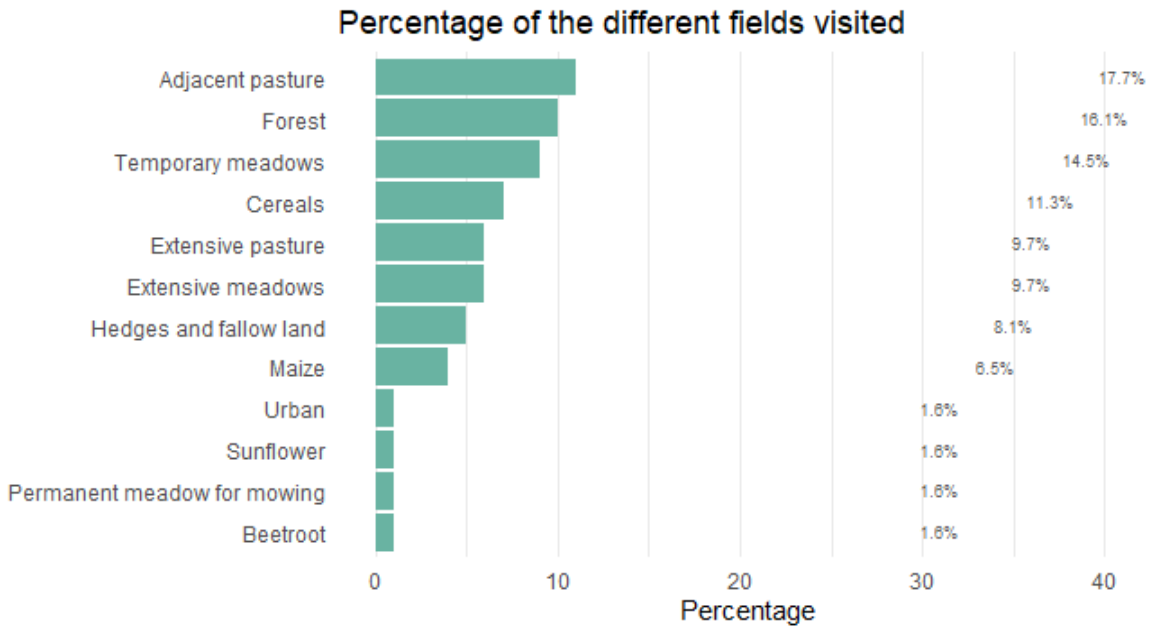

Figure 14: Percentage of the different fields indicated by the waggle dances of the bees. 53.2% of the time, the waggle dances indicated pastures and meadows, then with 16.1%, the forest was indicated. In the third position, the different fields of cereals were indicated with 11.3%. Each field visited count as one.

Round dance

I recorded 46 round dances. These dances indicate that resources are available around the hive within a radius of 100m (von Frisch K. 1967; 1946).

All the round dances are recorded for each apiary and each month (Table 4).

Number of round dances per month and apiary				
Apiary	May	June	July	Total
R05	1	3	1	5
R06	0	15	3	18
R07	7	14	2	23

Table 4: Number of round dances per apiary and month. The apiary R05 has 5 dances recorded, the apiary R06 has 18 round dances, and R07 has 23 round dances recorded.

I used a general linear mixed-effects model to know if an apiary has significantly more round dances than the others. The R05 and R06 apiaries do not show significant results (Apiary 5: Estimate Std. = -1.27, Error = 0.79, z value = -1.604, P value = 0.1086; Apiary 6: Estimate Std. = 0.9897, Error = 0.7718, z value = -1.282, P value = 0.1998). The 7th apiary has significatively more round dances than the other apiaries (Apiary 6: Estimate Std. = 1.77, Error = 0.77, z value = 2.298, P value = 0.0216).

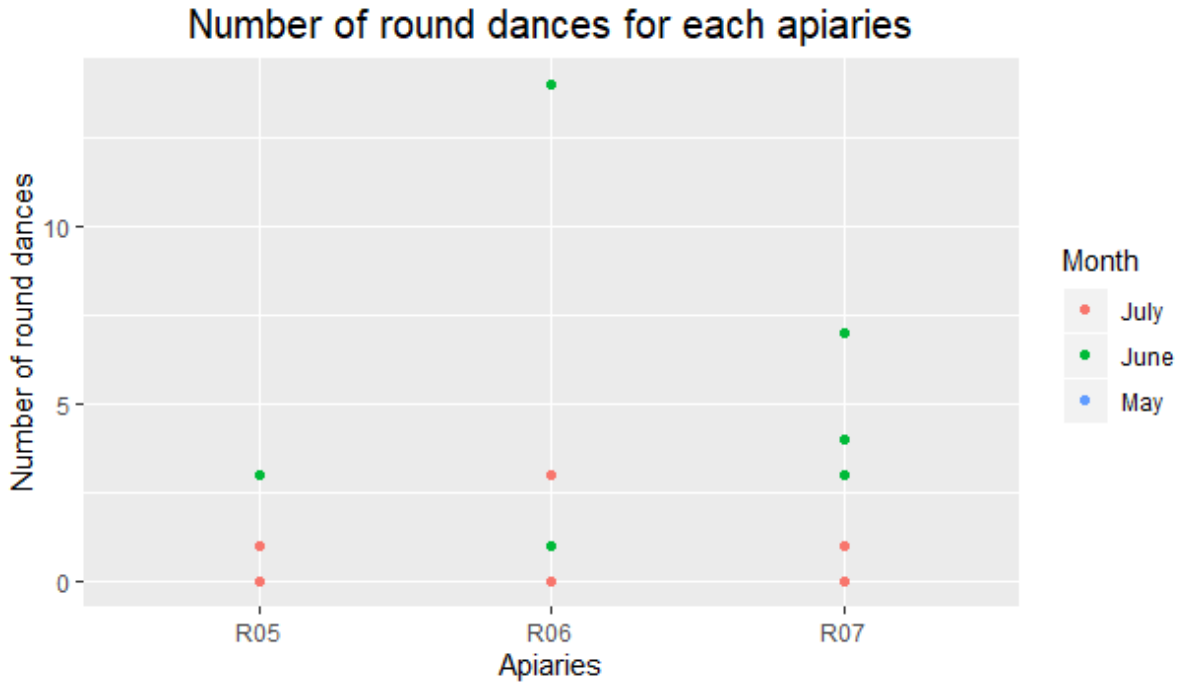

Figure 15: Number of round dances per month. On the x-axis are the different apiaries. The x-axis represents the different apiaries, the y-axis represents the number of round dances recorded, and the months are identified by the colors. The 5th and 6th apiaries do not have significant results. There are several points at different dates of the month when some round dances are recorded.

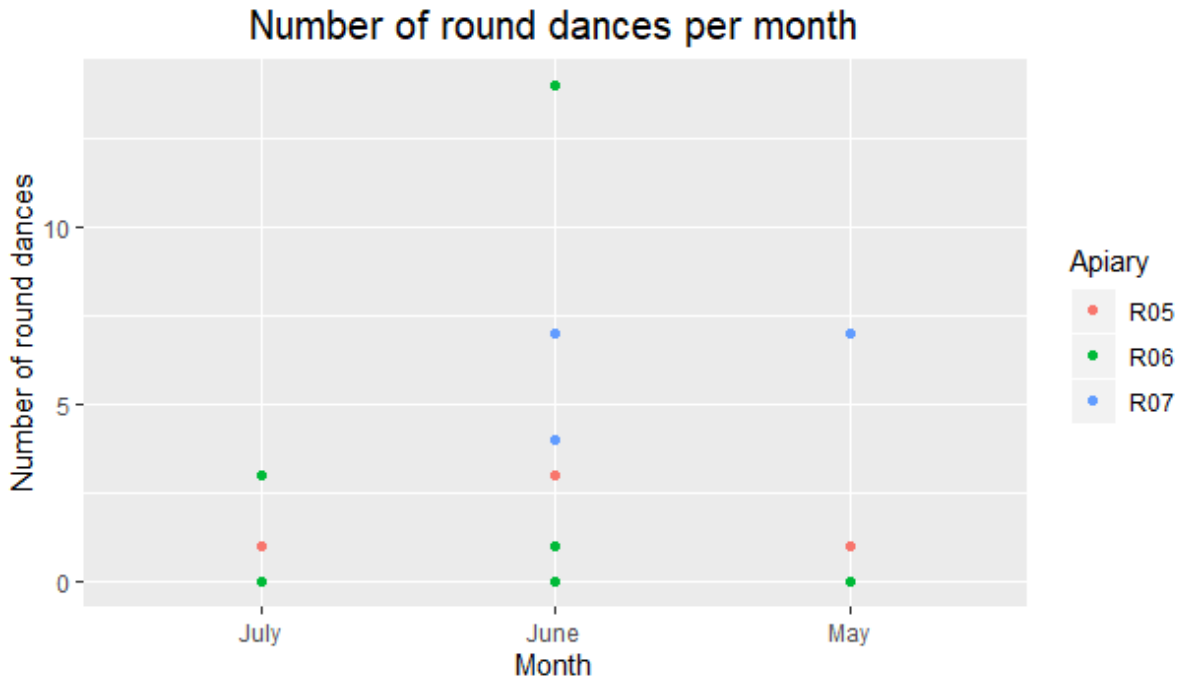

Figure 16: Number of round dances per month. The month is on the x-axis. On the y-axis the number of round dances recorded, and the colours represent the different apiaries. If I recorded round dances at different dates of the month, there are more than one point. The statistic result (Apiary 5: Estimate Std. = -1.27, Error = 0.79, z value = -1.604, P value = 0.1086, Apiary 6: Estimate Std. = 0.9897, Error = 0.7718, z value = -1.282, P value = 0.1998) The 7th apiary has significatively more round dances than the other apiaries (Apiary 6: Estimate Std. = 1.77, Error = 0.77, z value = 2.298, P value = 0.0216).

Around the apiary R05, 33.3% of the fields have agroecological measures, whereas only 20% of the fields around the apiaries R06 and R07 have agroecological measures (Table 5). The apiary R05 has 4 different types of fields, the apiary R06 6 different types, and the apiary R07 has 7 different types of fields around it. The following maps (Figures 17, 19 and 21) show the 100m where the round dance occurs. The histograms (Figures 18, 20 and 22) show the different categories of fields within the 100m around the apiary.

Round dance of the apiary R05

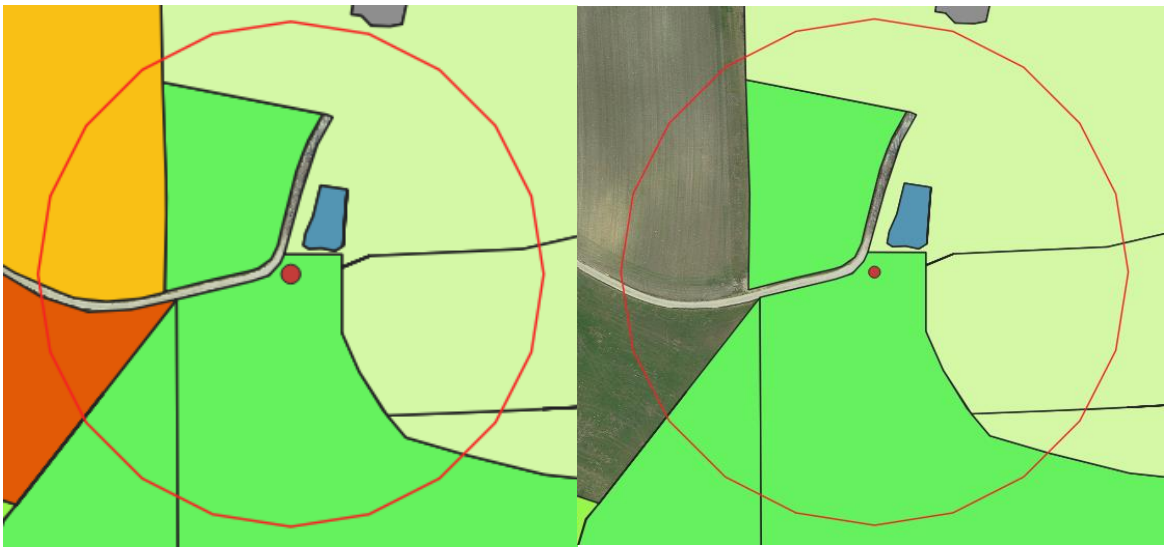

Figure 2: map showing a 100m radius of the apiary R05. The left map represents the fields with resources available on the 28th of May and the right map the resouces available from the 3rd of June to the 22nd of July 2020. In green are some fields of extensive meadow with an agroecological measure: "Mowing without conditioner on meadows", and in pale green some temporary meadows. In red, it is autumn rapeseed. In light blue, it is a pond, and in orange a field of triticale.

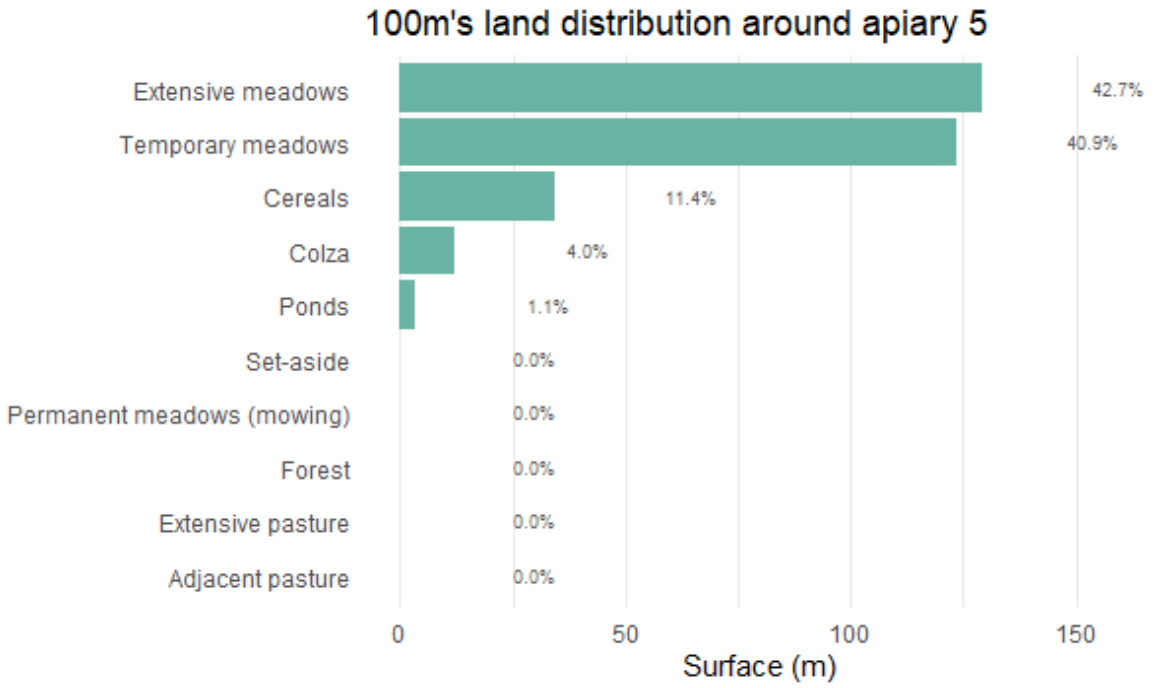

Figure 3: It is a histogram that indicates the proportion of the composition inside the 100m radius. The legends of the fields are in the appendices.

Round dance of the apiary R06

Figure 4: map showing a 100m radius of the apiary R06. The left map represents the fields with resources available on the 28th of May and the right map the resouces available from the 3rd of June to the 22nd of July 2020. In green are some adjoining pastures and in light green an extensive meadow. In pale orange, a field of autumn barley and in neon green an extensive meadow with an agroecological measure: "Mowing without conditioner on meadows". In orange it is a field of triticale.

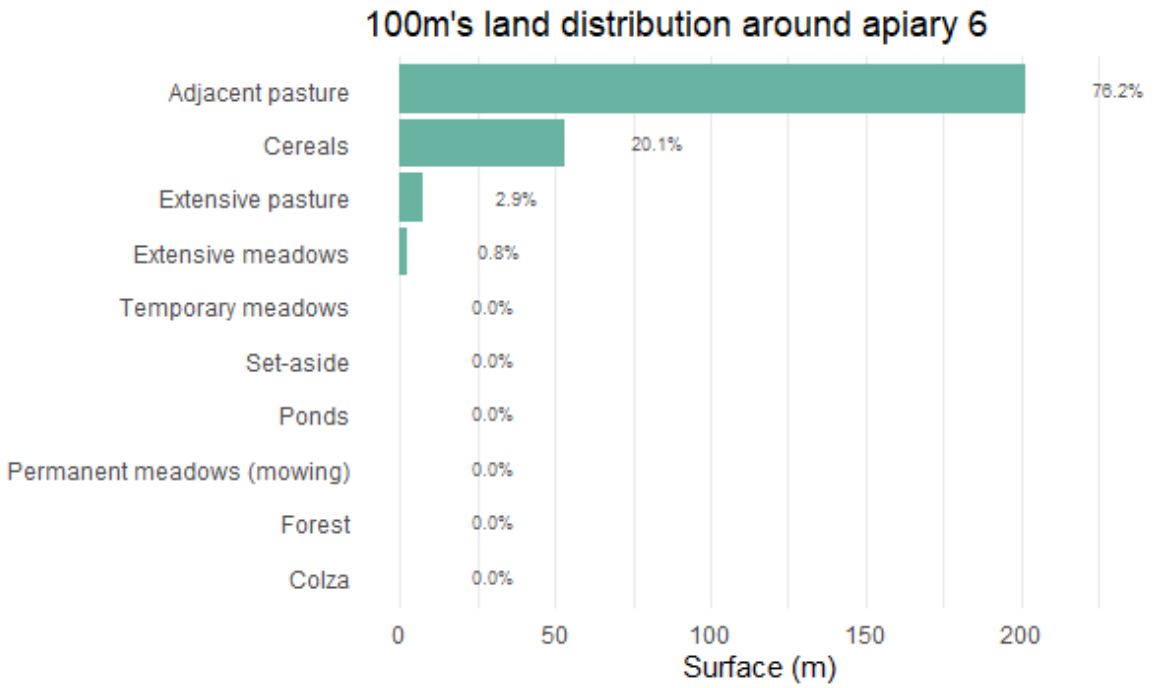

Figure 5: It is a histogram that indicates the proportion of the composition inside the 100m radius. The legends of the field are in the appendices.

Round dance of the apiary R07

Figure 6: map showing a 100m radius of the apiary R07. The coloured fields represent the resources available from the 28th of May to the 22nd of July 2020. In neon green, it is an extensive meadow, and in green a permanent meadow for mowing, on these fields, there is an agroecological measure: "Mowing without conditioner on meadows" and on one of them there is also "Installation and maintenance of nesting structures for wild bees". In orange it is a floral fallow, and in beige, a rotating fallow.

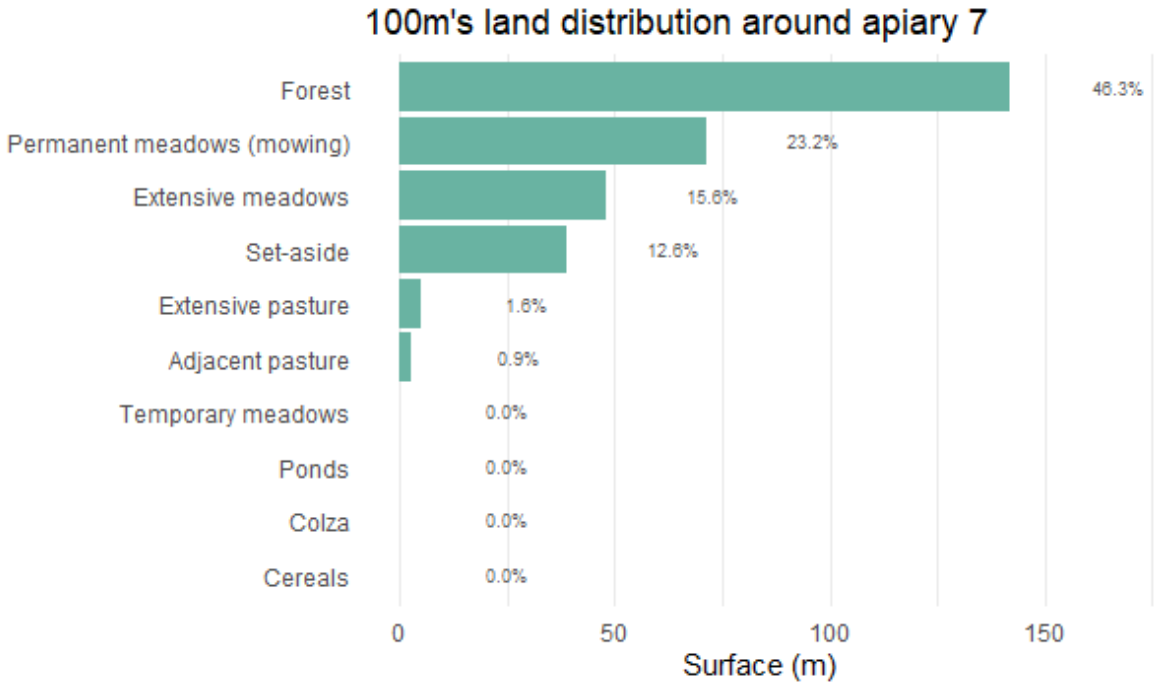

Figure 7 : It is a histogram that indicates the proportion of the composition inside the 100m radius. The legends of the field are in the appendices.

Table of the 100m radius around the apiaries and the fields with the agroecological measures

Apiary	Caterory	Ressources	Which measures?
R05	Extensive meadows	Yes	Mowing without conditioner on meadows
R05	Colza	Yes	
R05	Temporary meadows	Yes	
R05	Cereals	No	
R05	Water		
R06	Extensive pastures	Yes	
R06	Adjacent pastures	Yes	
R06	Cereals	Yes	
R06	Extensive meadows	Yes	Mowing without conditioner on meadows
R06	Cereals	Yes	
R07	Permanent meadows for mowing	Yes	Mowing without conditioner on meadows
R07	Permanent meadows for mowing	Yes	Mowing without conditioner on meadows and nesting structures for wild bees
R07	Extensive meadows	Yes	
R07	Forest	Yes	
R07	Fallow land	Yes	
R07	Fallow land	Yes	
R07	Adjacent pastures	Yes	

Table 5: Table of the 100m radius around the apiaries and the fields with the agroecological measures. The culture indicates the field where the honey bees waggle dances indicated. It is used in the discussion to analyse the waggle dances. The category categorised the field to a better understanding of the different graphs.

Discussion

During the nine field sessions, 22 waggle dances and 46 round dances were recorded. The round dances indicate that there are interesting resources within the 100m radius of the apiary. Whereas the decoding of the waggle dance, which is used to indicate resources at more than 100m for the hive, allows us to determine where the bee indicates interesting resources to the other foragers bees (von Frisch K. 1967; 1946).

The aims of the master thesis is to analyse (1) if the adapted design for recording honey bees waggle dances is applicable in the AGRIPOL project context on relevance of agroecological measures as a resource for honeybee colonies, or, more generally for future fields studies about honeybee's resources; and (2) what decoded dances can bring to a project such as AGRIPOL attempting to link the colony dynamic with the research of resources.

At first, I wanted to analyse the dances automatically with the protocol of Okubo et al. (2019). However, as the program was too expensive, I adapted the protocol to be able to analyse manually like did Couvillon (2012). Once the hive was prepared and installed, the major constraint of this system was the reflection on the glass. We had to find the most effective design to avoid it, which worked well with the black tissue. Then, we had to choose a frame to be recorded and it was most of the time not easy to select one, as we did not see waggles dances but only some wiggles. We had to choose which frame to put with the most wiggles at first sight. It is therefore possible that if we had chosen another frame, we would have had another amount of waggle dances recorded. The quality of the recording was done as best as we could. It was hard to avoid all the glass reflections and put the camera perfectly to see all the glass as the other hives are close. Therefore, for the master project, all the dances detected may not be effortless to analyse. In conclusion, the method is applicable directly in the field to detect waggle dances and round dances, but the analyses had to be done manually, as the software to analyse automatically was too expensive.

On the other hand, we wanted to see what decoded dances can bring to a project such as AGRIPOL attempting to link the colony dynamic with agroecological measures taken by farmers in the field. Currently, AGRIPOL project does not know exactly where the bees are finding their resources (pollen, honeyflow, etc). Thus, we were interested to know where the bees are going and if they are going on fields where there are some agroecological measures. Thanks to the waggle dances' analyses, we could suppose where the bees went and to determine the type of fields, they need at the moment in function of the resources needed for the dynamic of the colony (supply of pollen and/or nectar). The waggle dance analyses are a powerful tool to protect honey bees and wild insects as we can determine the landscape they are mostly visiting (Couvillon et al. 2014). Thanks to that, we can understand and protect, for example with the implantation of agroecological measures on fields. Further information is on the following discussion.

Round dance

The apiary R07 has significantly more round dances than the two others (Apiary 5: Estimate Std. = -1.27, Error = 0.79, z value = -1.604, P value = 0.1086, Apiary 6: Estimate Std. = 0.9897, Error = 0.7718, z value = -1.282, P value = 0.1998). It can maybe be explained by the variety of the resources thanks to the different compositions of the fields around this apiary with 7 different types of fields. In comparison, the apiary R06 has 6 different types of fields and the apiary R05 has 5 different types of fields.

In general, as we can see on the maps (Figures 17 to 22), the apiaries are mostly surrounded by fields that can have different resources for the bees during the season.

I asked the beekeepers if they have chosen their sites in function of the available resources around them. Two of them did not choose the site for the resources, whereas the last beekeeper chose his site because of the resources available around it.

R05

The apiary R05 was not chosen for the resources by the beekeepers (appendix 10).

In the table 2, we can see that the apiary R05 has only 5 recorded round dances. The location of the apiary can explain this. It is close to a farm and in an area that seems more cultivated than the other two apiaries. Around the apiary, bees' resources are lime-willow, rape, fruit trees, dandelion, meadows, and pasture (appendix 10).

In May, there was only one session in the field, during which the field in front of the apiary was in bloom (Carr-Markell et al. 2020). We see on the table that a round dance had been recorded on that date; there is perhaps a correlation between these two elements.

On the 23rd of June, the field in front of the apiary was mowed, but a field of clovers was in bloom within 100m of the apiary. On that day, 3 round dances were recorded. When there are a lot of resources close to the apiary, we recorded more round dances. However, on the 8 of July, the field of white clover was in bloom, but no round dances were recorded. This might be due to the weather, or because many resources were present so the bees did not need to indicate them (Bailey, S. 2014), or because other resources were more interesting for the need the colony (Di Pasquale et al. 2013).

R06

The beekeeper of this apiary has not chosen its location for the resources around it. He told me that he had a preference for it (Appendix 11).

I do not have any indication about mowing the fields around the apiary. There are more round dances than in the previous apiary. From my point of view, this is due to the location of the apiary in a wilder setting than the previous one. The beekeeper told me that there are many white clovers and dandelions in the adjacent pastures (Appendix 11). In addition, even if it is not seen on the map, there is a little bit of forest around the apiary with many blackberry trees that are interesting for pollen and nectar (Appendix 11).

R07

The beekeeper had several criteria: he wanted to be far away from the other apiaries to avoid a drift of *V. destructor* between the different apiaries as well as not disturbing other beekeepers by the addition of new hives. He wanted to be able to reach his apiary by car. Finally, he looked for the variety of resources around the site (Appendix 12).

The R07 apiary is located in the wildest of the three apiaries, at the edge of a young forest, which has many resources and is surrounded by meadows and fallow land. This variety of resources around the apiary could explain why no waggles dances but many round dances have been recorded (Seeley 1995), as well as many varied resources. Around the apiary, there is a wide variety of resources for the bees. Moreover, these resources are well distributed throughout the entire beekeeping season. There is, in particular, a fallow area that is very popular among the bees, according to the beekeeper. Following a plot reshuffle, old trees have been uprooted and young fruit trees producing many flowers have been planted instead. In the forest around the apiary, there is also a great diversity of trees so it is not a monoculture (Margaret J. Couvillon, Schürch, and Ratnieks 2014; Beekman and Ratnieks 2000; Steffan-Dewenter et al. 2002). There is a large lime tree, several large cherry trees, oaks, willows, maples, many blackberry trees, and firs (Appendix 12).

There is a great diversity around the apiary, whether it is a forest or a combe. It is also a different orientation of the different sun exposures, allowing for a staggering of resources (Appendix 12).

On the 23rd of June, the field in front of the apiary was mowed, but the forest around the apiary was dripping with honeydew from aphids. The beekeeper told me that in 2020, there was a lot of honeydew. Only 4 round dances were recorded. In my opinion, the amount of resources available explains why there were so few dances as there was no need to indicate resources (Bailey, S. 2014).

Waggle dance

It was relatively easy to decode the waggle dances thanks to the video recording. We had to analyse the direction and the duration of the waggle dance run (von Frisch K. 1967). However, the variation among the run of the waggle dances made it difficult to decode properly (Schürch and Couvillon 2013). All the waggle dances have a 50m radius circle around them that represent the marge of error. So, a dance represents 7854.9m^2. Obviously, the bee does not indicate all of this to the others honey bees. The honey bee with her waggle dance indicates an area smaller than the 50m radius, but it seems that even honey bees communicate with a percentage of error (Towne and Gould 1988; Tanner and Visscher 2009). The waggle dances' results have therefore to be interpreted as a probability of where the bee could have found a valuable resource (Schürch et al. 2013). Most of the dance with the error's margin indicated various fields. If a dance, with the error's margin indicated, for example, a field of beetroots, is it not where the bee went or is it for the poppies, as we know there are many of them.

Apiary R05

Some dances indicate the forest resources. The 12th of June, I recorded one dance (no 4) (Appendix 3) in the forest. The 23rd of June, a beekeeper told me there was a lot of aphid honeydew. I suppose there was already some honeydew on the 12th. The 23rd of June, the 7th dance (Appendix 4), the 14th of July, the dance number 17 (Appendix 5) and the 22nd of July, the dances 21 and 22 (Appendix 6) also indicate forest resources, which are interesting for propolis and honeydew (Bailey, S. 2014), that are present at that moment. The 14th of July, dance 15 (Appendix 5) indicates the forest, but in the 50m radius there is a field of adjoining pasture, which is flowering.

The 23rd of June I recorded 5 dances (Appendix 4). Dances 6 and 9 are outside of the 2km radius, so any measures are taken. The 50m radius of dance 6 is mostly in extensive pasture. Then, there are adjacent pasture and some forest. Dance 9 is surrounded by a permanent meadow for mowing, maize, an extensive meadow, and bedding surfaces.

Dance number 5 indicates a field of autumn wheat. However, this field is usually not flowering in June. Within the 50m error around the indicate point, there is the field of autumn barley. This field could not have been flowering either. But a third field is within the 50m radius. It is a corn field. It may not be flowering because the 23rd of June is week 26, and normally, the flowering of autumn wheat is at week 27. As we do not have field observation for the flowering, we use theoretical information, so it is possible that the flowering started earlier in 2020. Another possibility is that there were other flowers such as poppies on these fields, which are interesting for the honey bees (Chauvel et al. 2018).

The 8th dance is on temporary meadows, which is flowering and has interesting resources for the bees as clovers or lucerne (alfalfa) (Margaret J. Couvillon, Schürch, and Ratnieks 2014; Beekman and Ratnieks 2000; Steffan-Dewenter et al. 2002). There are two measures on the fields of temporary meadows in the 50m radius: “Floral resources for pollinators in temporary meadows” and “Delayed mowing of temporary meadow”. In the 50m radius, there are two other types of fields. One of the adjoining pastures, which has interesting resources for the bees and is flowering. One of spring wheat, which is not in flower, but could have other flowers, such as dandelions, clovers, and field thistle on the fields that can be interesting for the bees (Chauvel et al. 2018). The 14th of July, the dances 16 and 19 (Appendix 5) indicated temporary meadows, which is flowering, such as adjoining pastures, which is also flowering in the 50m radius. A temporary meadow of the dance number 16, as well as another temporary meadow of the dance number 19, have an agroecological measure: “Mowing without conditioner on meadows”.

The 14th of July, the dances 13, 14, and 18 (Appendix 5) were on adjoining pastures, which are flowering. In the 50m radius, there is extensive pasture, which is also flowering and can provided some floral resources such as clovers.

Apiary R06

The 3rd of June, three dances were recorded (Appendix 7). Dances 1 and 2 indicate temporary meadows that have floral resources for the bees, with the 50m error around the dances. Dance 1 can also indicate spelt, but it is unlikely as the field is not flowering. On the other hand, poppies can growth on the field and as said before, it is an interesting resource for the bees (Chauvel et al. 2018). Dance 2 could also indicate extensive grazing or grove, which are flowering. An agroecological measure is present on one of the two fields of temporary meadows of the dance 2: "Mowing without conditioner on meadows". Another agroecological measure is present on the field of beetroots of the dance 2: "Renouncing the use of insecticides on the flowering crops on the farm". This measure was on a field of beetroots, which are not directly interesting as a resource for honey bees. However, the field may have adventitious flora in it, which can be interesting for the bees. These agroecological measures (concerning mowing and not use of pesticides) are not directly linked to a major floral resource for honey bees, but due to the presence of adventitious flora, they will be able to find pollen and/or nectar resources required by the colony (Decourtye et al. 2007; Decourtye, Mader, and Desneux 2010).

The 23rd of June, three dances were detected (Appendix 8). Dance 10 indicates a garden, but in the 50m radius, it can be on adjoining pastures, which have an agroecological measure "Installation and maintenance of nesting structures for wild bees", have interesting resources for the bees and are flowering, even if the measure itself is useless for the honey bees.

Dance 11 indicates the autumn barley, which is not flowering. Within the 50m radius, there is three others field, among which a field of corn, which starts theoretically flowering the following week. As said before, other interesting adventitious flowers such as poppies can be there (Chauvel et al. 2018). A field of adjoining pastures, which is flowering and has interesting resources and has an agroecological measure: "Mowing without conditioner on meadows". Hedge, grove, or flowers are also in the 50m radius.

Dance 12 indicates adjoining pastures, and there is an agroecological measure:" Mowing without conditioner on meadows", which is flowering. In the 50m radius, it indicates a field of sunflower and another of beetroot. The sunflower enters theoretically in flower the following week and is interesting for the bees. Whereas the beetroots are not interesting for the bees, but other flowers may growth in the field (Chauvel et al. 2018).

The 14th of July, the dance number 20th is recorded (Appendix 9). It indicates two fields of temporary meadows, which are flowering and have two agroecological measures: "Mowing without conditioner on meadows" and "Delayed mowing of temporary meadow". Within the 50m error, there are hedge, grove, or flowers, which are flowering or forest, which can be interesting for propolis (Bailey, S. 2014).

Waggle dances conclusion

As we can see in figure 11, for the apiary R05 the waggle dances indicated 53.2% of the time the pastures and the meadows, whereas it represents only 29.7% of the landscape (Margaret J. Couvillon, Schürch, and Ratnieks 2014; Beekman and Ratnieks 2000; Steffan-

Dewenter et al. 2002). Then the forest was indicated 26.7%, but it represents 47.1% (Bailey, S. 2014). For the second apiary (R06), pastures and meadows were the most indicated with 46.4%. In the landscape around the apiary, it only represents 32.3% (Margaret J. Couvillon, Schürch, and Ratnieks 2014; Beekman and Ratnieks 2000; Steffan-Dewenter et al. 2002). Then the hedges and fallow land with 17.9%, whereas it represents at only 1.7% in the scenery(Margaret J. Couvillon, Schürch, and Ratnieks 2014; Beekman and Ratnieks 2000; Steffan-Dewenter et al. 2002). When I put all the dances of the two apiaries, we can see that 49.9% of the time the waggle dances indicated pastures and meadows, then with 15.5%, the forest was indicated. In the third position, the different cereals fields were indicated with 12.1% (Bailey, S. 2014). This shows that the bees prefer the fields with different plants on it rather than a field with a monoculture, because there are fewer resources available for a long period (Senapathi et al. 2015, Carr-Markell et al. 2020).

Observations and conclusion

To sum up, via the waggle dances recorded, we know that the bees have visited some fields with the following agroecological measures: (1) Mowing without conditioner on meadows, (2) Delayed mowing of temporary meadows, (3) Floral resources for pollinators in temporary meadows.

The measure (1) mowing without conditioner on meadows does not influence the attractiveness of the filed when mowing is happening, but if the bees are present when the farmers are mowing, the bees are not killed. However, we do not know if farmers were mowing when we analysed the hives. The bees cannot know that this measure is in place, so they cannot “choose” the field for this reason, but it benefits them even if we cannot link it to the biology of the bees. Furthermore, a few days after mowing the meadow allows the emergence of new flowers, mainly clovers, which can interest them.

The measures (2) delayed mowing of temporary meadow and (3) floral resources for pollinators in temporary meadows directly benefit the honey bees’ floral resources. Measure 2 can help as the mowing is delayed, and the flowers are available for the bees for a longer period. As the resources are present and wide, the honey bees could “choose” these fields thanks to the measures and in function of their needs for the colonny’s dynamic of different melliferous or polliniferous species (Di Pasquale et al. 2013).

The waggle dances indicate 19% of the time fields with agroecological measures. Waggle dances also indicate fields without agroecological measures implemented on them, such as colza, pastures, forest, etc or field where the farmer did not choose a measure. These fields without agroecological measures are also very interesting for the honey bees.

We do not have a lot of waggle dances and round dances recorded. In my opinion, the amount of resources available explains why there were so few dances as there was no need to indicate resources (Bailey, S. 2014). For example, on the 8th of July in the apiary R05 any round dances were recorded even if a field was in bloom close to the hive. It also depends on the complexity of the landscape around the apiaries. The more the landscape has fields composition diversity, the more possible it is to find different resources.

Honey bees have various needs in term of resources. They need nectar, pollen, propolis, water, etc. for the colony dynamic. The amount of each different resource depends on the development of the colony. It is for example important to have diversity in the pollen since they do not have the same nutritional values, as Di Pasquale et al. (2013) notice.

In my opinion, the honey bees need an environment with a lot of different resources such as pastures and meadows as we have seen with the graph of the visited fields (Figures 11 and 12). In addition, the PhD student found that the pollen brought back to the colony was predominantly clover pollen, which are present on meadows and pastures (Hernandez, J. 2020). And this amount of clover would be interesting during the "diet" periods when the environment and the crops are finished, between the beginning and middle of June. To sum up, thanks to the waggle dance we see that the bees indicate mainly resources on pastures and meadows and thanks to the pollen trap of the PhD thesis we know that the bees mostly take clover's pollen.

I think that the master thesis responds to its research question. Indeed, thanks to the analyse of the dances, we now understand which fields the honey bees principally go on. We see that they prefer pastures and meadows as 53.2% of the waggle dances indicated them and these fields are only present in the landscape at 31%. And we suppose that when they are going on cereal crops, they mostly take adventitious flora such as poppies (Hernandez, J. 2020). The waggle dance analyses are powerful tools for the conservation of honey bees (Couvillon et al. 2014).

Further research in the AGRIPOL project would be interesting to know if agroecological measures directly benefit the honey bees. It would be helpful to understand which measures are useful for the honey bees and more generally to fully understand the importance of keeping pasture and meadows for the honey bees and the insects, thanks to the flowers present on the fields.

To have a better answer to these questions, another study will be necessary, for example by taking all the apiaries in the canton of Jura and capturing more dances with a larger apiary sample in different landscapes. To have more recording, it could be interesting to record during a longer period of time, such as during one hour instead of thirty minutes and even recording the two simultaneously with two cameras side of the hive as both sides have a movable glass. It was not easy to choose which frame we recorded as we never or rarely saw a waggle dance. We choose the frame with the most wiggles. Adding a second frame filmed could also improve the chance of recording more waggle dances. In addition, it would be great to have free access to the hives to be able to go when the weather is good. Another amelioration for further research would be not to choose the frame but to record the two side frames. It would probably allow us to have free access to the hives as we disturb less the honey bees colony. For the entrance, it would be interesting to continue to use the 2cm thick foam and allow the entrance at the two extremities.

Depending on the research question it could be interesting to go recording every day of a week, for example if we want to see how the bees act when the colza is flowering, as did Balfour and Ratnieks (2017), or go on the field every week from the beginning of May to the

end of August. If we want to understand the seasonal foraging challenges, we can record on most foraging days of all the season (Couvillon, Schürch, and Ratnieks 2014). The number and the duration of the field session will depend on the question and on the floral resources. For example, for the AGRIPOL project they are interested on beekeeping season between April to beginning of October to see what is present in the environment.

For further research, it can be interesting to do a landscape analysis with the percentage of agricultural areas with measurements and the percentage of plots indicated by the honey bee waggle dances.

However, it should not be forgotten that this project is based on participatory research and that beekeepers are not professional. Indeed, they care a lot about their bees, and sometimes it was not possible to go to the field without their presence on the apiary. This required a non-negligible amount of organisation for the field sessions. Sometimes, a free access to hives would have been easier in logistical terms, but the human relationship with the beekeepers was one of the best parts of the project as I learned many things about honey bees and beekeeping with them.

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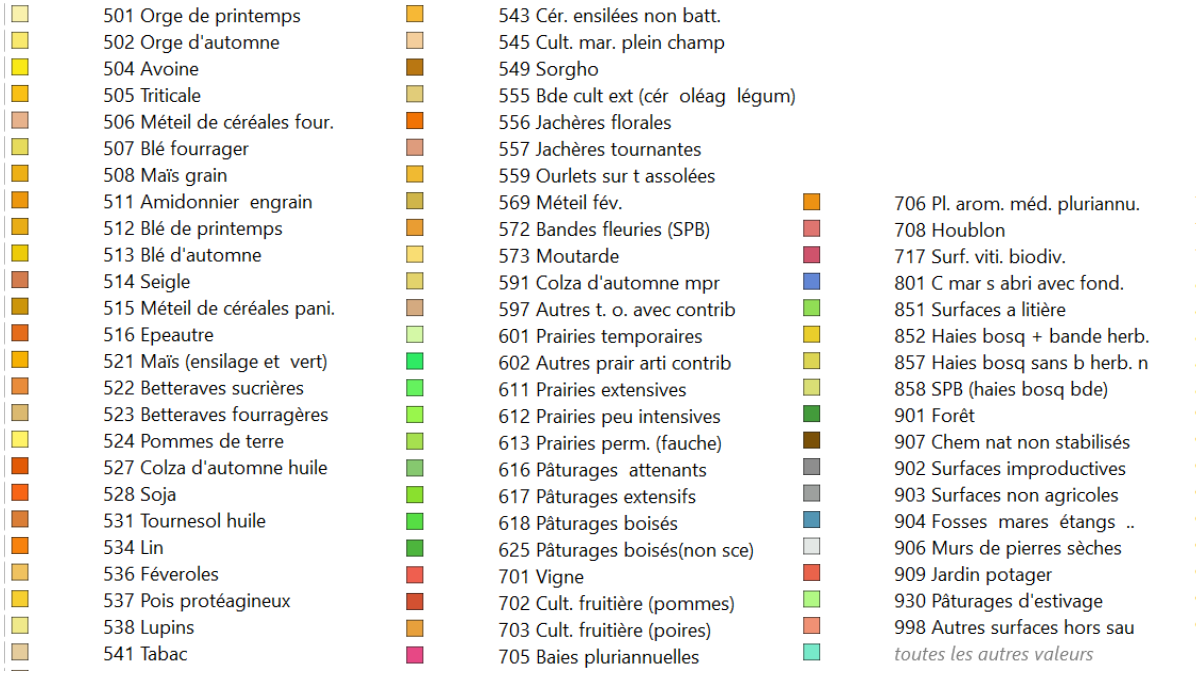
Appendices

Field legend on the maps



Appendix 1: field legends on the maps

Table of the waggle dances and the fields indicated with the agroecological measures

Waggle dance	Apiary	Date	Culture	Category	Flowering	Ressources	Measures	Which measure(s)?
1	R06	3.06	Spelt	Cereals	No	Yes	No	
1	R06	3.06	Temporary meadows	Temporary meadows	Yes	Yes	No	
2	R06	3.06	Extensive meadows	Extensive meadows	Yes	Yes	Yes	Mowing without spacers on meadows
2	R06	3.06	Extensive meadows	Extensive meadows	Yes	Yes	No	
2	R06	3.06	Temporary meadows	Temporary meadows	Yes	Yes	No	
2	R06	3.06	Hedges and fallow land	Hedges and fallow land	Yes	Yes	No	
2	R06	3.06	Extensive pastures	Extensive pastures	Yes	Yes	No	
2	R06	3.06	Beetroot	Beetroot	No	No	Yes	Renounce the use of foliar insecticides for beetroots
3	R06	3.06	Fall barley	Cereals	No	Yes	No	
3	R06	3.06	Hedges and fallow land	Hedges and fallow land	Yes	Yes	No	
4	R05	12.06	Forest	Forest	Unsure	Yes	No	
5	R05	23.06	Maize	Maize	No	Yes	No	
5	R05	23.06	Fall barley	Cereals	No	Yes	No	
5	R05	23.06	Fall wheat	Cereals	No	Yes	No	
6	R05	23.06	Forest	Forest	Unsure	Yes	No	
6	R05	23.06	Adjacent pastures	Adjacent pastures	Yes	Yes	No	
6	R05	23.06	Extensive pastures	Extensive pastures	Yes	Yes	No	
7	R05	23.06	Forest	Forest	Unsure	Yes	No	
8	R05	23 06	Adjacent pastures	Adjacent pastures	Yes	Yes	No	
8	R05	23 06	Temporary meadows	Temporary meadows	Yes	Yes	Yes	Floral resources pollinators temporary meadows
8	R05	23.06	Temporary meadows	Temporary meadows	Yes	Yes	Yes	Delayed mowing of

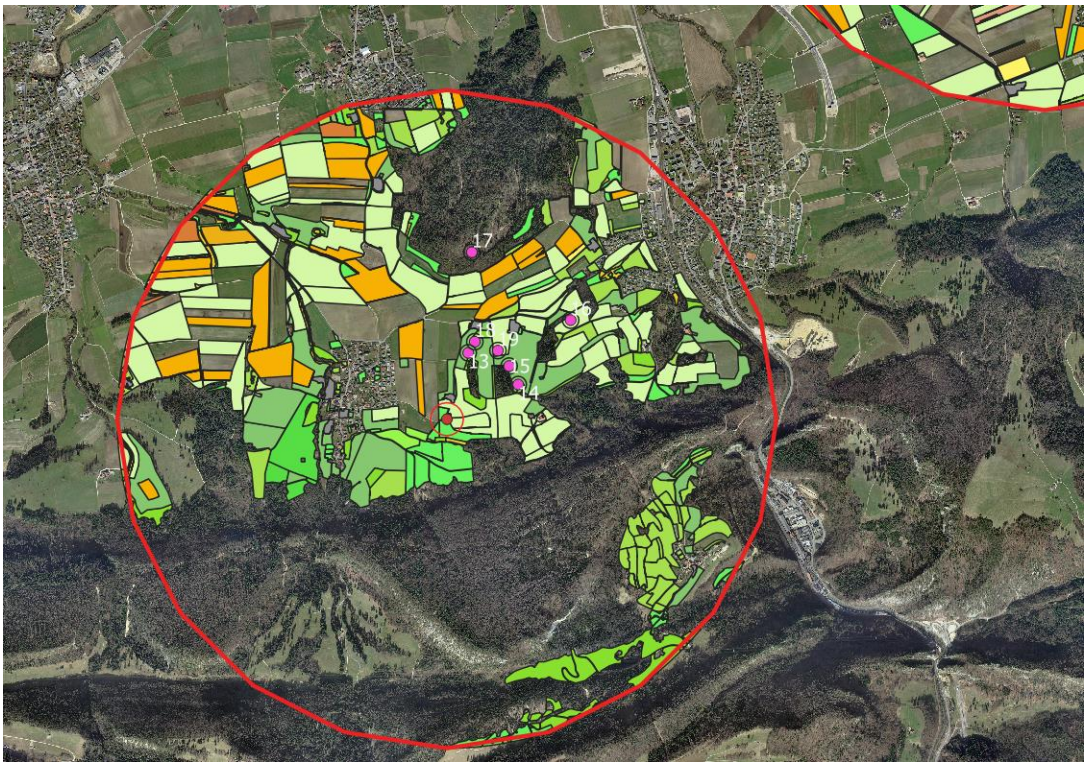
							temporary grassland
8	R05	23.06	Spring wheat	Cereals	No	Yes	No
9	R05	23.06	Maize	Maize	Yes	Yes	No
9	R05	23.06	Extensive meadows	Extensive meadows	Yes	Yes	No
9	R05	23.06	Permanent meadows for mowing	Permanent meadows for mowing	Yes	Yes	No
9	R05	23.06	Bedding surfaces	Bedding surfaces	Yes	Yes	No
10	R06	23.06	Urban	Urban	No	No	No
10	R06	23.06	Adjacent pastures	Adjacent pastures	Yes	Yes	Yes	Nesting structures for wild bees
11	R06	23.06	Adjacent pastures	Adjacent pastures	Yes	Yes	No
11	R06	23.06	Maize	Maize	No	Yes	No
11	R06	23.06	Maize	Maize	No	Yes	No
11	R06	23.06	Fall barley	Cereals	No	Yes	No
11	R06	23.06	Extensive meadows	Extensive meadows	Yes	Yes	Yes	Mowing without spacers on meadows
11	R06	23.06	Hedges and fallow land	Hedges and fallow land	Yes	Yes	No
12	R06	23.06	Extensive meadows	Extensive meadows	Yes	Yes	Yes	Mowing without spacers on meadows
12	R06	23.06	Extensive meadows	Extensive meadows	Yes	Yes	Yes	Mowing without spacers on meadows
12	R06	23.06	Fall barley	Cereals	No	Yes	No
12	R06	23.06	Hedges and fallow land	Hedges and fallow land	Yes	Yes	No
12	R06	23.06	Extensive pastures	Extensive pastures	Yes	Yes	No
12	R06	23.06	Sunflower	Sunflower	No	Yes	No
13	R05	14.07	Forest	Forest	Unsure	Yes	No
13	R05	14.07	Extensive pastures	Extensive pastures	Yes	Yes	No
13	R05	14.07	Adjacent pastures	Adjacent pastures	Yes	Yes	No
14	R05	14.07	Forest	Forest	Unsure	Yes	No

14	R05	14.07	Extensive pastures	Extensive pastures	Yes	Yes	No	
14	R05	14.07	Adjacent pastures	Adjacent pastures	Yes	Yes	No	
15	R05	14.07	Forest	Forest	Unsure	Yes	No	
15	R05	14.07	Adjacent pastures	Adjacent pastures	Yes	Yes	No	
16	R05	14.07	Adjacent pastures	Adjacent pastures	Yes	Yes	No	
16	R05	14.07	Temporary meadows	Temporary meadows	Yes	Yes	No	
16	R05	14.07	Temporary meadows	Temporary meadows	Yes	Yes	Yes	Mowing without spacers on meadows
17	R05	14.07	Forest	Forest	Unsure	Yes	No	
18	R05	14.07	Extensive pastures	Extensive pastures	Yes	Yes	No	
18	R05	14.07	Adjacent pastures	Adjacent pastures	Yes	Yes	No	
19	R05	14.07	Adjacent pastures	Adjacent pastures	Yes	Yes	No	
19	R05	14.07	Adjacent pastures	Adjacent pastures	Yes	Yes	No	
19	R05	14.07	Temporary meadows	Temporary meadows	Yes	Yes	Yes	Mowing without spacers on meadows
20	R06	14.07	Forest	Forest	Unsure	Yes	No	
20	R06	14.07	Temporary meadows	Temporary meadows	Yes	Yes	Yes	Delayed mowing of temporary grassland and mowing without spacers
20	R06	14.07	Temporary meadows	Temporary meadows	Yes	Yes	Yes	Delayed mowing of temporary grassland and mowing without spacers
20	R06	14.07	Hedges and fallow land	Hedges and fallow land	Yes	Yes	No	
21	R05	22.07	Forest	Forest	Unsure	Yes	No	
22	R05	22.07	Forest	Forest	Unsure	Yes	No	

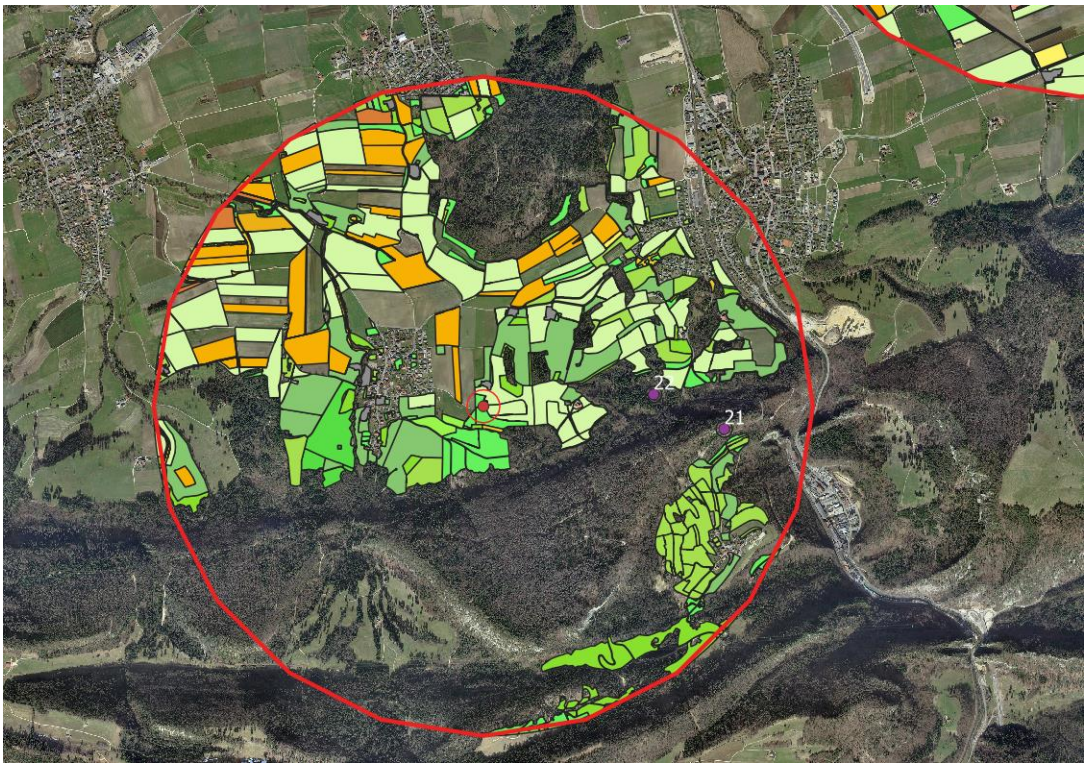
Appendix 2: Table of the waggle dances and the fields indicated with the agroecological measures. The culture indicates the field where the honey bees waggle dances indicated. It is used in the discussion to analyse the waggle dances. The category categorised the field to a better understanding of the different graphs. The resource category includes nectar, pollen, aphid honeydew and propolis, which are useful to honey bees.

Appendix 8: Apiary 5. One waggle dance was detected the 12th of June 2020. The coloured field is the one flowering and has interesting resources such as nectar or pollen for the bees. The meadows and pastures are in shade of green and the different crops in shade of orange. The legend is in the appendix (appendix 1).

Appendix 9: Apiary 5. Five waggle dances were observed the 23rd of June 2020. The coloured field is the one flowering and has interesting resources such as nectar or pollen for the bees. The meadows and pastures are in shade of green and the different crops in shade of orange. The legend is in the appendices (appendix 1).

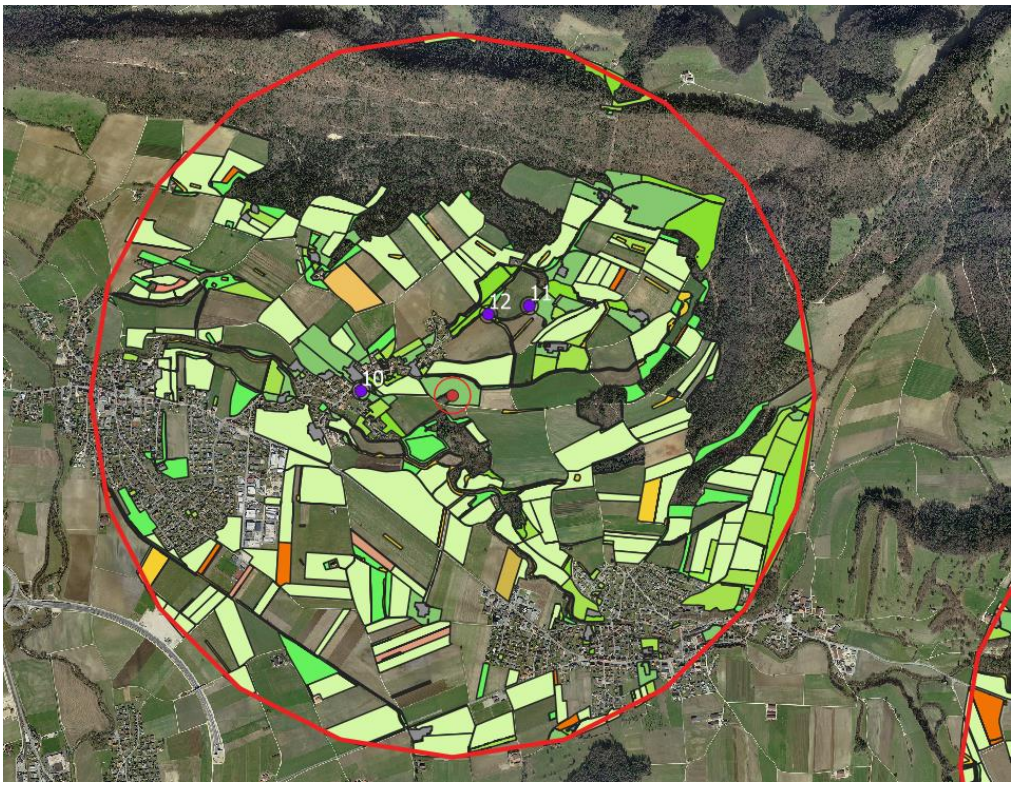


Appendix 10: Apiary 5. Seven waggle dances were recorded the 14th of July 2020. The coloured field is the one flowering and has interesting resources such as nectar or pollen for the bees. The meadows and pastures are in shade of green and the different crops in shade of orange. The legend is in the appendices (appendix 1).

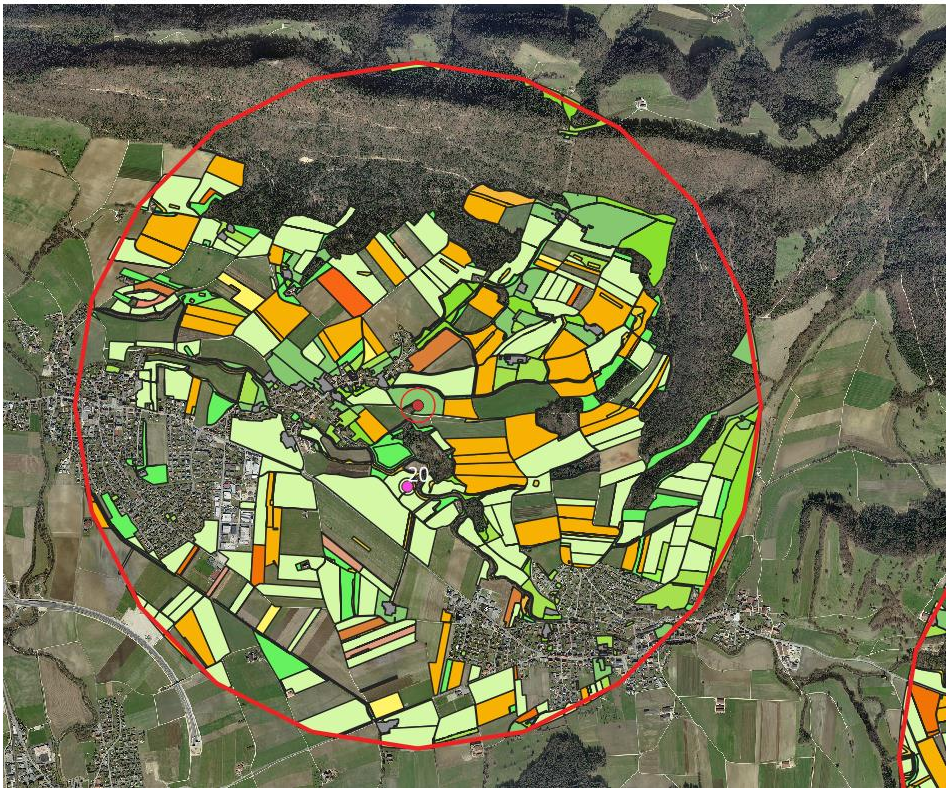


Appendix 11: Apiary 5. Two waggle dances were recorded the 22nd of July 2020. The coloured field is the one flowering and has interesting resources such as nectar or pollen for the bees. The meadows and pastures are in shade of green and the different crops in shade of orange. The legend is in the appendices (appendix 1).

Appendix 7: Apiary 6. Three waggle dances were observed the 3rd of June 2020. The coloured field is the one flowering and has interesting resources such as nectar or pollen for the bees. The meadows and pastures are in shade of green and the different crops in shade of orange. The legend is in the appendices (appendix 1).



Appendix 12: Apiary 6. Three waggle dances were recorded the 23rd of June 2020. The coloured field is the one flowering and has interesting resources such as nectar or pollen for the bees. The meadows and pastures are in shade of green and the different crops in shade of orange. The legend is in the appendices (appendix 1).



Appendix 13: Apiary 6. One waggle dance was observed the 14th of July 2020. The coloured field is the one flowering and has interesting resources such as nectar or pollen for the bees. The meadows and pastures are in shade of green and the different crops in shade of orange. The legend is in the appendices (appendix 1).

Interview recherche participative sur la danse des abeilles dans le cadre du projet AGRIPOL

Appendix 10 : Apiculteur du rucher R05, il travaille aussi dans le projet AGRIPOL à la FRI

1. As-tu une idée où vont tes abeilles ? (Discuter avec la carte des danses, parler aussi des round danses qui ne peuvent pas être analysées)
   Elles sont sur des prairies et des pâturages
2. Comment as-tu choisi ce site pour y installer ton rucher ?
   On ne l'a pas vraiment choisi. On nous l'a proposé puis nous l'avons accepté. Il est avantageux comme il est sur une zone de que captage d'eau. Cela veut dire que sur cette zone il ne peut pas y avoir de pâturages ni de cultures. Il doit y avoir de l'herbe.
3. Sais tu quelles ressources ont les abeilles à proximité des ruches ? (dans un rayon de 50-80m)
   Il y a du tilleul saule, colza, arbres fruitiers, pissenlit, prés et pâturages.
4. Comment as-tu vécu que je vienne chaque semaine ?
   C'était agréable, il y avait du partage, et tu étais une personne flexible. Nous ne devions pas venir avec toi ce qui est pratique.
5. Et vis-à-vis de tes abeilles ? / Que je doive ouvrir la ruche chaque semaine ou presque ?
   Non tant que je sais que la météo est bonne, ouvrir n'est pas un problème.

Appendix 11 : Apiculteur du rucher R06

1. As-tu une idée où vont tes abeilles ? (Discuter avec la carte des danses, parler aussi des round danses qui ne peuvent pas être analysées)
   Oui, je les ai suivies et elles vont à l'est, sud-est.
2. Comment as-tu choisi ce site pour y installer ton rucher ?
   Le site était un coup de cœur. Je n'ai pas choisi en fonction des ressources.
3. Sais tu quelles ressources ont les abeilles à proximité des ruches ? (dans un rayon de 50-80m)
   Alors oui, il y a un peu de sapins. Et comme on a vu sur l'histogramme (100m's land distribution around apiary 6) le pâturage attenant est rempli de trèfles blancs ou de pissenlits. Dans la foret il y a beaucoup de mûriers.
4. Comment as-tu vécu que je vienne chaque semaine ? Et vis-à-vis de tes abeilles ? / Que je doive ouvrir la ruche chaque semaine ou presque ?
   L'expérience c'est super bien passée, il a appris à voir la danse des abeilles et il pourra mieux l'expliquer aux enfants (il a une ruche vitrée pour accueillir des enfants et leur montrer les abeilles).
   Pour lui le protocole de l'expérience (ouvrir la ruche toutes les semaines pour filmer) ne l'a pas dérangé. Il est repartant si une nouvelle expérience se met sur pied.
   Super bien, il rigole, super expérience, il a appris la danse et la voir, petit, mieux expliquer aux enfants

Appendix 12 : Apiculteur du rucher R07

1. As-tu une idée où vont tes abeilles ? (Discuter avec la carte des danses, parler aussi des round danses qui ne peuvent pas être analysées)
   Sais-tu quelles ressources ont les abeilles à proximité des ruches ? (dans un rayon de 100m)
   Elles vont où il y a du nectar. Elles ont une jachère (très fréquentée) c'est super ! Il y a aussi du pissenlit et du colza (BIO !!)
   Il y a eu un remaniement parcellaire et ils ont arrachés des vieux arbres pour planter des fruitiers super fleuris
   Maintenant il y a le noisetier, des perse neiges (pollen).
   Autour du rucher il y a aussi une grande diversité d'arbres dans la forêt, ce n'est pas une monoculture : grand tilleul, plusieurs grands cerisiers, chênes, saules, érables, sapins. En juillet il y a du murier.
   En 2020 il y a eu beaucoup de pucerons top !!!
   Il y a une grande diversité autour du rucher : foret, combes. En plus les ressources sont bien échelonnées dans le temps.

2. Comment as-tu choisi ce site pour y installer ton rucher ?

- *S'éloigner de tous les autres ruchers*
  - *Varoa (comme les abeilles peuvent se le transmettre même en dehors de la ruche)*
  - *pas déranger d'autres apiculteurs*
- *Chemin d'accès en voiture*
- *Diversité de ressources*

Après coup il y a plusieurs autres avantages qui sont venus :

- *Pas exposé plein sud : elles sont plus lentes à se développer au printemps et c'est parfait selon moi parce que comme ça essaime moins si en avril la ruche est bien active et qu'il y a du froid. Au retour du beau il y a moins d'essaimages.*

3. Comment as-tu vécu que je vienne chaque semaine ? Et vis-à-vis de tes abeilles ? / Que je doive ouvrir la ruche chaque semaine ou presque ?
   Bien. Les ruches de production sont à côté. Et la ruche mise à disposition n'est pas une ruche de production mais une ruche en plus. C'est le rôle des apiculteurs de partager, transmettre leur savoir.