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Temperature changes above the upper hive body reveal the annual development periods of honey bee colonies

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ABSTRACT

Determination of the annual development periods of honey bee colonies can help in synchronising the beekeeper's activities with the developmental stage of individual bee colonies in apiaries. It is proposed to determine the development periods by measuring and analysing the ambient temperature and the temperature above the upper hive body. The temperature above the upper hive body is proportional to the energy which is released during bee colony activities. Throughout the year in 2000, measurements with interval of 15 min of the temperature in 14 honey bee colonies was done in Latvia, in the Riga region. One sensor per colony was located above the upper hive body. The annual curve of the average day and night temperature was approximated by five linear pieces that possibly correspond to particular periods. Explicit transition points to the next period were determined. Five sequential periods have been proposed in the bee colony's development: (1) winter brood rearing, (2) spring brood rearing, (3) summer brood rearing, (4) autumn brood rearing and (5) autumn broodless period. These periods collectively form a hat-like annual profile. All brood rearing periods demonstrate high thermal discipline: the hive temperature follows linear dynamics in spite of fluctuations in the ambient temperature.

A simple measurement system and criteria for automatic determination of transition from one period to another for apiary has been developed and tested. Thermal measurements above the upper hive body efficiently determine the transition from one period to another in the apiary. The computational system for the determination of developmental periods should be equipped with at least one ambient temperature sensor per apiary and one temperature sensor per observed bee colony.

1. Introduction

An understanding of the honey bee's adaptations for life in cold climates requires an examination of its biology throughout its annual cycle (Seeley, 1985). The characteristic seasonal pattern (Schmickl and Crailsheim, 2004b) can be split into the annual development periods of a honey bee colony with characteristic behaviour and the limiting/stimulating factors of the particular period. Knowledge about a particular period in the colony or apiary can contribute to an increase in efficiency in beekeeping, reducing the contradictions between the activities of the bees and the beekeeper. The commencement and the completion of different periods of colony development cannot currently be determined or predicted without regular inspection of the colonies. The ability to detect the colony stage in the annual cycle will assist in the care and health of bee colonies.

Seasonal management, from the beekeeper's point of view, is divided into four periods: (1) early spring management of overwintered colonies, (2) spring management, (3) summer honey flow management and (4) fall/winter preparation management (Ambrose, 1992). On the other side the development of the bee colony has its own annual rhythm as honey bees did not develop in an evolutionary way to suit the needs of a beekeeper (Winston, 1992; Seeley, 2002). To improve the collaboration between bees and the beekeeper, the developmental periods of a colony should be taken into account.

The periods differ by the goals and the limitations of the colony's activities. The optimal timing of changes of developmental periods in the bee colony is critical for optimising the use of energy and worker resources with respect to the annual cycle of the colony and its ability to reproduce by swarming (Seeley, 1985; Beauchamp, 1992; Winston, 1992; Seeley and Mikheyev, 2003; Schmickl and Crailsheim, 2004a). The timings of colony growth and reproduction are essential elements in the honey bee's suite of adaptations for winter survival (Seeley, 1985). The colony acting as "superorganism" (Moritz and Southwick, 1992; Moritz and Fuchs, 1998; Tautz, 2008) may have a flexible energy investment

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policy, whereby it adjusts its investment in reproduction in relation to its success in acquiring energy (Seeley and Mikheyev, 2003), by changing its collective behaviour radically, depending on several parameters which include climatic circumstances.

A change of development periods is a result of a decision taken by a colony which is mostly influenced by climatic circumstances. Phenologists are of the opinion that climatic changes firstly influence the development of nectar plants, which then determine the behaviour in the bee colony (Gordo and Sanz, 2006). In the case of social insects, a complex process of group decision, probably with conflicting interests between colony members (Conradt and Roper, 2005) has to be carried out. At the same time, the decision can also be a process of self-organising or decentralized control, where bees as sub-units of the bee colony, lack either communication or computational abilities (Seeley, 2002). The winter cluster is a characteristic of the passive phase of the colony representing a case of self-assemblage (Anderson et al., 2002). The cluster, as a self-assemblage, can be seen as the result of egoistic behaviour without direct communication, as a reaction to environmental parameters like temperature (Sumpter and Broomhead, 2000). Another example of self-assembling structure is the swarm (Anderson et al., 2002; Cully and Seeley, 2004).

The complexity and the high number of factors that contribute to the colony level decisions of bees do not encourage accurate predictions of the commencement and completion of particular periods without measurements. The aim is to register the start of the next period as soon as and as cheaply as possible. Recent advances in electronics and computer technologies allow relatively cheap and robust temperature monitoring systems (Vornicu and Olah, 2004; Meitalovs et al., 2009; Zacepins et al., 2010, 2011) as well as other electronic systems for monitoring of individual bee colonies (Ferrari et al., 2008; Mezquida and Martinez, 2009; Bensick et al., 2011). Bearing in mind that each specific type of behaviour of a bee colony releases specific amount of energy, it can be assumed that the annual measurements of the ambient temperature above the nest can shed light on the periods with differing activities of the bee colony during the annual cycle. This approach would allow to monitor the periods based on temperature measurements above the upper hive body without disturbing the bees and beekeeper. Differences between subspecies of honey bees in the timing of developmental periods can be determined.

The aim of the paper is to analyse the applicability of the temperature measurements using one conveniently placed sensor above the upper hive body for automatic determination of the commencement and completion dates of particular development periods of bee colonies and duration of periods.

As a result five developmental periods have been determined. The criteria for automatic period change determination are developed and statistical characteristics and correlations between measured parameters are analysed.

2. Materials and methods

2.1. Set up of experiment

Temperature measurements were done in Latvia in the Riga district from 1st January till 31st December, 2000. Temperature sensors were installed in 14 colonies. One of them had a Caucasian subspecies (*Apis mellifera caucasica*) queen bee (V10); one had a Buckfast queen bee (V4), three colonies had daughters of a Buckfast queen, which were naturally inseminated with unfathered drones (V2; V3 and V9). The queens in the rest of the observed colonies were unknown mixes (V1, V5–V8, 5–7 and 9). The size of the colonies in autumn was from 7 to 11 inhabited frames (435 × 300 mm each). Ten bee colonies (V1–V10) were living in a trailer with 13 frames sections per colony. The thickness of the wooden section walls was 35 ± 5 mm. Four colonies in the corners of the trailer had cold entrances and one common wall with a neighbouring colony; six other colonies had warm entrances and two common walls. The rest of the colonies were placed in stand-alone single walled (thickness 35 ± 5 mm) 15 frame hives with a 120 mm high underframe space. Upper bodies of hives were covered by polyethylene foil and thermoinsulating drapery pillow with a thickness of 8 cm (Fig. 1).

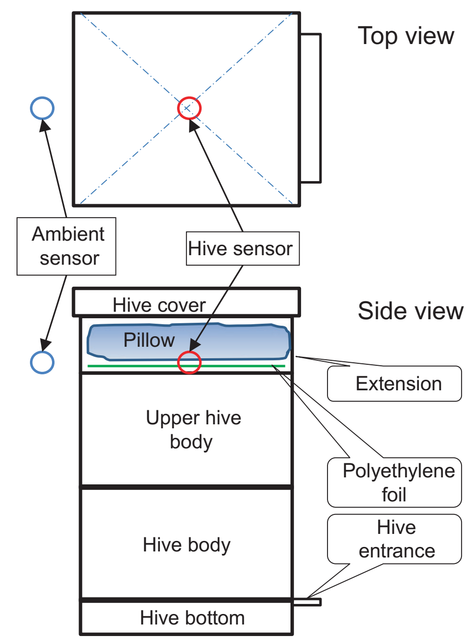

Fig. 1. Placement of ambient and hive temperature sensors. The hive sensor is placed between upper hive body covering polyethylene foil and thermoinsulating pillow.

Three colonies swarmed from the 15th May till the 25th July (V5; 7 and 9). In four colonies the queens were changed (V1; V5; V9 and 9). They began egg laying from the 1st of June till the 20th of July. The colonies were fed with sugar syrup from the 10th June till the 22nd June.

2.2. Temperature measurements

DS1820 (currently replaced by DS18S20, see http://www.maxim-ic.com/datasheet/index.mvp/id/3021) temperature sensors were placed accordingly to Fig. 1. Measurements were requested and recorded by computer using 1-Wire bus (see http://www.maxim-ic.com/datasheet/index.mvp/id/2815). One sensor was placed in each hive above the polyethylene foil covered upper hive body under the pillow (later referred to as "temperature in hive"). The air temperature outside the hive (later referred to as "ambient temperature") was measured by two sensors at the height of pillows close to the hives in the shadow at their northern side (see Fig. 1). The sensors were connected with each other and the computer by cables. Measurements were done throughout the day and night, every 15 min throughout the experiment.

2.3. Data processing

The time average hive and average maximum and minimum ambient air temperatures were calculated from temperature measurements from 1 day and night. The average day and night hive and ambient temperature changes during the year were described by a polynomial equation of the 4-th order and the temperature