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Department of Ecology

European Corn Borer

Biology, Damage and Management Strategies in Sweden

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European Corn Borer – Biology, Damage and Management Strategies in Sweden

Majsmott – Biologi, skadeverkan och kontrollmetoder i Sverige

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SUMMARY

The European Corn Borer (ECB) is one of the most important pests on corn in the world. An increasing interest from the farming community in Sweden, although currently cultivated in a restricted area, a change towards a warmer climate will probably make the ECB more abundant in Sweden. The management methods promoted today with cultural controls such as ploughing and harrowing are, for now, an effective way of control ECB population but an incorporation of insecticides or biological control agents together with scouting and day-degree models before and during the growth season would be beneficial for an effective control of today and future ECB population in Sweden.

SAMMANFATTNING

Majsmott är en allvarlig skadegörare på majs. Det ökade intresset för att odla majs i Sverige tillsammans med ett föränderligt klimat som blir varmare gör att det är troligt att angreppen av majsmott kommer att öka i framtiden. Kontrollmetoderna plöjning och harvning är effektiva metoder som används idag i lantbruket i Sverige. En långsiktig effektiv kontroll bygger på att även använda andra alternativ som fångstfällor och dag-grads modeller för att beräkna populations storlekar och tillväxt. En implementering av insekticider och biologiska kontroll metoder är fördelaktig för att minska kommande populationer och skador av majsmott.

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1. INTRODUCTION

In a growing world the human population's dependency on crops and food is constantly increasing. The world's population is growing faster than we can increase our food production and increased environmental concerns creates a challenge that means we need to increase quality and quantity of food production and at the same time decrease the ecological impact of food production (Masip *et al.*, 2013). In the beginning of our agricultural history, around 10,000 years ago, the need for more food was met by increasing the land we cultivated. But from the beginning of the 20th century, the centre of attention became to increase the productivity of the land we cultivate due to the decreasing availability of new expansion areas. Ever since, there has been a constant development of crop specializations. With an intensified agriculture there has been a significant increase in pest outbreaks (Abrol *et al*, 2012). The question arose as to how to maintain intensive profitable systems? And how to manage crop pests? In the early 20th century tactics such as physical, biological or cultural management where developed and used to prevent pests. But in the mid-20th century the invention and later the use of synthetic chemical substances increased exponentially (Abrol *et al*, 2012). One of the most important problems to address in future agriculture is how to prevent yield losses from pests in an effective and sustainable way. Today pests, both insects and weeds, are responsible for approximately 30-40 % of the general losses of crops worldwide (Pimentel, 2009). One of the six most grown crops worldwide is corn (*Zea Mays L.*) (Lobell & Field, 2007).

On corn the European Corn Borer (ECB) is considered to be one of the most invasive and important pests and is known to have the potential to greatly affect the yield outcome (Mutuura & Munroe, 1970). The ECB, *Ostrinia Nubilalis* (Hübner) belongs to the order of Lepidoptera and the family Crambidae. The pest originated in Europe and is considered to be a widespread problem across the continent (Hawkins & Cornell, 1999). European corn borer is the biggest pest problem in corn production in Europe (Meissle et al. 2010), and we can find the pest in most of the northern parts of the world from latitude 10 to 58 (Porter *et al.*, 1991). The pest was first noticed on corn in Sweden in 2012 and has seen an increase since then, with some variation between years (Swedish Plant Protection Agency, personal communication, July 2016). ECB has gone from being a rather unknown pest to a pest increasingly noticed by farmers and government agencies (Anderbrant, 2015; Anderbrant 2016). Climate change, with the predicted increase in temperature in Sweden (Kjellström & institut, 2014), might additionally increase the potential risk of ECB damage in the near future.

This report is the result of a literature search including scientific literature from Web of Science, Google Scholar, Primo and other available documentations from websites such as Swedish Chemical Agency (KemI) and Swedish Department of Agriculture (Jordbruksverket). The research resulted in 48 sources. Some information was also taken from personal communications with agronomist and workers at the Swedish Plant Protection Agency (Växtskyddscentralen) in Alnarp and Skara.

The aim of the study is to present a literature review of the biology of ECB, the damage done by ECB and to describe and discuss the methods available to control ECB and their use in future and present Swedish conditions.

2. RESULT

2.1 Corn

Corn is a major agricultural crop with a total production in 2014-2015 of 988.1 MMT worldwide. Of these only approximately 7.5 % were produced in Europe (US National corn growers' association, 2016). In Sweden, mainly in southern parts, the area used for corn production has increased during the 21th century, and cultivation area has been steady at approximately 16,000 ha for the last eight years (fig 1, Jordbruksverket, 2016A). Data on cultivation area from years before 2008 are only found in combination with other whole silage crops and could therefore not be included in the diagram. In Sweden, corn is mainly produced for silage to feed animals as roughage or ears harvested to be a part of fodder. An argument to grow corn instead of only grass, which is the common practice in Sweden, is to spread the risks: in a dry and warm year grass regrowth is slow and do not give a good yield, but under those conditions corn grows very well. Some studies have also shown that milk production in dairy cows increase up to possibly 10 % when corn silage was used together with grass (Jordbruksaktuellt, 2008). An interest in corn production for biogas has also seen an upswing in recent years but that number is still very low. There is almost no interest in seed or sweet corn productions (Jordbruksverket, 2016B). Generally, a warmer and dryer climate is more suitable for sweet corn and in areas with shorter growth season, colder weather and more precipitation, it is more beneficial to produce silage or fodder (Meissle *et al*., 2010).

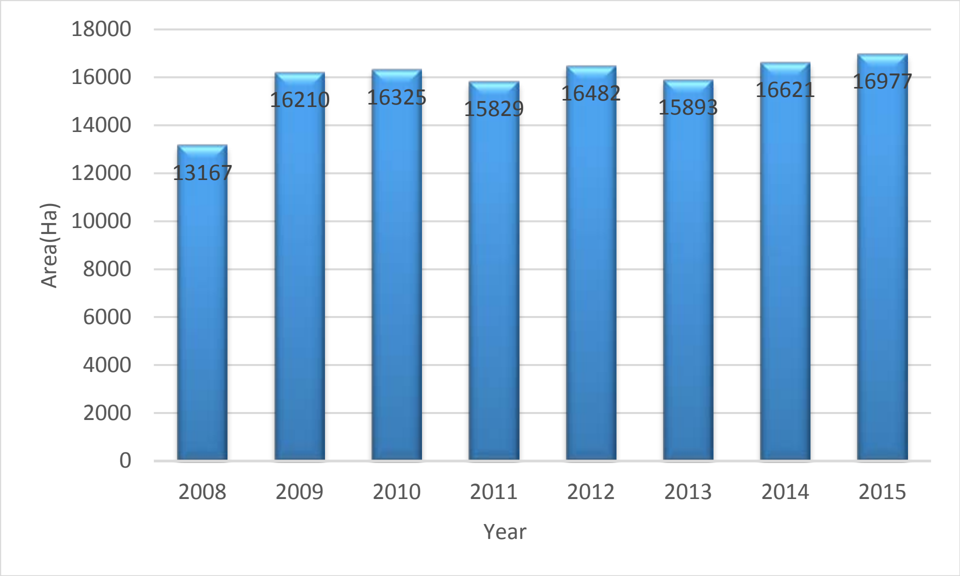

Figure 1. Area of corn production (ha) in Sweden based on numbers from Swedish Department of Agriculture (Jordbruksverket,2016A) (Gustafsson,O. 2016)

2.1.1 The phenological and physiological development of corn

To understand the damage done by ECB one needs to understand the growth of corn and its different development stages. Most of the different stages are illustrated in Figure 2.

The development stages in corn are divided into a number of vegetative stages and into six reproductive stages. The first stage of the plant is a vegetative stage called VE stage. In this stage the coleoptiles emerge from the surface and the first true leaf emerges from the tip of the coleoptiles. The growing point is still below the soil surface. Stages V1 to V18, each represent a new leaf with its collar showing. From V6, all plant parts are present and the lower leaves start to deteriorate and fall off because the root system is growing and resources need to be reallocated to ear and upper plant parts. At stage V18, the ear development is rapid. Soon after, the final stage of the vegetative growth takes place, called VT, in which tasselling occurs. A couple of days later the reproductive stages begin. First is silking (R1) which begins with silk being visible outside the husk. Falling pollen is captured by the silk, and the pollen then travels down to pollinate the ovules. In the next stage (R2) called Blister, the kernels are rapidly developing but most of its composition remains water. Milking (R3), sets in after silk stage and is a time of dry matter accumulation. The growth of kernels is here for the most part due to cell expansion. This causes the kernel to change colour to yellow and makes the fluid inside the kernel becomes white like milk. A couple of days later the dough stage (R4), begins. The kernels now start to dry and harden in texture due to a high amount of starch (Ritchie & Hanway, 1982; Darby & Lauer, 2000). At this point, the dry matter content in kernels are approximately 30 and is suitable for harvest if it´s used for silage (Jordbruksverket, 2014). The next stage in the process is denting (R5. Physiological maturity is then reached at (R6), and the maximum of dry matter is now reached (Ritchie & Hanway, 1982; Darby & Lauer, 2000). At this stage it is suitable to harvest if the production is for grain or sweet corn.

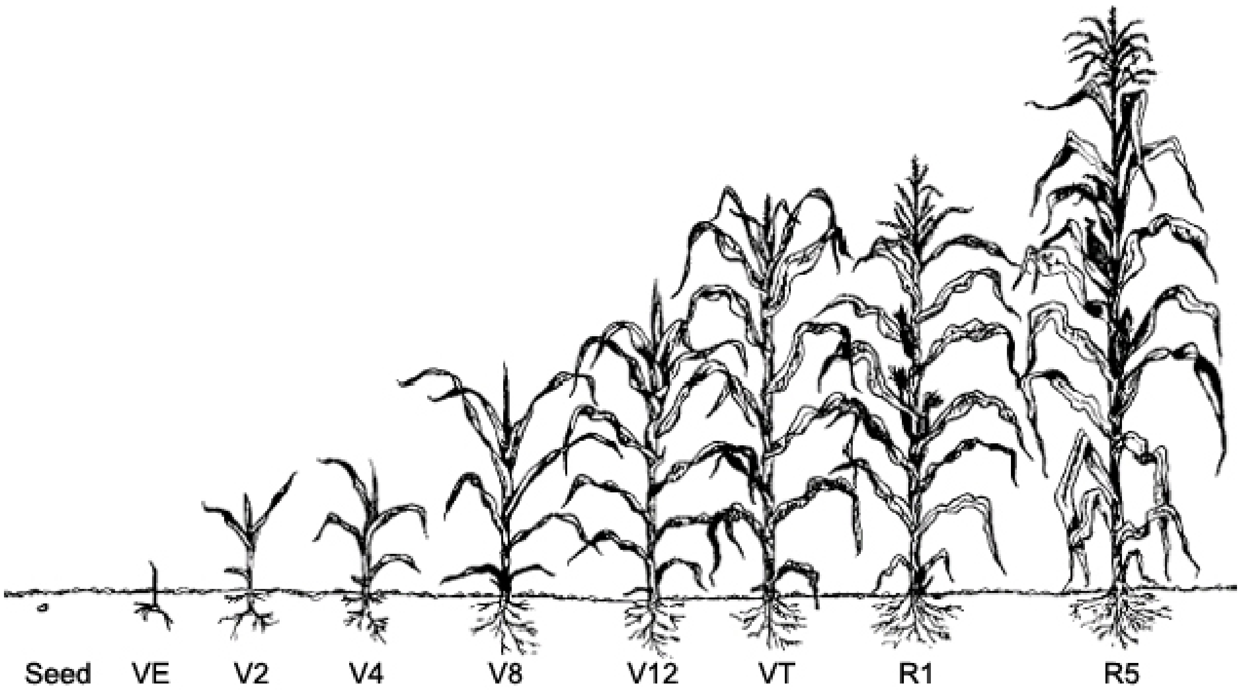

*Figure 2. Growth of corn (*Iowa State University, 1996*).*

2.2 The biology of ECB

European Corn Borer oviposits and develops on corn and a number of other wild and cultivated host plants. The only real limitation for being a host plant is that the stem's inner diameter has to be large enough to fit full grown ECB larvae (Capinera, 2014).

2.2.1 The life cycle of ECB

European corn borer goes through four life stages, eggs, larvae, pupae, and adults. Together these stages complete one full generation (Mason *et al*, 1996). The different life stages occurrence under Swedish conditions are illustrated in Figure 3.

Adult females (fig 5) lay eggs in clusters of 15-20 eggs on the underside of the leaves. One healthy moth can lay approximately 500-1000 eggs during its lifetime. The eggs are flat and oval with a white colour which changes during the aging process to a more orange/yellow colour. The eggs measure approximately 1 mm in length, and take between three to 10 days to hatch (Capinera, 2014). The larva (fig 4) is yellow at first but change colour to a yellow/brown colour during its aging process. The larva has several body segments and a dark head capsule and thoracic plate to cover its head. The larva has six instar stages, each representing an additional body segment. During their early instars, larva feed mainly on leaves and particularly the midribs, resulting in leaf breakage. The later instars bite through the whorl when the tassel has emerged. The larvae then enter the stem and start hollowing out the inside of it or reach into the ear of the corn.

The larvae live and feed on corn during the whole growth season, at which point the larvae have reached their full size of approximately three cm. The larvae travel down inside the stalk until it reaches the neck of the root, where they enter into diapause. In case of the univoltine strains, the diapause holds for the entire fall and winter. When the temperature is high enough in the spring, a response is triggered for the larvae to go into pupation (Hill, 1987; Capinera, 2014).

The pupation takes place inside the stem or in the soil under the plant in the late spring. The pupa then stays in this state until it reaches its development threshold at approximately 13°C. Adult ECB moths have a body length between 12-14 mm and a wingspan between 25-30 mm (Hill, 1987). The colour of the moth is normally of different variations of yellow/brown with brown markings on the wings. There is a clear difference in size between the male and female moth, with the male noticeably smaller and slender than the female. The moth is night active and their lifespan is normally a couple of weeks (Mutuura & Munroe, 1970).

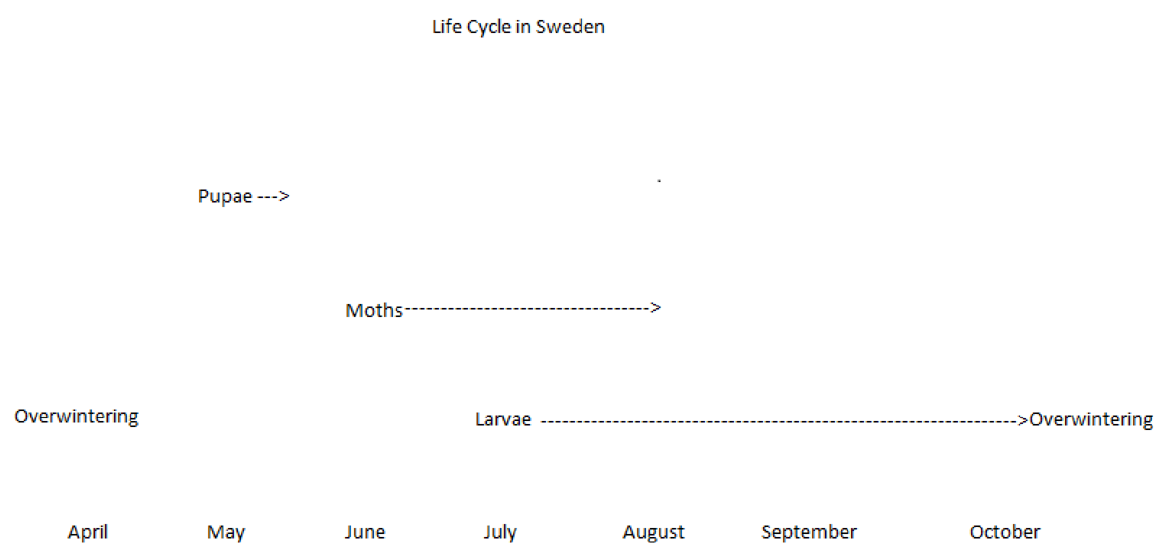

*Figure 3: Lifecycle of European Corn Borer in Sweden, an estimation based on scouting in Sweden by Swedish Plant Protection Agency (*Gustafsson, *O. 2016).*

Figure 4. European corn borer larva (Weller, 2016) *Figure5.. Adult female* (Ben, 2014)

2.2.2 Genetic types of ECB

There are two genetically different variations of ECB, with one primarily feeding on corn and the other feeding mainly on mugwort *(Artemisia vulgaris L.)* and hop *(Humulus lupulus L)* (Bethenod *et al.*, 2004). These show no morphological difference to each other. Each ECB genetic type also has at least three different known strains in USA, each having its own type of diapause pattern. The strain to which the ECB belongs to depends on the climate (Gelman & Hayes, 1980).

The distinction between the two different variations of ECB is made by a difference in sex pheromones emitted by the female. This pheromone, 11-tetradecenyl acetate forms two different stereo isomeric forms, E and Z, in different ratios, attracting different male moth with corresponding pheromones receptors (Roelofs *et al.*, 1985). Both genetic types are often present, and a study shows that there is a cross mating of the pheromone variations. However, the same study points out that the effectiveness of the populations' survival is dependent on how well the male and female moths communicate with their pheromones. This means that not all ECB populations in a specific area contribute equally to reproduction (Klun *et al.*, 1973). According to Ponsard *et al.* (2004), it also means that the two variations and abundance of each different genetic strain determine how effective the agricultural system management will be in terms of resistance of pesticides, outcome of control by biological agents and cultural management.

Both Z and E types of flying moths have been found in corn fields during a three-year trial in southern Sweden. The collection of larvae in corn fields was only of the Z-type, indicating that Z-type were the only ECB type that oviposits in corn (Anderbrant, 2015; Anderbrant, 2016). This is also confirmed by other studies, but author in those points out that it`s still unclear to what extent the E/Z cross mated types lay eggs on corn or other host plants (Pionsard *et al.*, 2004).

2.2.3 Strains of ECB

In studies from the USA showed that there are at least three different strains of ECB, which only differed in their diapause patterns. The most northern parts of the USA and southern parts of Canada were shown to have an ecotype which was univoltine and with obligate diapause. However, with warmer climate and milder winters further south, the ecotypes changed to polyvoltine strains with either obligate or facultative diapauses. This is confirmed by Mason *et al.* (1996), who highlight that in warm climates ECB complete two to three generations, whereas in a colder climate as in northern USA, Canada and northern parts of Europe, ECB is univoltine. The time needed to complete a generation cycle differs depending on a number of environmental factors such as temperature, humidity and day-degrees (Hill, 1987).

Studies show that both the photoperiod and the temperature influence the development of the larvae and the time when the larvae enter pre-diapause which prepares the body for overwintering (Gelman & Haynes,1980). In Sweden, only the univoltine strain of ECB is found (Anderbrant, 2015). This seems natural since parts of northern USA and Canada share the same

Kööpen-Geiger Climate classification as Sweden (Peel *et al.*, 2007). This means that the biology and management methods for ECB in countries with approximately the same classification could possibly be applicable in Swedish agriculture.

2.3 ECB damage to corn

2.3.1 Physiological damage to corn

European corn borer damages corn in a number of different ways. The physiological damage done to plants starts with the first and second instar larvae damaging the whorl and leaf tissue during the early vegetative growth, creating the characteristic shot-hole damage on leaves and breaking of midribs. The larvae tunnel inside the stalks of the corn and when tasselling occurs the larvae start eating on the tassels, silk and on falling pollen. The larvae eat into stalks and ears of the corn and do substantial damage to the plant by creating tunnels (Capinera, 2014). These tunnels interfere with the translocation of water and nutrients causing a halted growth, and in severe cases contribute to stalk breakage, lodging and ear dropping (Martin *et al.*, 2004). The potential yield loss caused by the ECB is primarily due to reduced ears and kernel size (Capinera, 2014). Characteristic for ECB damage is lodged plants, drill holes or residues that indicate a drill hole (Swedish Plant Protection Agency (Växtskyddscentralen), personal communication, July 2016).

2.3.2 Vectors and gateways for fungus infections

The tunnelling introduces a secondary problem by facilitating infections of different fungi that cause stalk and ear rots, such as *Fusarium* spp., *Pythium* spp., *Rhiozoctonia* spp., and *Acremonium* spp. Infections will either appear because of easier penetration of spores through the entering holes from larvae or can be a result of the larvae acting as vectors for spores from leaves and taking the spores inside the stalk (Sobek & Munkvold, 1999). Of these fungi, *Fusarium* spp. has been shown to be one of the most economically significant diseases of sweet corn in Europe. This fungus, *Fusarium* spp. causes a production of mycotoxins that are unhealthy to humans and animals (Meissle *et al.* 2010). A study in Italy aimed to investigate the correlation with ECB damage to formation of a mycotoxin, Moniliforme (MON), and the *Fusarium* species causing MON production (Scarpino *et al.*, 2015). They showed that corn grown in Northern-Italy with ECB larvae increased the occurrence of the specific *Fusarium.* species: *F. proliferatium* and *F. subglutianas*. The study concluded that there was a linear relationship between MON production and ECB injuries, but to some extent the metrological conditions would also play a great role in the production of mycotoxins. Under Swedish conditions, it could be argued that the later *F. subglutainass* would be more important than *F. proliferatium* since it has a significantly lower optimum temperature growth (between 15-25°C compared to the later having an optimum growth at approximately 30°C). A number of other studies have showed that there is a strong correlation between damage from ECB and infections of *Fusarium* spp. There is also definite evidence that the use of different control methods including insecticide treatments, biological control and the use of genetically modified *Bt*-maize (see section 4) have decreased populations of ECB and damage of corn, thus significantly decreasing levels of *Fusarium* and formation of mycotoxins (Blandino *et al.* 2015).

2.4 Management methods for ECB

In the mid-20th century, the environmental concerns where growing and entomologists understood the importance of an effective crop protection strategy to uphold a sustainable agriculture (Romeis *et al*, 2008). At this point the entomology society and the farmers wanted to achieve a control method that took in account the economic benefits, as well as the environment. As of 2014, integrated pest management (IPM) became compulsory to all EU countries including a decreased usage of pesticides as well as taking into consideration the risk for humans and the long term impact on the environment (Razinger *et al.*, 2016). In corn production, management strategies are built both on preventive and responsive tactics (Romeis *et al*, 2008).

The preventive management methods include forecasting with traps, modelling methods, cultural management, and host plant resistance methods. The responsive methods are either through the use of biological control or chemical agents to prevent ECB damage.

2.4.1 Forecasting ECB

The moths can be scouted in order to assess the future population of the pest, and thus assess the possible need to take control measures. The scouting is used to determine the potential economic loss or the estimated number of insects in a population (Brindley & Dicke, 1963). There is a strong correlation between the plant phenology of the corn and the development of ECB in the sense that ECB eggs are only laid when corn leaves are large enough, and that the larva eats inside the stalk only if the stalk is large enough to fit a larva. From the knowledge on temperature, sowing dates and the phenological development of corn, an assessment can be made on how ECB has developed and if measures need to be taken (Porter *et al.*, 1991). To scout them, different traps are used and of these the black light traps and pheromone traps are the most common (Capinera, 2014), however not used in Sweden, with the exception of the Plant Protection Agencies.

The pheromone traps are designed to attract only males by mimicking the chemical communication between females and males (Capinera, 2014). These traps can be set with different pheromones to attract either the Z- or E-type (Roelofs *et al.*, 1985). That has also been confirmed in trials in southern Sweden where the pheromone traps with Z-pheromones only caught Z-type ECB and vice-versa (Anderbrant, 2015; Anderbrant 2016). These traps are not commercially available in Sweden but could be bought from overseas. The black light trap, which is available in most hardware stores, collects both genders. The light attracts most flying insects inside a container with a killing agent, meaning that it is not only the ECB moths that are attracted to light traps, thus some time has to be spent on identification (Capinera, 2014). The backside of the black light trap being that it is very time and labour intensive.

2.4.2 Degree day model

Porter et al (1991) described a modelling method in which the effective temperature sum, known as degree-days, often is used to examine the phenological development of both pest and crops. Different insects have specific temperature thresholds to initiate development. The trials concluded that ECB has a temperature threshold of 10 degrees. The study showed that the number of degree-days was different depending on the region and environmental conditions. Another study conducted in Alberta, which has the same Kööpen-Geiger Climate classification as Sweden (Peel *et al.,* 2007), concluded that the standard threshold of 10 degrees was suitable for modelling univoltine strains of ECB. In their study, the model also concluded that moth emergence would peak at 124 degree-days after pupation and that first instar larvae would peak at 310 degree-days and second instar would respectively coincide with 450 degree-days (Kelker *et al.*, 1990). This information is of use when predicting both the time for insecticide management but also for prediction of population size and growth and could be used in Sweden.

2.4.3 Cultural control

Since the beginning of corn cultivation and the introduction of ECB, farmers have used cultural methods to control the insects (Romeis *et al*,2008). The ECB population and damage can be decreased by physically removing the ability for them to survive until the following season by ploughing after harvest in the fall or before planting in the spring. The ploughing destroys stalks and turns residues into the soil (Mason *et al.,* 1996).

Another effective method is to limit ECB by changing the sowing and harvest to delay or advance the first generation (Mason *et al.,* 1996). The method affects both the vulnerability for the larvae since the sowing date influences the phenological growth and development of corn, and impacts the plant's coping ability towards environmental stresses (Obopile *et al.*, 2012). Non-host plants and different cultivations methods are used in the rotation to decrease ECB survival over multiple years (Romeis *et al.,* 2008). In Sweden, the recommendations from the Swedish department of Agriculture (Jordbruksverket) are mainly to not grow corn after corn, harrow or in some other way destroy corn residues from harvest during the autumn and plow to a minimum of 10 cm deep at autumn or spring (Swedish Plant Protection Agency [Växtskyddscentralen] personal communication, July 2016)

2.4.4 Host plant resistance

Entomologists, scientists, and plant breeders have, during the last decades, focused on enhancing corn resistance by natural breeding. The focus has been on changing the plants' attractiveness towards insects, increasing the tolerance for insect injuries and changing the development of plants to minimize the effects of insects (Romeis *et al.,* 2008). Studies on sweet corn in Mediterranean countries have shown that inbreeds and hybrids of some common sweet corn varieties showed a reduction in ear damage caused by ECB compared to the original varieties (Pablo *et al.,* 2002). There is a correlation between the thickness and composition of the stalk and damage from ECB. A change in stalk-composition towards more crude proteins, lignin and cellulose was positive against second generation ECB, rind damage and lodging but showed no evidence of having a strong effect against first generation ECB (Martin *et al.*, 2004). There are, however, other studies indicating that some inbred lines of corn have a greater resistance towards stalk lodging from first generations ECB (Willmot *et al.*, 2005). The secondary problem with fungus infections by ECB injuries has also been studied and efforts have been made in breeding towards greater resistance. The resistance for *Fusarium* spp. has been shown to be inherited quantitatively and can be linked to genes from at least nine different chromosomes of corn (Stuthman *et al.*, 2007). In Sweden, a different numbers of varieties are used, but all of them being chosen mostly for their ability to withstand colder weather and with a high starch and dry matter content (Jordbruksverket, 2015). These are important since the main usage is for silage or fodder, and little has been cared for characteristics good for prevention of ECB damage.

2.4.5 Bt-Corn

Genetically modified corn that works by producing a crystalline protein (cry protein), that acts as an insecticide to insects of Lepidopteran larvae has been implemented in corn production worldwide. The protein is derived transgenically from the plasmids of the soil bacteria *Bacillus thuringensis* (*Bt*) (Meissle *et al*., 2010). *Bt*-production in plants was first introduced in the USA in 1996 and has been extensively used since then outside of Europe. The cry proteins produced are host specific and have no or little effect on beneficial insects outside the Lepidopteran family. *Bt*-corn has been shown to be very effective against stalk injuries from ECB (Obopile *et al.*, 2012). Farmers have had to weigh the decision to grow *Bt*-corn between the increased seed cost against the probability for an infestation to occur. Even if studies from the USA have showed that the financial returns often are greater when *Bt*-corn is grown, they also show that the return is a definite response to the total usage of *Bt*-crops within an area. When more farmers grow *Bt*-corn within an area, the pest would be more suppressed, thus the individual farmer that choses to grow non-*Bt* corn would benefit the lower seed cost and still get the positive effects of other farmers growing *Bt*-corn. Since farmers communicate and the number of *Bt*-corn growers would change over time, there are no definite profits to be made calculated over a longer time period (Milne *et al.*, 2015). The use in Europe is limited due to regulations of genetically modified organisms (Meissle *et al*., 2010). In Sweden, the use of genetically modified crops is not allowed.

2.4.6 Biological control

The current EU commission directive restricting pesticides registrations and usage as well as a change in the EU policy towards a reduced pesticide usage has resulted in bio-control being more important (Hillocks, 2012). European Corn Borer and other corn pests can be, to some extent, suppressed by natural enemies, such as predators, parasitoids and pathogens present in agroecosystems. Farmers use what is called conservation biological control to conserve natural enemies, by for example establishing habitats surrounding the fields, to support them with beneficial living conditions and alternative food sources (Romeis *et al.*, 2008; Meissle *et al.*, 2010). The classical biological control method with importation of certain biological control agents has also been used by farmers with a long term impact of ECB. In the early 1900s, different wasps and flies where imported to the USA and established to keep ECB below economic levels (Romeis *et al.*, 2008). In Europe today, augmentative biological control agents such as the small wasp *Trichogramma* spp. are used. The small wasp is an egg parasitoid used as a biological agent against ECB and other Lepidoptera in countries such as France, Italy, Slovenia. There are contradicting studies on the effects (Meissle *et al.*, 2010). Trials with *Trichogramma* have been conducted in Europe, but only on the second generation ECB. In the trial, wasps were released one week after 25-30 % of the pupation had occurred, and in some cases a second application was done approximately two weeks after the first. The effectiveness of the release was measured over a two-year period and showed different results from 50-80 % parasitism of ECB eggs. The study did not show any effect on yield compared to insecticide application or the control (no treatment), but the authors of the study states that there are other studies made that contradicts their results. The total cost of the treatment differed much between countries since all had different operations and labour costs, but in all cases the biological control method with *Trichogramma* was more expensive than the use of insecticides. The pros for using *Trichogramma* is that the window for application would be greater than that of an insecticide and that there would not be any negative effect on naturally occurring enemies of ECB or other potential effect on the environment (Razinger *et al.*, 2016). In Sweden, no inundative biological control is used today.

2.4.7 Insecticides

Insecticides are commonly used by farmers in Europe and America to prevent ECB from reaching the damage threshold; however, application is problematic due to the short time span during which the pest is vulnerable to the insecticides (Romeis *et al.*, 2008). The most common use of insecticides against ECB in corn is foliar treatment (Meissle *et al.*, 2010). For foliar treatment to be effective the timing is important. The treatment must be at the time between the hatching of the larvae and before the larvae eat their way into the tunnel of the stalk, where they are protected (Meissle *et al.*, 2010). Observations in Germany show that the time for treatment can differ greatly between years (Swedish Plant Protection Agency, personal communication, July 2016). The time of this occurrence can be predicted using, for example, the Day-degree model described earlier. The most commonly used spray insecticides in Europe are pyrethroids and organophosphates (Meissle *et al.*, 2010). However, only one insecticide is approved in Swedish agriculture from the beginning of summer 2016 (Kemikalieinspektionen, 2016). The product, Steward 30 WG (DuPont, USA), is an insecticide based on the active substance Indoxakarb, which targets insects by either direct contact or ingestion and is only approved to be used once per season and at a specific phenological state of corn, right before or at tassel emergence (Indoxacarb, 2016). The problem with these wide spectrum insecticides is that they often negatively impact ECB´s natural enemies making conservation biological control less effective (Meissle *et al.*, 2010). In addition, careless use of insecticides has been shown to significantly decrease population of pollinators and other beneficial insects. (Klein *et al.*, 2007) The use of insecticide in Sweden is also controversial since corn is mainly used for silage and therefore the possible fungus infections are more important in Sweden to address and that might be done better with the use of a a fungicide during the silage process or against *Fusarium* spp. during the corn growth rather than trying to reduce the damage done by ECB.

3. DISCUSSION

3.1 Swedish conditions and potential shift of climate

According to both Meissle *et al.* (2010) and Porter *et al.* (1991), a change towards a warmer climate will results in a change of the population boundaries of ECB. The statistics over corn production in Sweden shows that corn production is now stable and has not increased in recent years but in personal communication with the Swedish Department of Agriculture (Jordbruksverket) the indication is that production will increase. From that information, the conclusion must be drawn that ECB most likely will become more abundant in Sweden in the years to come. Most of the corn production in Sweden is used for silage or harvested for animal fodder. The physical damage done by ECB is therefore not that important since the animals do not care if there is a larva in the fodder or that the larva has eaten its way inside the ear. It does not affect the quality of the silage or fodder as it does for sweet corn grown for human consumption. The importance of ECB damage today lies in the production of mycotoxins in corn silage and fodder by fungi, and the effect that this has on the quality of the crop. In Sweden, grass and not corn is a major source for silage. This would mean that ECB is at present not equally important in Sweden as it is in many other places around the world where corn is more important in silage as well as being grown for human consumption. It is arguable that it´s still important in Sweden to the extent that we further in the future probably will have corn as a bigger part of our rotation and therefore would be advised to address the problem at an early stage. Corn can in the long term be safer than grass if the climate is dryer and warmer, since the production of silage from corn would be bigger if the regrowth of grass is reduced due to climate. As an example, Denmark currently uses mainly corn in silage instead of grass, and uses ears in fodder to a greater extent. Mycotoxins are unhealthy to animals and humans and it is important to understand that with growing corn production, there is a probability of increased problems due to mycotoxins in the fodder.

A warmer climate could also mean that Swedish farmers could shift toward growing sweet corn. European Corn Borers does not differ between a sweet corn plant and corn for animal fodder. If there are generations of ECB in silage corn in Sweden, they will most likely be in all eventual sweet corn fields as well. It is also important to remember that a farmer wants to spread their risk by not growing only one crop and for only one purpose. If the climatic conditions where favourable to grow both silage and sweet corn, farmers would probably do both. In the case sweet corn is grown, farmers would need to control the ECB population to ensure a good quality of the end products. Not only because of the health risk but also to be able to sell the yield and compete on the global market.

Today, only the univoltine strain of ECB is present in Sweden. However, a potential shift in climate could result in an emergence of polyvoltine strains. As described in the results the second generation larvae are capable of much more physical damage to corn plants. If a second generation occurs, the total annual population of ECB would increase, which would likely increase the pest pressure over years.

3.2 Management methods

Studies outside of Sweden have given a good understanding of how ECB lives, what damage it does, and how it could be managed. However, these studies are carried out outside of Sweden and under different circumstances. Even if some parallels with these countries could be drawn, there are still many parameters that are not the same when it comes to controlling ECB. Particularly, the rest of Europe and America do not have the same type of strategies than Sweden regarding ECB management and.

The usage of different forecasting methods is limited and for now the scouting and collection of larvae of ECB is mainly from instances such as the Swedish Department of Agriculture. The suggestion would be to start with giving farmers the options to easily buy pheromone and/or black light traps to track when moths are present in the fields for themselves. Basic models that involve the use of day-degrees and counting of larvae and eggs on plants could easily be standardized and taught to farmers from the local farmers counselling offices. In order to help them further track and follow the progression of ECB population, support should be available from several locations in Sweden by government funded instances.

The advice given to farmers today in Sweden to control ECB is, as described earlier, mainly to use cultural control, often ploughing and harrowing which is effective when one does not want to increase the population to next year. The problem remains for those that use no-tillage systems, who do not plough crop residues into the soil. This results in more overwintering ECB larvae, which could increase the ECB damage in case corn is grown year after year. If a no-tillage system is used a crop rotation after corn would therefore be very important to minimize pest damage. Farmers are also given the advice to harvest as soon as possible to minimize the damage and to reduce the number of larvae that have grown big enough to travel down the stalk for overwintering. In theory, it is a good measure to take, but in practice the harvest date is often decided on the phenological stage of the corn and its optimal stage for the silage process. These events do not always coincide.

Today, corn varieties used in Sweden are chosen primarily for characteristics beneficial for the end product silage or harvested for fodder. In the future, it would be beneficial to also strive for a usage of corn varieties which have good natural resistance to ECB damage.

The USA, Australia, and parts of Europe are using *Bt*-corn which is not an option for now in Sweden. The use of *Bt*-corn is possible in the future. However, thinking of the Swedish conditions with colder climate and the fact that it is primarily for silage and that the variety has been breed for usage in a warmer climate makes it unlikely to be beneficial. If or when more corn is grown in Sweden it could be an interesting alternative. The cost of *Bt*-corn seeds is higher and studies have to be made in Sweden on the potential economic profit. The use of *Bt*-corn is also driven by the market. Currently, there are strong feelings against genetically modified products by Swedish consumers, so that even if grown, there are no certainties that the products could be sold on the Swedish market.

When it comes to reducing the damage in field there are no really good responsive management options at present. Conservation biological control is used to increase the number of natural enemies in the sense that we do not use unnecessary pesticides and we have a rotation that benefits multiple insects. A classical use of an imported biological control agent is arguably not a good option in the sense that it is very hard to predict the long term influences on the current ecosystem. An augmentative biological control agent such as the use of *Trichogramma* spp. is interesting because in many studies a decrease in ECB damage has been shown. Their use is, however, expensive and since it is an augmentative control measure it mainly affects the ECB damage that year, careful consideration and calculation on the possible profit should be made before its use. Nevertheless, its positive side of not being equally dependant on an exact application window, contrary to insecticide use, and more environmental friendly could outweigh the negative sides.

European countries, the USA and many others countries have a lot more approved insecticides than Swedish farmers have access to. In the beginning of summer 2016, the first insecticide Steward was approved for usage in corn fields against ECB in Sweden. The reason for not having any approved insecticides before is most likely the low pressure of ECB damage on corn in Sweden, but also due to a much harder legislation towards pesticide usage than other countries have. With the approval of Steward, farmers have a responsive method which can be very effective if the application and timing is successful which is not always the case when it comes to corn. It is a large crop and foliar treatments will never be 100 % effective. The height of corn makes it important that the right machinery is used to be able to spray the foliar treatment. Before implementing into the agricultural practice the potential economical profit should be calculated.

The different genotypes Z and E are both found in Sweden and there is evidence from studies in Sweden and worldwide that they can crossbreed. The crossbreeding could potentially result in survival of crossbred E/Z types on other plants than corn; meaning that they potentially can crossbreed with Z -type moths the following year. Since the management strategies only concern moths that are present on the corn field, eventual E- type ECB moths outside of the corn fields have not been dealt with. This could result in a bigger population the following year. It could also mean an increased likelihood of resistance towards insecticides since it theoretically would mean a greater genetic diversity.

4. CONCLUSION

Sweden is looking at a warmer and moister climate which will be beneficial for ECB in Sweden. The Swedish farming community needs to create a clearer preventive decision support system and a responsive strategy to control future problems with ECB. The strategy must include a sustainable IPM method adapted and based on monitoring of ECB in Swedish agriculture systems. As stated by Anderbrant (2015; 2016) from Swedish investigations, ECB is already a present and with the climate change we are facing, and the possibility of more reduced tillage and more corn in our rotations it would be unwise to not develop a plan for it. The Swedish Department of agriculture (Jordbruksverket) has already set up a number of basic preventive control measures for farmers to follow. In summer 2016, the Swedish Chemical Agency (KemI) approved one insecticide, which means that some responsive measures are taken to help farmers cope with current ECB populations. However, no biological control methods are yet promoted in Sweden.

For the most part the studies made on ECB concerns the polyvoltine strains elsewhere in the world and are therefore based on the assumption that more than one generation will occur and damage corn plants. The damage done by one generation is not equally great as that from multiple generations. A change in climatic conditions in Sweden could result in the emergence of polyvoltine strains. This study has shown that there are already good management methods that can be used and that they are possible to apply to Swedish conditions. I also emphasize that there is an obvious need for more research under Swedish conditions on both how the univoltine strains lives and progresses in Sweden and the possibility of an emergence of polyvoltine strains in Sweden.

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6.2 Personal Communication

Swedish Plant Protection Agency, (Växtskyddscentralen), July 2016

6.3 Pictures and Figures

Figure 1: Gustafsson, Oskar. (2016) *Area of corn production (ha) in Sweden based on numbers from Swedish Department of Agriculture*.

Figure 2: Iowa state University (1996). *how a corn plant develops - Google Search*. [online] Available from: https://www.google.se/search?q=how+a+corn+plant+develops&client=firefox-b-ab&source=lnms&tbm=isch&sa=X&ved=0ahUKEwj60Pezu5HPAhWiDpoKHSV8BD0Q_AUICCgB&biw=1920&bih=762#imgrc=6Cxa--AzY7UwUM%3A. [Accessed 2016-09-15].

Figure 3: Gustafsson, Oskar. (2016) *Lifecycle of European corn borer in Sweden, an estimation based on scouting in Sweden by Swedish Plant Protection Agency*

Figure 4: Weller, K. (2016). *European corn borer, Ostrinia nubilalis Photo by Keith Weller*. [online]. Available from: https://commons.wikimedia.org/wiki/File:Corn_borer.jpg. [Accessed 2016-09-15].

Figure 5: Ben, S. (2014). *Farmland - Braughing Friars - Field Trip - 19/07/14* [online]. Available from: https://commons.wikimedia.org/wiki/File:(1375)_Ostrinia_nubilalis_(14691963426).jpg. [Accessed 2016-09-15].