A review of the bee pollination research on temperate zone crop plants in the past decade: results and the need of further studies

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Summary: Intense research was made on the pollination of cultivated crop plants in the temperate zone region during the past decade. Some 400 publications appeared on the subject and some additional 150 papers on the effect of pesticides to the most important pollinating insects, the honeybee and the wild bees. Progress of knowledge is discussed in this paper based on the most important publications. Most new results relate to field crops and deciduous fruit species and much less to field vegetables and small fruits. Great effort was taken to improve insect pollination of crops grown under cover. All these are connected to the utilization of the honeybee as a pollinating agent and much less to native or managed wild bees. However, a number of questions arose partly from the results of latest pollination research and partly from practical experiences in commercial plant production. These indicate several research tasks to understand and to solve the problems possibly in the near future. The questions concentrate on the effectiveness of bee visits in the pollination of individual crop plants and their different cultivars and on the reliable estimate of the overall amount of bees as well as on the control of bee density during the flowering periods of crops for optimal, controlled pollination in the changing environment of agricultural crop production.

Key words: insect pollination, honeybees, temperate zone crop plants, pesticides, fruits, vegetables, field crops, wild bees

Introduction

The role of insects in crop pollination has been recognized long ago. The majority of temperate zone crops for cultivation are insect pollinated. Wind pollinated crops are much less in number and there are several crops that are considered to be auto self-pollinated. Although, these non insect-pollinated crops are grown on larger acreage than insect pollinated ones, the insect-pollinated crops are absolutely indispensable for human alimentation and feeding animals as well as for seed production. As these crops definitely need the contribution of pollinating insects to yield formation, their growing technologies are usually more complicated and more risky in the practice than of wind pollinated and auto self-pollinated ones. To reduce risk and improve productivity, the growers need reliable advices to utilize pollinating insects in a proper way. This can be supported by research on the insect pollination of cultivated crop plants. The information accumulated on this field was reviewed by *Free* (1993) in the comprehensive handbook "Insect pollination of crops (second edition)" some ten years ago. After the appearance of this book, research on crop pollination has remained intense. Some 400 publications appeared in this subject during the past decade, and some 150 more on the side effect of pesticides on pollinating bees and on the relationship between insect pollination of crops and pesticide applications (Apicultural Abstracts). The majority of recent publications corroborated earlier findings, supplementing earlier data, first of all, on the importance of bees in pollination, on the foraging behaviour of bees on crop plant flowers and partly on the known effects of selected environmental factors to bee activity at blooming crop fields. The aim of this paper is to give an outlook onto the state of knowledge in this field and to point out the need for further research. Accordingly, first of all those publications are reviewed which contained new information.

Fruit trees

The pollination of fruit trees is the most intensively studied subject of crop pollination of all. Pollination requirements of temperate zone fruit crops, their pollinating insects, the rewards to attract bees and the foraging behaviour of bees on their flowers as well as the effect of bee pollination on the yield is fairly well known *(Free* 1993). Lately, intensive studies were carried out on variety features affecting bee activity. There were few indications in the literature that some differences between cultivars, for example the relative position of petals and stamens, or the nectar and pollen production of flowers had a definite influence on bee behaviour and on the pollinating efficiency of bees at some instances (see in *Free,* 1993). This problem, however, attracted little interest. For this reason lately large series of cultivars were inspected for apple *(Benedek* et al., 1989b, *Benedek & Nyéki*, 1996a, *Devary-Nejad* et al, 1993), apricot (*Benedek* et al., 1991b, 1995), peach and nectarine (*Benedek* et al., 1991a, *Benedek & Nyéki,* 1996b), sweet and sour cherry (*Benedek* et al., 1990, 1996) and plum (*Szabó* et al., 1989, *Benedek* et al., 1994). Differences were detected among cultivars in flower sizes, in the number of stamens/flower, in the relative position of petals to stamens and to pistils, in the nectar content of flowers, in the sugar concentration in nectars, in the anther size and in the pollen production, and finally in the intensity of bee visitation at the flowers. In case of apricot, flower characteristics varied considerably depending on the year and site, greater differences occurred at the same cultivar in consecutive years than between cultivars in given years. Similarly, no consistent differences were found in the bee visitation at a number of almond cultivars in India; floral preferences varied from year to year (*Thakur* et al., 1995). Contrarily, at the rest of the mentioned fruit species, the differences in the flower characteristics of cvs were consistent in different years, and consequently, also their bee visitation differed. In the case of pear, the opening order of flowers within inflorescence was different; cvs fell into three types of opening order which also differed in the average number of bee visits per flower; this was explained by the different number of flowers and differences in the longevity of flowers within the inflorescence of the tree types (*Dibuz* el al., 1997, 1998).

In other studies the nectar content and the bee visitation of several almond (*Abrol,* 1995), peach (*Nyéki* et a., 2000), pear (*Benedek* et al., 2000a) and quince cultivars were compared (*Benedek* et al., 2000d, 2000e); cultivars with higher sugar concentration, i.e. with higher caloric rewards usually attracted more foraging insects compared to other cultivars of the same fruit species, except pear (*Abrol,* 1995, *Benedek* et al., 1997, 1998b, 2000e, *Benedek* 2000). Nectar production of pear is generally regarded to be very poor in the literature (*Free,* 1993); in fact, it has been shown lately that pear flowers could produce a plenty of nectar, but the amount of nectar was extremely dependent on the weather (*Benedek* et al. 2000a). However, pear nectar always contains very little amount of sugar (*Benedek* et al., 2000a) which is not attractive to bees at all (*Free,* 1993). That is why honeybees collect almost exclusively pollen on pear, even with high nectar production (*Benedek* et al. 1997, 1998b, *Benedek & Nyéki,* 1997a, *Benedek,* 2000).

Comparing the nectar production and the bee visitation of fruit tree flowers at the species level, the amount of nectar/flower was the highest at sour cherry, followed by apricot, apple, plum, peach and nectarine; pear always produces very small but sometimes can produce very high amount of nectar (*Benedek & Nyéki,* 1997a). The mean sugar concentration of pear nectar was always very low, regardless the amount, and the sugar concentration of nectar was the highest at sour cherry, followed by apple, plum, peach and nectarine (*Benedek & Nyéki,* 1997a). Mean intensity of bee visitation was also different according to the fruit species, and again, it was clearly related to the sugar concentration of the nectar (except pear), but the amount of nectar had no effect on the bee visitation at the species level (*Benedek & Nyéki,* 1997a).

Different factors, weather conditions first of all, can restrict pollinating insects to work the flowers of fruit trees during their blooming period. In spite of this, very little information has been available in the literature on the rate of limitation that affected the fruit set and yield. For this, reason experiments were made on this issue lately with apple (*Benedek* et al., 1989a, *Benedek & Nyéki,* 1996c, 1997b), with pear (*Benedek* et al., 2000b), with quince (*Benedek* et al., 2000f), with sour cherry (Benedek et al., 1990), with plum (*Szabó* et al., 1989, *Benedek* et al., 1994) and with apricots (*Benedek* et al., 2000b). Summarizing the results of relevant experiments, the main conclusion was, that in the case of self-sterile fruit species and cultivars (apple, pear, quince, some plums, some sour cherries) even partial limitation of the effective duration of the bee pollination period significantly reduced the fruit set and the yield; in the case of self-fertile fruits (some plums, some sour cherries, some apricots), on the other hand, the effect of partial limitation was usually small, and the complete (or incomplete but strong) limitation resulted in a strong reduction of yields; it means that not only self-sterile, but also self-fertile fruit cultivars definitely need insect pollination (*Benedek & Nyéki,* 1995, 1996d, *Benedek* et al., 2000b).

Lately flower constancy of honeybees at fruit trees was investigated by analysing the pollen loads of pollen gatherer honeybees captured at fruit tree flowers (*Benedek & Nagy,* 1996, *Benedek* et al., 2000c); the fidelity of bees was fairly high for pear, but it was smaller for apricot, much smaller for apple and even smaller for sour cherry. Competing plants influenced the flower constancy of honeybees and the influence was greatly different for fruit species; it was very little at pear (*Benedek* et al., 1998a, *Benedek* 2000). High fidelity of pollen gatherers was also observed towards cultivars, since bees returning to the hives had 80–90% of their loads from only one cultivar out of the 5 or 6 in an almond orchard (*Vezvaei & Jackson* 1997, *DeGrandi-Hoffman* et al., 1992). However, bees with high amount of pollen from a single cultivar usually had some pollen from other cultivars, too (*DeGrandi-Hoffman* et al., 1992).

The gene flow, as investigated with isozyme markers, was quite restricted in almond orchards in Australia, being the strongest between neighbouring halves of cross-compatible pairs of trees (*Jackson & Clarke,* 1991, *Vezvaei & Jackson,* 1997). However, the nut set on branches adjacent to compatible pollen sources did not differ significantly from the set on branches adjacent to the trees of the same cultivar in one other experiment in the US (*DeGrandi-Hoffman* et al., 1992).

Small fruits

Strawberry: Insect (bee) pollination is known to increase set and yield and to decrease the ratio of malformed fruits (*Free,* 1993). These findings have been corroborated by a number of latest reports at open plots and also in enclosures, because using honeybees to pollinate strawberries in greenhouses and plastic tunnels became a practice during the past decades. In Canada honeybees are more efficient pollinators of strawberry than small bodied, indigenous, solitary wild bees (Andrenids, Halictids, Megachilids); data show that these two groups play a complementary role is strawberry pollination *(Chagnon,* et a. 1993). Lately, also bumblebees were used to this purpose, they have been found to be at least as effective in strawberry pollination as honeybees *(Eijnde,* 1992). There are some opinions in the literature that strawberry yields were the highest, when honeybees and bumblebees were used together *(Paydas,* et al. 2000). It is a very important new finding, that excessive visit of honeybees or bumblebees under plastic or glass can lead to fruit malformation of strawberries similarly to insufficient bee activity *(Lieten,* 1993). Based on series of bee density measurements 10 to 15 thousands of worker honeybees or 60 to 70 bumblebees are recommended (the latter being much more active!) to optimal pollination of strawberries per 1000 sq. meter under cover *(Lieten,* 1993). In Italy Osmia cornuta was successfully utilized to pollinate strawberry in greenhouses. The bees collected nectar and pollen, the yield was slightly (not significantly) higher, and the rate of malformed fruits were much lower (*Pinzauti,* 1993).

Raspberry: Raspberry cultivars are largely self-fertile, but bee pollination increases set, reduces the rate of malformed fruits and increases fruit sizes to some extent *(Free,* 1993). Honeybees are known to be effective pollinators but bumblebees are more rapid, can carry more pollen on their bodies, deposit more pollen on raspberry stigmas, forage for a longer period a day and work flowers even at poorer weather; so they are preferred pollinators of raspberry *(Willmer* et al., 1994). The better pollinating efficiency of bumblebees on raspberry is correlated also to their flower visiting behaviour, since they favour young (receptive) flowers, especially in the morning when pollen is most abundant, while honeybees visit young, medium and old flowers unselectively *(Willmer* et. al., 1994). Bumblebees can also be used for raspberry pollination under cover as reported recently from New York State (USA); raspberries grown in outdoor plots were moved into a greenhouse for the winter period where flowering and good yield was obtained by using bumblebees (Bombus impatiens) for pollination from late winter to early spring *(Pritts* et al., 1999).

Cucurbits

Melon, Cucumis melo, produces much better yield, earlier crop and sweeter fruits with than without insect pollination, and sometimes no fruits are set under cover without pollinating insects *(Free,* 1993). This knowledge was confirmed by some latest publications. Additionally, it was found that nectar gatherers as well as mixed behaviour bees (nectar + pollen collecting) are equally effective *(Vaissiére* et al., 1992), but bees collecting pollen forage at greater distances from the hive. On the other hand, Africanized honeybee colonies consistently forage closer to their hives than the European and hybrid lines, and so colonies of Africanized bees should be distributed more closer to the target crops with less distance between apiaries in cantaloupe pollination *(Danka* et al., 1993). Interestingly, bee activity seems to be higher in the morning and the yield is also higher when honeybees are located at the southern end of plastic tunnels *(Dag & Eisikowitch,* 1995). Apart honeybees, bumblebees (Bombus terrestris) have been found to be equally effective in the pollination of melon under cover *(Dasgan* et al., 1999). Cucumbers, Cucumis sativus, also need insect pollination, except parthenocarpic cvs that produce misshapen fruits when pollinating insects are present during the flowering period *(Free,* 1993); and this was corroborated in some latest publications, too.

Vegetables

Tomato: Latest reports on tomato pollination corroborate earlier findings *(Free,* 1993) that insect pollination both by honeybees and bumblebes is efficient and generally are more effective than mechanical pollination by electric devices vibrating the flowers. However, the efficiency of the methods may be influenced by the season. In Israel both had similar effects on fruit set, seed number, fruit size and yield in an unheated greenhouse under moderate climatic conditions of autumn and early winter, but under more severe winter conditions bumblebees were superior *(Pressman* et al. 1999). It is an important finding that some native bumblebee species can be equally efficient in the pollination of tomato under cover than the managed Bombus terrestris and native species can be effectively be used in greenhouses with no ecological risk to accidental introduction of the managed species where it is are not native *(Asada & Ono,* 1996).

Sweet pepper of paprika: Using bees for the pollination of sweet pepper is a fairly new development. The first trials were made with honeybees in the Netherlands on paprika grown in greenhouses some ten years ago. Paprika flowers produce nectar and pollen and are attractive to honeybees *(Ruijter & Eijnde,* 1991). The bee pollination advanced the time of the harvest and increased total yield to some extent (from 18 to 19 kg/m^2), associated with somewhat increased average fruit size and increased number of seeds/fruit *(Bruijn & Ravestijn,* 1990, *Ruijter & Eijnde,* 1991). It was stated later that honeybee pollination increased yield and fruit size in spring and autumn but fruit setting presented no problem in greenhouses in the summer period *(Ruijter* et al., 1991). Later on bumblebees were also used and were found to be effective in the pollination of sweet pepper. Their flower visiting activity increased the fruit weight and was resulted in the greater percentage of large and extra-large fruits *(Shipp* et al., 1994). In Italy similar advantages were reported for bee pollination in greenhouses *(Porporato* et al., 1995a) and plastic tunnels *(Porporato* et al., 1995b), and it was also found that some cultivars were more visited by honeybees and bumblebees than others. A comparison of the pollinating efficiency and the foraging rates of honeybees and bumblebees is sweet pepper pollination in greenhouses has shown no noticeable differences between the two kinds of bees, but bee pollinated plots have produced significantly higher yield with significantly more high quality fruits *(Dag & Kammer,* 2001).

Eggplant: The role of insects in the pollination of eggplant seems to be contradictory. It appears that auto-pollination may give adequate set and the set is limited by the bearing capacity of the plants *(Free,* 1975). In Turkey, however, bumblebee pollinated plots gave 23% higher yield, 22% more fruits/m^2 and 62% more seed/fruit than plots with no insect pollination *(Abak* et al. 1995). Bumblebee activity peaked between 10.00 and 11.00 in the morning, and bumblebee pollination was better than vibration pollination with an electronic device *(Abak* et al., 2000).

Vegetables seed production: Seed production of vegetables is known to depend on insect pollination *(Free* 1993). *Onion seed production* is a specific problem, because bees do not prefer onion flowers for several reasons, if more favourable nectar and/or pollen sources exist nearby. This encouraged authors to search for a method to increase bee visitation to flowering onion fields. Several techniques were tested to increase and stabilise bee activity at onion fields (different bee attractant sprays, feeding colonies scented sugar syrup, serial introduction of bee colonies, encouraging colonies to collect more nectar and pollen using Hi-Line, conducted selection for colonies that preferred foraging on onion, diluting nectar with overhead irrigation, interplanting onion field with lucerne to attract bees to the field), but none of them recruited or forced honey bees and wild bees to visit onion flowers and did not improve greatly the seed yield *(Mayer & Lunden,* 2001). Also several non-Apis bees were tested (Bumble bees, lucerne leaf cutting bees, the blue orchard mason bee and the alkali bee), to increase seed yield of onion but the experiments led to no significant yield increase *(Mayer & Lunden,* 2001).

Seed production of cabbages and other related vegetables are known largely to depend on insect pollination, and there is a specific problem in hybrid seed production, because bees discriminate between fertile and cytoplasmatically sterile parental lines, the latter being much less attractive *(Free,* 1993). Latest publications corroborated this knowledge. In case of Chinese cabbage, self-incompatibility was successfully overcome, since spraying plants with common salt successfully increased the pollination efficiency of bees, the result depended on the time of spraying and the concentration of the sprayed solution *(Rui* et al., 1995). In case of radish (wild radish), the effect of flower morphology on pollinator efficiency was studied in detail *(Conner* et al., 1995). It was found that the pollen removal increased with the amount of pollen available to bees, butterflies and syrphid flies. Interestingly, the nectar feeding butterflies had higher pollination efficiency than honeybees. The pollen deposition on recipient flower increased with the amount of pollen removed from the donor flower, and there was a positive relationship between deposition and the time bees spent on the flower *(Conner* et al., 1995). This corroborates earlier findings, that pollen deposition at the stigmas in radish (wild radish) flowers has a significant, positive function with the number of honeybee visits at flowers, and after some 9 visits sufficient amount of pollen is deposited (some 2401 grains) to fertilize all of the ovules of the flower *(Young & Stanton,* 1990). Accordingly, this seems to be a good measurement to determine the optimal intensity of honeybee visitation at radish seed production.

The importance of pollinating insects in the *production of carrot seed* is well demonstrated in the literature *(Free,* 1993). Bees are the most effective pollinators, but taking into account their abundance, foraging activity, proboscis length, body size, number of pollen grains carried all over the body, they can be ranked effectively *(Kumar & Rao,* 1991). In general, most pollen can be found on the bodies of pollen gathering bees rather than on nectar gatherers *(Rodet* et al., 1991). Although honeybees are effective pollinators of carrot, lately two wild bee species, Osmia rufa in the greenhouse *(Vasilevskii* et al., 1994) and Megachile rotundata in field cages *(Tependino,* 1997) has been introduced with success for hybrid seed production of carrot. For the pollination of hybrid carrot Megachile rotundata females are regarded to be equivalent to 100 worker honeybees *(Tependino,* 1997).

No information had been available on *the pollination of caraway,* Carum cavi. The first report on the subject was published by *Bouwmeester & Schmid* (1995). Caging of field plots to prevent insect pollination reduced seed yield by 15–20%, but in normal field conditions more than 90% of the hermaphrodite flowers were fertilized.

Medicinal and aromatic plants

Most medicinal and aromatic plants very probably need insect pollination, since almost all of them have "insect-type" flowers. In spite of this, no detailed information is available on their pollination requirements and on the effect of insect activity on the yield, except very few data on American ginseng, castor, lavender, medicinal poppy and peppermint *(Free,* 1993). Accordingly, it is noticeable that the foraging activities and the pollinating efficiency was investigated lately on 5 medicinal plant species in Korea (*Rosa multiflora, Poncirus trifoliata, Crataegus pinnatifida, Ziziphus jujuba, Zanthoxylum schnifolium*), each of them had a higher fruit yield when insect pollinated. The main insect visitors of flowers were dipterans and bees. Honeybees were dominant on all but one species; the latter was frequented mainly by dipterans *(HyungRae* et al. 1995). There are a number of medicinal plants, which are utilized as fruits or propagated reproductively by means of seed. For this reason, intense research would be needed to explore their pollination requirements, the structure of their flower visiting insect populations, the foraging behaviour of pollinators, the effect of insect pollination on yield, on seed production as well as on the quality.

Field crops

Seed production of fodder legumes: Lately Richards (1996a) published a comprehensive review on the comparative efficacy of bee species for pollination of legume seed crops. Re-evaluating the pollination requirements of the crops involved and the efficacy of their pollinators, he emphasized that a comparison of non-Apis bees and honeybees was needed to meet growers' expectations concerning pollination in sustainable agriculture.

Clovers: The corolla tube of red clover flowers is known generally to be too long for nectar gatherer honeybees. For this reason, the selection of red clovers with shortened corolla is an old project in many countries. Researchers in Poland have been successful in this respect. They discovered a short corolla tube mutant decades ago and they spent 36 years to obtain a stabile, short corolla tube genotype, which made nectar easily accessible to honeybees. Thus honeybee visitation is some 12 times more intense than at traditional, long corolla red clover lines, which resulted in seed yield at least one third higher *(Jablonski,* 2001). It is a general rule that long corolla tube fodder legumes can more effectively be pollinated by long tongue bees (wild bees). On the other hand, at white clover, which is a short corolla legume crop, long tongued bumblebees were less effective pollinators than short tongue ones, perhaps because the longer tongue bees obtained nectar more rapidly with less contact with the stigma *(Williams & Marshall,* 1997). Honeybees can be utilized in breeding programs, to produce seed of valuable breeding material in greenhouses during the winter *(Zaryanova,* 1989).

Lucerne: Lucerne is an exception among cultivated field crops in Europe, because it fails to benefit honeybee visits for pollination. The unique, irreversible tripping mechanism of its flowers is extremely unpleasant to honeybees, so they try to avoid it, if possible. Side working nectar gathering is the solution. In temperate climate (first of all in Europe) the vegetation is always rich enough, enabling honeybee colonies to gather pollen from other, more easily accessible sources, but under semiarid and arid conditions, where even seed lucerne must be irrigated, no other pollen source is available and therefore they are forced to open flowers for gathering pollen at lucerne (discussed in *Benedek* 1972). Some authors argue lately for the importance of honeybees in lucerne pollination in Brazil and Bulgaria *(Dequech & Becker,* 1990, *Dimitrov & Dimitrova,* 1994). However, an analysis of stored pollen samples of more than one hundred honeybee colonies situated in lucerne crops showed very poor representation of lucerne, indicating that it is not an attractive pollen source of honeybees in Europe *(Warakomska* et al., 1994). For this reason wild bee activity is needed for a good crop at lucerne fields grown for seed. Should there be no wild bees nest inside the lucerne fields, the wild bee visitation will greatly be correlated with the distance of the lucerne fields from wild flowers, e.g. in Canada where bumblebees and megachilids are the most abundant *(Brookes* et al. 1994). In Europe, however, caged bumblebees alone seem to be less effective in lucerne pollination than mixed wild bee populations at open pollinated plots *(Gosek,* 1993). Bee activity affects the number of open flowers during the flowering period of lucerne fields grown for seed, namely the decline in open flowers during the flowering period is at least a partial consequence of intense pollinating activity of bees *(Strickler,* 1997). Consequently seed yields are maximized when pollination occurs rapidly and completed quickly due to high density of bees effective in the pollination of lucerne flowers.

Faba beans: In the case of faba beans no doubt about the benefit of bee pollination, but substantial yield can also be achieved with no bee activity *(Free,* 1993). This was confirmed by a number of publications in the past decade, too, however, some differences were found among cultivars. Insect pollination had no effect on seed production or abortion rate of a self-fertile line, but insect visitation was necessary to reduce abortion and to increase yield at a line with low self-fertility *(Guen* et al. 1993). Similar differences between cultivars were recorded in Poland, but the results were also affected by the weather *(Koltowski,* 1996). No differences were found in the pollination efficiency of honeybees and bumblebees *(Mesquida* et al., 1992). At regions with abundant bumblebee populations the daily activity of honeybees seems to be most numerous in the afternoon, while the number of some Bombus species (B. subterraneus/hortorum) seems to increase and those of others (B. lucorum) decrease towards afternoon *(Varis,* 1995). The behaviour of bees, however, may be different at regions with different conditions, since bees moved more frequently from plant to plant in Spain where bee abundance was 32 times higher at field bean crops than in France *(Pierre* et al. 1999).

Production of hybrid seed of faba beans is a new development. Using honeybees is a less expensive and less time-consuming mode of pollination in large-scale breeding programmes than manual crossing *(Rashid & Bernier,* 1994).

Sunflower: Several papers corroborated the well known fact that sunflower produces much more seeds per head with than without bee pollination and that honeybees are the most abundant visitors of flowering sunflower fields. *Meynié & Bernard* (1997) found significant difference between the pollinating efficiency of different bees at sunflower inflorescences. They found Bombus terrestris to be the most effective (106%), Megachile rotundata and Calliphora spp. to the less effective (77, 73%), while honeybees were intermediate (88%). Several authors agree that honeybee activity starts early morning at sunflower fields and there is a morning peak in bee activity between 9.00-10.00, 8.00–11.00 or 9.00–11.00 *(Hoffmann,* 1994, *Arya* et al., 1994, *Kumar* et al. 1994) or around noon *(Ortiz-Sánchez & Tinaut,* 1994). One other afternoon peak also existed in some studies *(Toit & Holm,* 1992) and bees forage sunflower up to late afternoon *(Kumar* et al. 1994, *Toit & Holm,* 1992). Examination of returning foragers revealed that pollen foraging predominated up to 9.00 and nectar foraging prevailed thereafter *(Toit & Holm,* 1992), but at other places the pollen collection was maximal around noon, and foraging pattern was correlated with air temperature, but not with nectar secretion *(Ortiz-Sánchez & Tinaut,* 1994). Pollinating insects may be more abundant at different cultivars or hybrids *(Arya* et. al., 1994a) and the effect of insect pollination may be different at different types of sunflowers *(Arya* et al., 1994b). This may be related to the considerable differences shown in the nectar production of sunflower cultivars *(Holm,* 1992, *Kamler*, 1997), because cultivars secreting the most nectar received most honeybee visits *(Kamler,* 1997). In the Czech Republic, honeybee colonies moved to sunflower crops gave a large honey harvest *(Kamler,* 1997). On the contrary, in Italy, sunflower was not a particularly good nectar and pollen source for honeybees *(Zandigiacomo* et al., 1993), no more than 52–76% of the pollen came from sunflowers at bee colonies moved to flowering sunflower crops and 4–14% of the pollen was of Trifolium repens and 9–23% of Phacelia tanacetifolia in the pollen traps fitted to the hives. In dry weather the amount of nectar may be rather low with high sugar concentration and the result may be a loss of weight in honeybee colonies during the days of the flowering period of sunflower crops *(Hedtke,* 1996).

Hybrid sunflower seed production is a special problem in pollination. Bees foraging on male-sterile lines collect nectar; whereas, on male-fertile lines most of them gather pollen *(Sinha & Vaishampayan,* 1995). The most important problem is how often pollinating insect carry pollen from male fertile lines to male sterile ones. DeGrandi-Hoffman and co-workers contributed to this issue most. They established that when equal number of male-sterile and male-fertile rows was planted, all honeybee foragers had some sunflower pollen on their bodies. When male-sterile rows outnumbered male-fertile ones, majority of honeybees also had sunflower pollen on body hairs but the amount was significantly less as the distance from male-fertile rows increased. As a consequence, the seed set decreased with the distance from the male-fertile line. Seed set of male-sterile rows adjacent to male-fertile ones did not differ that of male-fertile plants, but it decreased further away *(DeGrandi-Hoffman* et al., 1993): The number of honeybees flying from male-fertile- to male-sterile rows varies between some 6–13% only, so pollen transfer in the hive may be a component in the creation of cross-pollinating honeybees. However, honeybees that forage only on male-sterile plants apparently obtain much of the sunflower pollen on their bodies from previously visited male-sterile heads, that had been transferred from male-fertile rows, so most foragers did not need to visit male-fertile rows first or receive pollen in the hive in order to cross pollinate sunflower *(DeGrandi-Hoffman & Martin,* 1995). They spread this pollen as moving along the male-sterile row. The amount of sunflower pollen on honeybee foragers was positively correlated with the size of non-Apis bee population *(DeGrandi-Hoffmann & Watkins,* 2000) but not with the size of the foraging population of the colonies *(DeGrandi-Hoffman & Martin,* 1995). This fact suggests that mixed bee population might be more effective in the pollination of hybrid sunflowers than honeybees alone. However, in mixed populations not all bee species visit necessarily both male-fertile and male-sterile rows. For example in a study in India 3 Apis species and Trigona iridipennis frequented both male-fertile and male-sterile heads, but Apis dorsata and A. florea confined themselves to male-fertile rows *(Rao* et al., 1996).

Brassicas: An excellent review appeared recently on the bee pollination of canola, which covers the latest results on winter rape pollination, too *(Westcott & Nelson,* 2000). It was clearly outlined that Brassicas can produce substantial seed yield in lack of bee pollination, but insect pollination can increase the yield at least to some extent and the activity of pollinators leads to a number of advantages which improves the quality of the seed. It is interesting to notice that differences were found in the structure of pollinating insect population at the two oilseed Brassica species; however, the total pollinator abundance was similar *(Brunel* et al. 1994). Namely, more dipterans were found on B. campestris, and honeybees were much more numerous on B. napus, while bumblebees and solitary bees were present at a similar quantity on both. Besides honeybees alfalfa leafcutter bees are being utilized for canola pollination *(Westcott & Nelson,* 2000). These two bees were compared recently to Osmia cornifrons for controlled pollination of Brassicas and it was found to be at least as effective or even better than the other two species *(Wilson* et al., 1999). In fields for hybrid rape seed production foraging honeybees are known to concentrate on male lines, and the importance of nectar production is also known to affect bee densities *(Westcott & Nelson,* 2000). At apetalous strains, however, this difference was not demonstrated, but honeybees were much more numerous at apetalous strains, they showed constancy towards the two flower types, and so flights between types were not frequent *(Pierre* et al., 1996). Unfortunately bees typically fly from one plant to another nearby in the same row *(Cresswell* et al., 1995).

Buckwheat: Buckwheat belongs to the less studied field crops for pollination. Its flower visiting insect populations are largely changeable in structure and density. This is reflected in some latest studies. Honeybees were most abundant among insect visitors in the USA *(Björkman,* 1995) and in Germany *(Hedtke & Pritsch,* 1993), but flies dominated (83%) in Korea *(HyungRae & MiHyun,* 1997). The presence of honeybees increased grain yield by 50–80% in Korea *(HyungRae & MiHyun,* 1997) and Taiwan, resp. *(ChiTung & MeiLig,* 1994). In the USA, however, honeybee visits are considered not to increase daily seed initiation, in spite of the fact that those flowers were frequented fairly often. It is concluded that the behaviour of honeybees is not well adapted to this crop *(Björkman,* 1995).

Flax: Contradictory results can be found on flax pollination in the literature *(Free,* 1993). In a controlled experiment in the UK lower honeybee visits to flax resulted in earlier petal fall, but no increase was noticed in seed production *(Williams* et al. 1991). It is concluded therefore that the crop is self-fertile, self-pollinates well and inadequate pollination is not a factor limiting yields. Hence, there is no reason to hire colonies for pollination, as concluded by *Free* (1993).

Genetically modified (GM) crops

The risk of spreading modified genes of GM crops to non-modified cultivars within the same crop species and also to their wild (rather often weedy) relatives has been evaluated recently by *Williams* (2001). All research on bee-mediated pollen flow is closely related to this topic and the results gained from this work can serve as a theoretical basis to research on the pollen flow originating from GM crop fields. All theoretical considerations on the pollen and gene dispersal from GM crops to other plants, however, should carefully be checked in real situations. In spite of the theoretical and practical importance of this problem, very little research has been made so far specifically on this issue.

It has been established that the attractiveness of transgenic and traditional rapes seem to be fairly similar to honeybees *(Anchling,* 2001), however, some lines can produce more or less nectar or pollen than other cultivars (see in *Bailez* et. al., 1993, *Picard-Nizou* et al., 1995), but this is a normal pattern even among conventional cultivars or hybrids. Some authors investigated if transgenic oilseed rape influences the activity and the foraging behaviour of honeybees. There is a general agreement so far, that honeybee behaviour is similar on transgenic rape crops and on its traditional cultivars *(Bailez* et al., 1993, *Picard-Nizou* et al., 1995). Analysis of the contents of pollen traps and of honey showed that when bees were foraging on winter rape, they visited very few other plant species, but when visiting summer rape, they also exploited a number of other plant and this fact shows that bees can disseminate pollen from transgenic spring rape *(Anchling,* 2001). The risk of transgene dissemination by leafcutting bees was studied on lucerne *(Amand* et al., 2000). Results indicated: the leafcutter bees show a directional, non-random bias when visiting flowers within the fields, resulting in the movement of pollen directly towards and away from the bee domicile. Within-field pollen movement was only up to 4 m or less, but dispersal of pollen between fields occurred at distances up to 1000 m.

Similar studies with other crops are greatly needed to calculate reliable minimum isolation distances for GM crops. Also the effectiveness of using trap crops and other suggested methods to prevent or at least minimize the risk of gene flow from GM crops to traditional cvs of the same species (see in *Williams,* 2001) should be carefully studied. However, pollination studies with GM crops are difficult to organize in many cases, because field studies are often prohibited for safety reasons. Therefore, the problem should be approached by model experiments as *Pierre* (2001) has done for example, investigating the risk of pollen flow from oilseed rape to its weedy relative, wild radish. She has found that honeybees and Bombus terrestris were more constant to rape, whereas Bombus lapidarius to wild radish. This led to a relatively low frequency of movements between the two plant species. Accordingly, the flower constancy of bees effectively prevented the direct gene flow between the two plant species.

Improving the efficiency of honeybees in crop pollination

A number of techniques have been known to increase the pollinating efficiency of honeybees by increasing the bee visitation to target crops, increasing the ratio of pollen collecting foragers, improving their pollen dispersal, and so on *(Free,* 1993).

However, to increase the bee visitation of the target crop is rather a hard task, hence it depends on several characteristics of the crop and of cultivated or wild plants grown in the surroundings, on the food demand of the honeybee colonies, and of course, on the weather. This may be the explanation why a number of different methods, neither the application of bee attractants, nor sequential introduction of colonies to the flowering crop, nor feeding bees, nor diluting the nectar with overhead irrigation, nor interplant alfalfa increased the number of honeybees and increased the yield significantly at seed onion fields *(Mayer & Lunden,* 2001).

On the other hand, *Winston & Slessor* (1993) reviewing their results on the recognition and the use of the queen mandibular pheromone (QMP), predicted that its most significant commercial application would be in crop pollination. This statement was based on good results obtained in field experiments. Spraying flowering crops increased the number of honeybees foraging on apple, pear, cranberry, and blueberry *(Currie* et al., 1992a, 1992b, 1994, *Higo* et al., 1995, *MacKenzie,* 1992). The effect of QMP, however, is greatly dependent on dosage and partly on crop. Namely, 0.1 queen equivalents/ha was ineffective, but 1000 was effective on apple and pear *(Currie* et al. 1992a), the same dosage failed to increase bee visits on sweet cherry *(Naumann* et al. 1994), while 100 was the most effective on cranberry and 100 was as effective as 1000 on blueberry *(Currie* et al., 1992b). In other instances, with pear and apple, QMP application increased only fruit sizes without actual yield increase, and this still resulted in higher profits *(Currie* et al., 1992, *Naumann* et al., 1994). On he contrary, on sweet cherry a negative correlation arose between bee visits and fruit size. These experiences, however, are not consistent enough, and therefore further research is needed on this topic, not only in the US but also in other countries with different weather conditions. Also, the profitability of the method should be analysed, as its acceptance in the practice depends on its profitability. There is one other, cheaper kind of application of QMP in crop pollination, because the pollination value of queenless "disposable" pollination units can be improved when QMP is added, which may increase the foraging activity; moreover should brood be present, even pollen collecting activity is increased *(Currie* et al., 1994). Other kinds of bee attractants (e.g. Beeline, Be-Q, Beehere, lavender oil, citral, geraniol, etc.), however, did not increase the bee visitation at a number of different crops *(Ambrose* et al., 1995, *Mayer & Lunden,* 1997, *Neira* et al. 1994, *Ortiz-Sanchez,* 1993, *Sing & Sinha,* 1996, *Zvedenok,* 1996).

As in-hive pollen transfer is recognized to be an important factor in pollen dispersal among compatible but self-sterile or self-fertile but readily cross-fertilizing cultivars of some crops (e.g. *Dag,* 2001, *DeGrandi-Hoffman* et al., 1984, *DeGrandi-Hoffman & Martin* 1993, 1995, *McLaren* et al., 1996), the methods increasing pollen exchange between foragers of the honeybee colonies can be regarded to be very important. Following the pioneer work of *Free* et al. (1991), several kinds of hive entrance devices were used lately to brush pollen from incoming and deposit on departing bees *(Hatjina,* 1996, *Eijnde,* 1995, *Szalai,* 2000). This type of research should be continued in order to develop the most effective devices without harming foragers and without decreasing germination capacity of the pollen.

However, the mechanism and the effectiveness of in-hive pollen exchange are not adequately studied and its role in crop pollination is probably underestimated. Latest research on the fruit set of large single-cultivar blocks of apple indicates that in-hive pollen exchange (or possibly carrying pollen on the body hairs of bees from one foraging trip to the next) could be much more important in the effective pollination of orchards than believed so far, because even large and very large single-cultivar blocks in apple plantations can sometimes effectively be pollinated in lack of pollinizer cultivars inside the block *(Blažek,* 1996, *Benedek* unpublished). Therefore, the in-hive pollen transfer among bees needs to be studied thoroughly with fruit trees and other crop plants.

Recently, the role of electrostatic charges for non-contact pollen detachment between pollinating honeybees and flowers is confirmed, and this can be utilized for supplementary pollination in commercial production *(Vaknin* et al., 2000), this new approach, however, needs further research to base commercial implementation.

Managing wild bees and other insects for crop pollination

Managing and utilizing wild bees as pollinators attract more and more interest, because some wild bees are relatively easy to manage and they posses several advantages as pollinators compared to honeybees. The subject has been surveyed lately in two excellent reviews *(Richards,* 1993, *Cane,* 1997).

Lucerne leafcutting bee and bumblebees: Most research on wild bee management for crop pollination was made with lucerne leafcutter bee and bumblebees. Managed lucerne leafcutting bee, Megachile rotundata, has been used for crop pollination for decades. Its rearing techniques have been improved in some minor details lately *(Goerzen & Watts,* 1991, *Goerzen & Murrell,* 1992, *Rand & Rank,* 1990, *Richards,* 1996b). The commercial usage of bumblebees has become a practice in the past fifteen years. Their rearing techniques are well based by many research and the methods are well elaborated *(Ruijter* 1997a, 1997b). Both Megachile rotundata and Bombus species are used to pollinate more and more field crops and fruits as well as vegetables and small fruits outdoors and under cover (see for example *Fairey & Lefkovitch,* 1993, *Richards,* 1995, *McKenzie,* 1997 for Megachile, and *Ruijter,* 1997a, *Mayer & Lunden* 1997a, *Dasgan* et al., 1999 for Bombus). As an interesting concept, selective breeding of lucerne leafcutter bee has been initiated in Poland increasing its body sizes from 8–9 to 9–10 mm for better pollination of lucerne *(Ruszkowszki* et al., 1996). The practical utilization of the leafcutter bee and the bumblebees does not need too much future work, with the exception of establishing and rearing indigenous Bombus species, instead of using Bombus terrestris and other successfully reared European species outside of Europe.

Solitary bees other than M. rotundata: More and more attention is paid to rear different mason bees and other bees for pollination. In temperate regions, Osmia cornuta seems to be the most promising mason bee to this purpose. Its normal seasonal activity starts very early spring, and coincides well with the flowering period of fruit trees *(Bosch* et al., 1993). There are some serious parasites that can restrict its population size *(Bosch,* 1992, *Bosch* et al., 1993). Pollen collected for provisions show that the species prefers to collect Prunus pollen, and switches to Malus pollen when it is more readily available *(Márquez* et al., 1994). It is calculated that during almond flowering, each female potentially visit as much as 9.5 to 23 thousand flowers, and therefore 3 females/tree are sufficient for almond pollination *(Bosch,* 1994a)! Cocoons were exposed to different overwintering and incubating temperatures trying to manipulate the time of emergence but with little success so far *(Bosch & Blas,* 1994). Suitable nesting material was searched for *(Bosch,* 1994b, 1995), but further research is needed. Osmia cornuta has been tried to be used for blackberry pollination in plastic tunnel with success *(Pinzauti* et al., 1997). Very probably it will be suitable to pollinate other fruit crops too, hence this issue also needs further studies.

One other closely related species, Osmia rufa was used with success to pollinate onion seed crops, fennel and carrot in breeding cages *(Matuszak,* 1995). This species, however, exploits much wider range of pollen sources than O. cornuta. The food stored in the nests contained the pollen of 25 different plant species in a study in Italy; hence this bee is regarded as unsuccessful for orchard pollination but might be successful for a number of crops under cover *(Ricciardelli d'Albore* et al., 1994). Some other mason bees, Osmia lignaria propinqua, O. californica, O. montana were also successfully managed for mobile orchard pollination in the US *(Torched,* 1991), and O. cornifrons for Japanese pear and apple pollination in the Far East *(Maeta* et al., 1993, *DooHyun* et al., 1996, *Sekita,* 2001). There are some additional proposals to manage some other solitary bees for crop pollination; Andrena flavipes – which also occurs in Europe – was proposed to manage in India *(Abrol,* 1993) and Anthophora pilipes villosula in Japan *(Batra,* 1994).

Stingless bees for pollination in enclosures: Honeybees are utilized for a long time in the production of vegetables, first of all under cover *(Free,* 1993). This is an effective and profitable method in most cases, but honeybees cannot work effectively at low temperatures. For this reason the use of managed bumblebees become more and more widespread in the past fifteen years, since they are at least as effective as honeybees but are able to work the flowers even at much lower temperatures *(Griffiths & Robberts,* 1996). Bumblebees, however, are sensitive to high temperatures. Their pollination efficiency can last for 2 months in heated greenhouses in the cold season of winter (December–February), but their activity and survival reduces dramatically down to 30–50 days only, when the temperature increases to 40^o or higher in the glasshouse in mid-April or later *(ChiTung & FengKong,* 1996, *Palumbo* et al. 1996). For this reason, trials were initiated with stingless bees in greenhouses. The first experiments in Japan and Korea indicated that if sufficient food is available, stingless bees can successfully be managed even at relatively high temperatures, suggesting that they are potential pollinators of greenhouse crops *(Maeta* et al. 1992, *KunSuk* et al., 1996). Further studies were made in Costa Rica with good success *(Slaa* et al. 2000, *Sánchez* et al., 2001). Hence, this method seems to be promising for the future, but further research is needed to solve technical details of rearing and transport for large-scale commercial pollination.

Landscape management of wild bees for pollination: Changes in land management and changing agricultural practices have affected natural wild bee communities in agricultural areas. Generally an overall decrease is expected *(Williams,* 1994) but this is not always the case. In Hungary, detailed studies over a 25 years' period on the specific structure and the population densities of pollinating wild bees on flowering lucerne fields (comprising close to 150 different species, some 30 of them being common at most places) have shown that changes were unfavourable to some wild bee species (mainly to Eucera spp.), and as a result, their densities decreased dramatically over time, however, the population densities of other wild bees (Melitta leporina, Rhophitiodes canus) increased simultaneously, the changes being favourable to them, and a number of other wild bees (e.g. Andrena, Halictus, Bombus spp.) were not affected definitely *(Benedek,* 1972, 1997). The main reasons of the changes in wild bee populations were as follows: overall changes in the concentration of seed lucerne production (big fields instead of small ones), decrease of leguminous and labiate food plants of bees (for chemical weed control), gap in the continuous food supply for wild bees prior to and after the flowering period of lucerne fields (for mechanical weed control on road sides and around arable fields). Harmonizing agronomical and plant protection practices on a landscape level with the nesting activity of a wild bee, Rhophitiodes canus, a massive increase of its population density was attained in the former Czechoslovakia *(Ptaček,* 1984, 2001). Similar result were obtained in Hungary by sequential mowing of seed lucerne fields over an area, thus providing unbroken feeding possibilities to wild bees being oligolectic on lucerne, Melitta leporina and Rhophitiodes canus, for at least a two months period, which completely covered their flight period (Benedek unpublished). Similar changes can be expected to the pollinator wild bee communities at other parts of Europe and at other crops; bee communities being very sensitive to any changes in the environment. Accordingly, research would be needed to explore changes in lucerne pollinating wild bee populations in those countries, where wide-scale surveys were made in the past decades, first of all in Hungary, Czech Republic, Poland and France.

Additionally, a monitoring scheme should be established in European countries to survey the present state of pollinating wild bee communities of selected crops and to check the changes in their structure in the future to propose landscape management techniques to avoid unfavourable changes. In fact, pollinating wild bees could have been a very good indicator of the state of the environment in agricultural areas, as their food sources (cultivated and wild plants) and nesting possibilities can greatly be influenced by agricultural practices and pest control can also affect their populations.

Syrphid flies: Recently a successful experiment was made to pollinate sweet pepper with a syphid fly, Eristalis tenax, in a greenhouse *(Jarlan* et al., 1997). Insect visits resulted in a greater percentage of heavier fruits with higher seed set, the longer duration of insect visits significantly increased both. Hence, the use of Eristalis in the pollination of greenhouse sweet pepper may be promising, but further research is desirable.

A need of controlled bee pollination

As successful pollination may be a limiting factor of a good yield, growers would like to know how many honeybee (or bumblebee) colonies are needed and how to organize them for optimal pollination at the field. We can give general instructions based on experiments and/or measurements about timing the placement and the arrangement of the location of the bee colonies inside or round the target crop, but the number of bee colonies needed is much more difficult to define on a reliable basis.

On the other hand, the recommendations on the stocking rates of bee colonies needed to pollinate the crop plants are based on assumptions rather than on experimental results. There is very little information in the literature how to estimate the necessary number of bee visits/flower or the necessary bee density/per unit area of optimal pollination or about the optimal set of various crops (the examples are sunflower, cotton, hairy vetch as well as fruit plantations to some extent: see in *Free,* 1993). This kind of information would, however, be very important in the practice, because not only the inadequate activity of pollinating insects, but their excessive activity can also be disadvantageous to the yield.

The unpleasant consequences of oversetting, numerous but too small fruits, poor quality, the need of laborious and expensive thinning, are well know for some fruit trees in the practice, for peach and nectarine for example. Lately, both insufficient and excessive visiting of bees (honeybees and bumblebees) for pollination of strawberry have been found to be undesirable, both causing faulty pollination under cover. A density of 10–15 thousands of worker bees/1000 sq. metres in plastic tunnels or glasshouses is recommended, but neither the lower nor the higher densities are desirable *(Lieten,* 1993). Similar results were obtained with cucumber; fruit set and the number of filled seeds were the higher when there were some 0.5 honeybee colonies per some 2000 plants, reduced number of bees was resulted in lower yields, on the contrary overpopulation caused so strong competition for flowers (for pollen) which reduced the yield *(Cervancia & Forbes,* 1993). In the case of sunflower crops some 10 thousand bees/hectare was found to be optimal for pollination in Hungary, however, increased bee visitation did not affect the yield *(Benedek* et al., 1972). Similarly, additional extra hives at flowering pear increased bee numbers in the orchard, but not the fruit set in New Zealand *(McLaren* et al. 1996).

For this reason, it is important to explore the relationship between the number of bee visit/flower and the set. In the case of pumpkin, for example, latest results show that some 10 insect visits are needed that enough pollen grains are deposited onto the stigma needed for a good set *(Masierowska & Wien,* 2000). In the case of squash each plant requires at least one honeybee visit during the optimum pollination time (that is between 06.00 and 09.00 in this case) *(El-Fattah,* 1991), and some 5–6 bee-visits/flower are needed for maximum productivity of raspberry *(Oliveira* et al., 1991). Based on experimental results 6–12 bee visits were necessary in Hungary during the life of a single apple flower to set a fruit *(Benedek* et al. 1989). Both fruit set and quality were related to the number of bee visits/flower in experiments with apple in Canada, but an other experiment gave inconclusive result due to overall poor fruit set caused by bad weather *(Brault* et al., 1995).

In fact, the present practice to move certain number of bee colonies to the target crop just prior to, or at the start of flowering, and to leave them on site until petal fall, is an inadequate solution to crop pollination problems. This can be exemplified by a sequential introduction of honeybee colonies to pear pollination; namely, placing additional bee colonies in pear orchards at 50% flowering resulted in more bees visiting the flowers for at least one day which significantly increased fruit set in 10 out of the 14 experimental orchards *(Mayer,* 1994). However, growers need some kind of method, as simply as possible, to decide if they should do something with bees during the flowering period of crops. A simple solution was suggested in Hungary. Taking some factors, the number of bee visits per flower necessary to set a fruit, the length of the receptive period of the flowers, the required ratio of fruit set and the patters of the daily bee activity into account, 3–6 bee visits per 50 opening flowers during a ten minutes period was recommended as the optimal intensity of bee visitation in apple orchards to get a good crop *(Benedek,* 1996). The growers were recommended to control the intensity of bee pollination during the flowering period and to move additional colonies to the orchard immediately, when the bee visitation was much lower than the proposed optimal level thus avoiding insufficient, low sets. At other instances, however, excessive bee visitation was decreased during the flowering period to avoid unwanted oversetting at some crops. This kind of bee pollination management should be implemented during the flowering period of crops, which would lead to controlled bee pollination in the agriculture.

Consequently, intense research is needed to base controlled bee pollination experimentally for those crop plants, of different fruits first of all, where lower and higher than optimal sets are equally undesirable for profitability reasons. Growers should be recommended to carry out simple observations or should be given sophisticated, but user-friendly computer simulations, as the well-known PC-REDAPOL for example, which can reliably predict the apple yield *(DeGrandi-Hoffman* et al., 1995). This enables growers to decide what to do during the flowering period for the optimal pollination of their insect pollinated crops. The problem is especially crucial in the new type, high density orchards with semi-dwarf or dwarf fruit trees being the productive life much shorter, 10 to 15 years at most, than of traditional, large crown fruit plantations, which can stand and produce fruit for decades. During the short productive period of high density orchards no single year with bad yield or with bad fruit quality can be suffered, because the investment cost of this type of orchards is very high and also their cultivation is much more expensive than of a traditional plantation, consequently the production must be profitable each year of their short productive life. Accordingly, pollination must not be an unstable element of their management system.

There is a host of factors affecting the general behaviour of bees towards the rewards that different crops and competing other plants, flowering simultaneously offer to them. Other environmental factors affect also the foraging behaviour, and consequently the pollinating efficiency of bees visiting the flowers of crop plants (more of social than of solitary bees). Weather and competitor plants seem to have the most decisive influence on bee activity. The effect of weather conditions is fairly well known, but the effect of competing plant species is contradictory and confusing. Lately, even massive appearance of flowering dandelion, that is known to have very strong competitive effect on honeybees in fruit orchards, failed to affect bee visitation in pear orchards, neither sour cherry attracted bees from pear *(Benedek* et.al, 1998). There are some other indications that the effect of competitor plants is not sufficiently explored, accordingly this item needs further studies to understand why certain plant species are strong competitors in some cases and no similar effect can be recognized at other instances.

Pesticide usage and bee pollination

Pesticide usage and bee pollination of crops has been a matter of conflict for a long time. This is a fairly well studied topic, which has been dealt with in more than 150 papers worldwide only in the past decade. The problem, however, has recently been reviewed *(Benedek,* in press), and the conclusions are summarized below instead of a detailed analysis of the subject here.

Pesticide usage during the flowering period may affect the fruit set and the yield in two different ways. One of these is indirect, because pesticides can cause serious bee losses and, consequently, inadequate insect pollination. It is clear that some pesticides are greatly harmful to bees when applied on flowering crops while others are not risky at all. Information on the risk of pesticide usage to bees is adequate to decide whether a pesticide can be used in flowering crops safely.

Vast majority of the information on the effect of pesticides to pollinators is related to honeybees, and rather few studies have been made with wild bees. Therefore, more attention should be paid on the effect of pesticides on wild bees in future research (see for example *Mayer* et al., 1993, 1994, *Schaefer* et al., 1996, *Mayer & Lunden,* 1997b). There are two other subjects that need more detailed research. One of this is the sublethal effect of different pesticides to different kinds of bees (e.g. *Tasei* et al., 1994, *Peach* et al., 1995), because it can affect their pollinating efficiency. The other subjects is the possible synergism between different compounds, the importance of which has been recognized lately *(Colin & Belzunces,* 1992a, 1992b *Pilling,* 1992, *Belzunces & Colin,* 1993, *Pilling & Jepson,* 1993, *Meled* et al., 1998). This is very important because almost no information is available on the effect of pesticides mixtures to bees, however, their effect on bees can be greatly different than the effect of the mixed compounds alone (see in *Benedek,* in press). Much more information would be needed on this issue because it is very seldom the case when pesticides are applied alone in the practice, contrarily most often at least two or rather 3 to 4 four different products are used together as a tank mix.

Pesticides, however, also have a direct influence on the fruit set and yield since, pesticides, first of all fungicides may affect the germination and the pollen tube growth of pollen grains. For this reason, fruit growers claim reliable assessments of the risk of pesticide usage during the blossoming period to the fruit set and the yield of the orchards affecting pollen behaviour and the pollination success.

In spite of intense research, however, we are far from having understood the whole problem, as the results are dependent on the method, on the environmental conditions and also on the fruit species and sometimes possibly also on the cultivar (see in *Benedek,* in press). The best reproducibility is obtained from experiments performed in the laboratory, but *in vitro* experiments always give results witnessing much stronger effects than *in vivo* tests. Although field conditions are much better imitated by *in vivo* techniques than by *in vitro* ones, many products that proved to be harmful in the laboratory had a scarcely perceptible effect in field experiments. Nevertheless, there are a considerable number of products that significantly decrease the fruit set after field applications. In other cases the field data are contradictory, which cannot be explained convincingly by differences in the susceptibility of the species or cultivars. We are still unable to assess the risk of pesticide usage on fruit set due to the direct effect of pesticides on the pollen and the pollination success. The evidence available is still insufficient to distinguish between fruit species or cultivars according to their susceptibility to particular compounds, but we have enough reason to postulate some differences of that type. Accordingly, intense research would be needed to clarify the effect of pesticides reliably to the pollen germination and the fruit set of fruit tree species.

Conclusions

Based on the above discussion there seem to be a number of topics that greatly needed intense research in the near future to improve the knowledge on as well as the technology of the insect pollination of crop plants cultivated in temperate zone regions. These are partly related to the pollination requirements of selected crops and to managing some solitary wild bee species for crop pollination. The problems, however, concentrate on the effectiveness of bee visits in the pollination of individual crop plants (and their different cultivars) and on the reliable estimate of the stocking rates of bees for crop pollination as well as on the management of actual bee density during the flowering period of crop plants for optimal controlled bee pollination. Additionally, there are some selected problems on the effect of pesticides to bees being especially important from the point of view of crop pollination; but scarcely studied so far because bee poisoning has been dealt with first of all from the beekeepers' point of view but not from the point of view of crop pollination. The following topics are proposed as the subject of further research in the coming years:

1. Pollination requirements of crops and the pollinating efficiency of bees

- Further studies are needed on the flower constancy of honeybees on fruit trees as related to their pollinating efficiency.
- The pollinating efficiency of honeybees on self-incompatible fruit tree species should be re-evaluated by investigating the gene flow with isozyme markers.
- The pollination requirements of those European medicinal and aromatic plants should be explored which are utilized as fruits or propagated by means of seed. Their flower visiting insect populations should been studied and also the foraging behaviour of the pollinators and the effect of insect pollination on their yield as well as on the quality.

2. **Genetically modified (GM) crops**
   - Studies are needed to calculate reliable minimum isolation distances for GM crops.
   - Effectiveness should be studied of using trap crops and other suggested methods to prevent or minimize the risk of gene flow from GM crops to traditional cvs under field conditions.
3. **Improving the efficiency of honeybees in crop pollination**
   - The effect of the queen mandibular pheromone sprays is to be studied further to increase the pollination efficiency of honeybees at target crops in flower.
   - Further research is needed on the mechanism and the effectiveness of in-hive pollen exchange among honeybees during crop plant pollination.
   - Further research is required to develop the most effective devices increasing pollen exchange between foragers of honeybee colonies for pollination.
4. **Managing wild bees and other insects for crop pollination**
   - Further research is needed to develop rearing techniques for commercial usage of the European orchard mason bee, Osmia cornuta, for fruit tree pollination. One other closely related species, Osmia rufa, might be successful for a number of crops under cover.
   - Repeated survey would be needed to explore changes in lucerne pollinating wild bee populations in those countries, where wide-scale surveys were made in the past decades.
   - A monitoring scheme should be established in the European countries to survey the present state of pollinating wild bee communities of selected crops and to check the changes in their structure in the future to propose landscape management techniques to avoid unfavourable effects.
5. **A need of controlled bee pollination**
   - Intense research is needed to base controlled bee pollination experimentally for those crop plants, of different fruits first of all, where lower and higher than optimal sets are equally undesirable for profitability reasons. Growers should be recommended to carry out simple observations or should be given sophisticated, but user-friendly computer simulations to manage flower visiting bee populations at an optimal level during the flowering period of insect-pollinated crop plants.
   - Further studies are needed on the effect of competing plant species to understand why certain plant species are strong competitors in some cases and no similar effect can be recognized at other instances.
6. **Pesticide usage and bee pollination**
   - More attention should be paid on the effect of pesticides on wild bees in future research.
   - Sublethal effects of different pesticides to different kinds of bees need more detailed research, because it can affect the pollinating efficiency of bees.
   - Research is needed on the effect of frequently used pesticide mixtures on pollinating insects and further research should be made on the possible synergism to pollinating insects between different compounds.
   - Intense research would be needed to clarify the risk of pesticides usage on the pollen germination and the set of fruit tree species under field conditions.

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