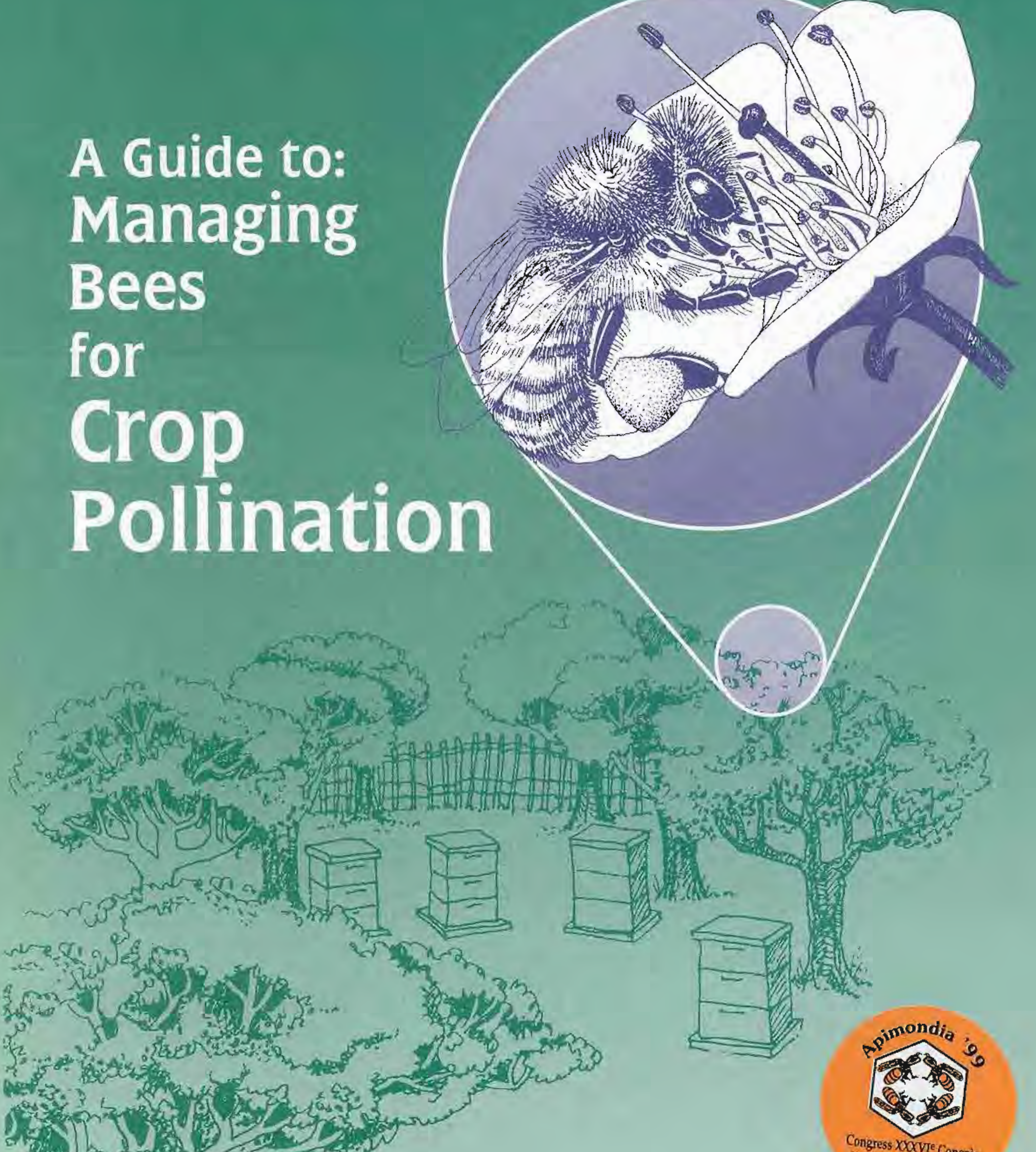
A Guide to: Managing Bees for Crop Pollination



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I. POLLINATION

i) Introduction

This guide provides information for growers and beekeepers concerning the biology and commercial management of bees for pollination. Pollen transfer from the male, pollen-producing part of the plant (anther), to the female stigma and eventually the "egg" (ovule) is necessary to fertilize plants, thereby setting seed and producing fruits and most vegetables. Bees are the most important agents of pollen transfer for many agricultural crops.

Successful pollination is essential to the economic production of agricultural and horticultural crops worldwide. Growers can provide the best agronomic practices and genetic stock, but still fail to obtain a bountiful harvest if adequate pollination is not achieved. Good pollination is required for many crops to produce any fruit, while in other crops proper pollination can substantially increase set, size, and/or quality of fruit, resulting in higher yields and profit to the grower. Wind is the principal pollinating agent of grain crops and a few other plant species. However, many agricultural and horticultural crops that have conspicuous, coloured and scented flowers require insects to move pollen between flowers. The primary domesticated insect pollinator of cultivated crops is the honey bee. Without their contribution to the agroecosystem, modern agriculture would simply not exist in its present form. In Canada, the value of honey bee pollination has been estimated at 10 times more than the value of the honey and beeswax produced ($443 million vs. $49.6 million), and close to $10 billion worth of U.S. crops require or benefit from bee pollination (Appendix I).

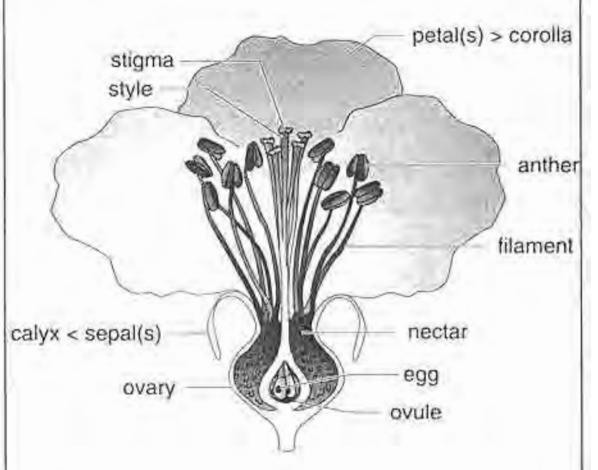


Figure 1. A cross-section of a flower showing the reproductive structures.

ii) Flower Structure

All flowers have the same basic structures, but with many variations. Typically, the flower is composed of sexual organs that are surrounded by brightly coloured petals (Figure 1). The petals, collectively called the corolla, may flare outward or form a protective tube around the stamens and pistil; they may be separate or united. The corolla is surrounded by the usually green, more durable sepals which, are collectively, called the calyx. Within the petals are stamens, the male sexual organs, that usually consist of fine filaments bearing the pollen-producing anthers on their outer tips. There may be only a few to hundreds of stamens present, depending on the flower species.

The female sexual organ, the pistil, also is surrounded by the petals. The pistil consists of the ovary, containing the female germ or egg cells, and the style with a pollen-receptive stigma on or near its tip. Typically the pistil is surrounded by the stamens, and occupies the central area of a flower. Nectar is secreted from nectaries, located at the base of the pistil inside the corolla.

Most plants have the male and female sexual organs within the same flower. Others have male and female sexual parts in separate flowers on the same plant (i.e., corn, cucumbers, and melons). Still others have the male and female sexual organs on totally different plants (i.e. kiwi fruit, wild grapes, holly, willow, poplar).

II. POLLINATING AGENTS

There are a number of different agents that effectively move pollen between flowers. These pollinating agents include wind, water, birds, mammals, insects, and mechanical or artificial agents. Insects are the most significant pollinating agents of flowering agricultural crops. Bees are by far the most important insect pollinators, although many other insects can pollinate crops. Bee pollinators include honey bees (Figure 2) and native bees - such as orchard, leafcutting, alkali, and bumble bees.

III. PRIMARY INSECT POLLINATOR - The Honey Bee

Honey bees (Apis mellifera L.) are the most important managed pollinator world-wide because they 1) are easily managed, 2) are easily transported, 3) can be managed for other income besides pollination, and 4) visit and pollinate a large number of crop species (Figure 3). For these reasons, honey bees are economically and numerically predominant in managed pollination systems.

Figure 2. A worker honey bee foraging for pollen and nectar on canola.

Indeed, loss of native bees as a result of habitat destruction, insecticide impact, and lack of diverse forage in monocultural systems has made many crops dependent on managed honey bees to provide adequate pollination.

Crop pollination requires a large population of bees during the brief blooming period of each crop, and honey bees are

Figure 3. Honey bee colonies in a cherry orchard.

one of the few potential pollinators that can be cultured in large numbers. A single colony may contain 30,000 to 50,000 individual worker bees, of which approximately 5,000 to 15,000 bees may be foraging at any time. Colonies can be fed and managed so that peak populations are obtained to coincide with bloom, even for crops that bloom early in the spring. The numbers of foraging bees can be adjusted further by manipulating the number of colonies moved to crops during the bloom. Thus, management of honey bees for pollination can be fine-tuned so that the necessary numbers of bees are available for crops with different pollination requirements.

Ease of transport and placement of hives is a second advantage for using honey bees in pollination systems. Colonies can be moved at almost any time of year, and worker bees adjust and orient to their new locale within 1 or 2 days. Honey bee colonies can also be distributed in almost any pattern in and around crops, and colonies can be moved to two or more crops each year, allowing for maximum exploitation of the bees in pollination management.

Economic versatility is a third quality of honey bees that has resulted in their extensive use for pollination. Most growers do not want the extra work involved in maintaining bees, and the fees paid to beekeepers to provide this service are highly cost-effective for growers. This system also has worked well for beekeepers, because they not only receive pollination fees but their bees sometimes collect large quantities of nectar and pollen from some of the blooming crops. Indeed, beekeepers in many North American locations cannot make sufficient income from honey sales alone, and pollination contracts often make the difference between profit and loss. Unfortunately, problems with honey bee mite pests, Africanized bees and market competition with cheap imported honey have resulted in beekeeping becoming an increasingly marginal occupation economically. Thus, pollination fees may rise in the future.

Honey bees are valuable crop pollinators because they are generalist foragers that tend to visit a broad spectrum of crop species (Appendix II). An additional advantage of honey bee foraging behaviour is that in most cases, once they are trained to a crop in bloom, they will generally continue foraging on the crop until the flowering period is over.

Although they may not be the most effective pollinator for all crops, honey bees are useful for most, and there are many advantages to culturing one bee species for use on a diversity of crops. In addition, healthy honey bee colonies produce massive amounts of brood (ie. developing young), that in turn require the protein contained in pollen. Honey bees, therefore, place a high priority on pollen collection, making them effective pollinators.

Although other insects may be valuable pollinators for some crop systems, the honey bee will continue to be the insect "work horse" for pollination management in the foreseeable future.

IV. MANAGEMENT OF HONEY BEE COLONIES FOR POLLINATION

i) Basic Introduction to Beekeeping

Honey bees are social insects that live in colonies composed of specially designed beekeeping equipment (Figure 4). A colony generally consists of one queen (reproductive female), a few hundred drones (male) and many thousands of workers (infertile females). The behaviour and biology of individual colony members is geared towards the survival of the colony. Colony members increase their population so they can gather and store enough food to enable colony survival during periods when foraging is not possible.

Honey bees forage on flowering plants to obtain nectar (carbohydrate) and pollen (protein and fat). Pollen is consumed by nurse bees to produce brood food to feed larvae and so is essential for colony growth. While foraging for food, honey bees often pollinate the flowers they contact. This incidental pollination is extremely valuable in the reproduction of wild plants and cultivated crops.

A honey bee colony's population increases or decreases in response to the forage available and the time of the year. In early spring, after the stress of winter confinement, many bees have died and the colony's population is at its lowest. When pollen and nectar become available the colony grows rapidly. By early summer, populations peak and remain high until early fall. At that time, lack of forage results in a reduction of egg laying by the queen and a subsequent decline in the colony's population. Only a small amount of bee replacement takes place during the winter.

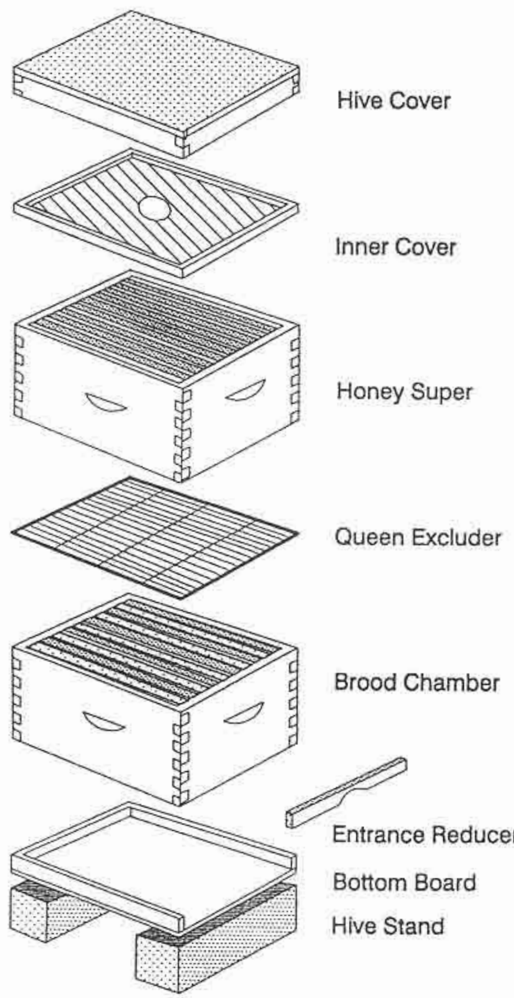


Figure 4. Components of a hive.

The goal of a beekeeper is to have colony populations peak at the same time as nectar production by flowers in the surrounding area. A beekeeper's management system should enhance the natural cycle of colony development. In the spring, beekeepers often feed carbohydrate and protein supplements to stimulate colony growth, control diseases and requeen colonies with young productive queens if necessary. Such management usually results in winter stores of honey, a pollen supply and surplus honey for the beekeeper. In the fall, beekeepers provide supplemental feed for the colony. Colonies are also provided with adequate ventilation and insulation for the winter cold. If well prepared, colonies survive the winter with large populations.

Many beekeepers rent their colonies to farmers for crop pollination. Farmers recognize that honey bees can increase the quality and quantity of most crops. Weak colonies are of little use in pollination, so beekeepers must manage their colonies to produce large populations of foraging bees, just as they do for honey production. Because some crops flower early in the spring, beekeepers must feed supplements to colonies early in the season, to properly prepare them for crop bloom. This managment procedure results in an added expense for the beekeeper.

ii) Colony Standards for Pollination

Some provinces and states make recommendations concerning strength of the colonies used for pollination. Usually the number of frames of bees and brood (eggs, larvae and pupae) are specified. The standard sized frame used is the Langstroth deep frame which contains about 270 square inches (1,742 square cm) of comb surface.

For orchard pollination, a colony should have a minimum of 8 deep frames completely covered by adult bees (e.g. approximately 20,000 adult bees) and 5-6 frames of brood in all stages of development (Figure 5). Brood combs usually are not completely filled with brood, so a more accurate measure is the actual area of brood in the combs. Oregon's regulations require that Grade A colonies for orchard have at least 600 square inches (3,870 square cm) of comb occupied by brood. This measurement is equivalent to 5 frames with 50% of the area occupied by brood.

Figure 5. Honey bee colonies used for pollination should have 5-6 frames of brood in all stages of development and 8 frames covered with adult bees.

Although one hive body can easily hold the minimum recommended amount of bees and brood, pollinating colonies should be kept in a minimum of 2 standard Langstroth deep hive bodies or their equivalent. If this recommendation isn't followed, lack of space for colony expansion will cause some colonies to swarm or stop working.

Poor weather often occurs during the pollination period for early crops, so each colony should contain a minimum of 20 lb of honey to prevent starvation if bees are confined for a few days.

Colonies used for pollination must be free of both brood and adult diseases, and have a low incidence of parasitic mites.

iii) Manipulating the Number of Nectar and Pollen Collectors

Honey bee colonies should be managed to maximize the number of workers foraging on the target crop. On many crops, pollen foragers are more effective pollinators than are nectar foragers.

Pollination efficiency can be increased by manipulating colonies to increase the ratio of pollen to nectar foragers. A colony's foraging activity (ie. pollen or nectar collection) depends upon its population size, the quantity of brood, the quantity and composition of food stores, the genetic make up of the worker population, and the queen and her pheromones. (Pheromones are mixtures of chemicals produced in honey bee glands that are used for communication in the colony). The total number of foragers is directly correlated with the size of the worker population. Thus, the most effective way of increasing the total number of pollen and nectar foragers is to manage the colony to maximize the worker population present at the time the target crop is in bloom.

Brood also is important in stimulating bees to forage, especially for pollen. The proportion of foragers that collect pollen is directly related to the amount of brood present. The addition of extra frames of brood to colonies can be used to stimulate pollen collection, although in many situations this may not be economically feasible. Since both queen and brood are critical to stimulate worker foraging, colonies used for pollination should be contain a laying queen and a minimum of 4-6 frames of brood.

The ratio of pollen to nectar foragers can be increased by altering colony food stores. Pollen shortages caused by the removal of pollen, or the use of pollen traps, stimulate more bees to forage for pollen. In contrast, pollen supplements added to colonies during bloom can decrease pollen foraging and should be avoided when bees are used for pollination.

Queen pheromones can be important in regulating both the total number of foragers and the proportion of the colony's workers that forage for pollen. The queen produces a 5-component pheromone called "Queen Mandibular Pheromone (QMP)" that has been synthesized (FruitBoost ®), and can be used to stimulate foraging in colonies (Figure 6). QMP is mixed with water and sprayed on crops slightly preceding peak bloom. Research on apples, pears, cherries, cranberries, and blueberries indicate that QMP is effective in increasing the number of honey bees foraging on these crops under a wide range of environmental conditions, orchard management systems and geographical locations. While increased attraction of bees to crops treated with QMP seems to be a fairly general phenomenon, yield and profit increases are highly crop-dependent. Research into the impact of QMP and other pheromone products is being conducted on a wide range of agricultural crops.

iv) Scheduling Delivery of Colonies for Pollination

The economic benefits of pollination by honey bees can be maximized by scheduling the delivery of colonies to coincide with period of bloom when the crop is most receptive. The optimal bloom time for pollination depends on the crop's attractiveness, the attractiveness of competing flora, and the plant species or cultivar.

The attractiveness of a crop to honey bees depends greatly on the amount and sugar concentration of the nectar. Crops that produce little or no nectar, such as cranberry or flax, attract few honey bees. Crops that produce nectars low in sugar also are relatively unattractive. Flowers of pear, for example, produce dilute nectar (average of 15% sugar) and are unattractive to honey bees. Crops such as canola that produce high volumes of concentrated nectar (average of 36% sugar) are highly attractive. Pollination of relatively unattractive crops can be improved by bringing colonies in after the target crop has begun to bloom; if colonies are brought in too early, the honey bees commence foraging on other nearby flowers that are already blooming. Further, honey bees often do not switch to the target crop once the bloom begins. Colonies can be brought to crops when bloom begins for crops that produce ample nectar and are more attractive to bees (eg. sweetclover, canola, apples and cherries).

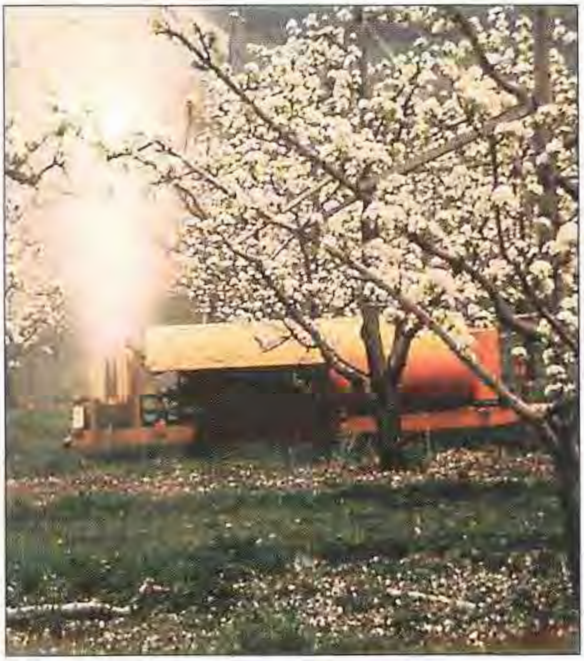


Figure 6. Pollination efficiency of honey bees can be improved by spraying crops in blossom with bee pheromones.

Honey bee colonies are generally moved into a crop requiring pollination during the night or early morning when all the bees are in the hive. Colony movement at this time of day minimize the loss of forager bees.

v) Number of Colonies Recommended for Specific Crops

The numbers of honey bees foraging on a target crop can be increased by increasing the number of colonies placed on or near the crop. Recommendations for the number of colonies/acre (colonies /hectare) required for specific crops are compiled in Appendix 2. These recommendations, however, are approximations. The number of colonies required to effectively pollinate a target crop and maximize economic returns varies widely with plant species and cultivar, planting density, the number of competing plants in the surrounding area, as well as agronomic and environmental factors. In situations where planting densities are high (i.e. more blossoms to pollinate per hectare), weather is poor for bee flight activity, or other crops compete for pollinators, additional colonies may be moved in to maintain the desired number of foragers on the target crop.

The introduction of additional colonies may help to increase pollination if insufficient bees are present. Careful consideration should be given to the timing and placement of colonies on a crop in order to maximize economic benefits.

vi) Distribution of Colonies in the Field

More effective pollination is achieved when honey bee colonies are close to or within the target crop. However, there are different opinions concerning whether colonies should be evenly dispersed or placed in groups. The importance of colony location may vary with topography, weather, and crop-type. Economic considerations also influence the placement of bee hives.

An even distribution of foragers can be obtained by placing groups of 3-5 colonies in field crops and 10-20 colonies in orchard crops throughout the area to be pollinated. The number of colonies required is based on both the total acreage or hectareage and type of crop. The nature of the terrain often limits colony placement to areas that are accessible by vehicle. If this is the case it may be necessary, especially in field crops, to place large numbers of colonies in a group (ie. more than 30 colonies). If colonies cannot be placed within the crop, they should be placed downwind so that the scent of the crop reaches the forager bees. Colony locations that are sunny during the morning, dry and protected from the wind should be favoured to encourage maximum foraging activity.

vii) Colony Replacement or Rotation

Colony replacement and rotation are management options used to increase foraging on the target crop. Bees that are just moved into an area tend to forage on the closest source available but rapidly radiate outwards, sometimes to competing forage. Thus, pollination of the crop might be enhanced by replacing colonies that are no longer foraging on the crop with new colonies. This technique is particularly valuable for unattractive crops with long blooming periods. (eg. Colonies rotated between locations should be moved distances greater than 2.4 km to prevent bees from returning to their original hive location).

Sequential loading, or the movement of additional colonies into a crop during the bloom period, may also enhance pollination. New colonies can be moved into crops that bloom over an extended period of time, thus maintaining the population of foragers on the target crop as the bloom progresses.

The cost of moving, rotating and replacing colonies is high and therefore should be done only when monitoring of foragers in the target crop and economics indicates it is warranted. The loss of a proportion of foragers is an additional cost of moving colonies so colony rotation should be used in high value crops where moving colonies would be economically feasible.

viii) Contracts and Payment for Pollination Services

Most pollination services are rendered without a written contract. Although this may work well for experienced growers and beekeepers, contracts can be valuable for inexperienced operators, for beekeepers dealing with new growers or growers dealing with new beekeepers. The advantage in using a contract is that both parties' responsibilities are clearly outlined.

Contracts should contain the following information:

≠Name and address and phone numbers of the parties
≠Crop to be pollinated and location
≠Number of colonies to be provided and their strength
≠Right of colony inspection at grower's request
≠Timing of delivery and removal and notice of movement
≠Placement within the crop
≠Right of entry and access for beekeeper
≠Rental fee and schedule of payment
≠Advance notice to beekeeper if pesticides are to be applied
≠Compensation to beekeeper for pesticide damage or vandalism to colonies
≠Compensation to grower if the contract is not honoured
≠Payment for additional movement of colonies or other extras
≠Liability associated with stinging incidents

Sample contracts can be obtained from local beekeeper organizations and government or private extension offices.

ix) Pollination Aids

Pollenizers

A pollenizer is a plant variety that provides a source of compatible pollen for use in cross-pollination. Fruit growing has evolved from the small holdings of pioneer fruit growers, when literally hundreds of varieties were grown, to the present practice of growing large plantings of a single variety. If the main variety selected by the grower is self-sterile, the interplanting of pollenizers with compatible pollen is essential for fruit production.

Apples provide a good example of pollenizer plantings. McIntosh, Spartan and Red Delicious apple varieties are self-sterile, but are suitable pollenizers for each other. The bloom period of good cross-pollenizers must overlap to provide maximum cross-pollination. It is also essential to have a high population of honey bees to distribute the pollen between pollenizers and self-sterile main varieties.

Many traditional fruit growing regions are changing from plantings of large standard-sized trees to hedgerows or high density , supported orchards of varieties such as Gala, Mutsu, Jonagold, MacIntosh, Empire, Northern Spy, and Courtland. Selected ornamental crabapple varieties also are being investigated as pollenizers for main varieties.

Some of the advantages of crabapple pollenizers are: 1) minimal space requirement; 2) overlap of blooming time; 3) multitude of bloom and abundant pollen; and, 4) quick growth habit.

More studies are needed in many aspects of pollenizers in high density and hedgerow plantings, to determine numbers and placement of pollenizers in relation to main varieties, overlapping of bloom and placement of bee hives for best advantage. For example, honey bees tend to forage along the rows of trees, but not as often between rows. This behavior can decrease the frequency of pollen transfer between the main crop and the pollenizer variety.

Pollen Inserts

Temporary methods of providing an immediate source of pollen can be used where pollenizers are not available in an orchard. These methods include: 1) hive entrance pollen inserts; 2) bouquets of blooms from suitable pollenizer varieties; and, 3) hand applicators.

There are several different types and designs of pollen inserts. The basic principle of the insert is to force the outgoing foraging bees to travel through a layer of cured anthers containing pollen.

One standard type of pollen insert can be attached to cover all but a 3" opening of the hive entrance (Figure 7). This opening permits returning bee foragers to re-enter the hive freely. However, outgoing bees must pass through the insert, where they pick up pollen on body hairs and distribute it to flowers as they forage. This technique has been useful in self-sterile varieties of tree fruits, including most varieties of sweet cherries and pears.

Figure 7. A pollen insert can be attached to the entrance of a hive so that outgoing forager bees pick up pollen on their body hairs and distribute it to flowers as they forage.

More recently, a simple entrance block designed with an inward sloping entrance has been used as an inexpensive and effective type of dispenser. The dry anthers and pollen are spooned onto the floorboard through the sloping entrance, permitting both incoming and exiting bees to be dusted with the pollen.

Pollen from pollenizer varieties can be purchased from pollen dealers. Pollen should be refrigerated until it's used; while pollen is being transported for distribution into the inserts, it should be stored in a small cooler with an ice pack. Inserts should be placed into the hive entrance at least one day before the pollen is used to allow the bees to adjust to the presence of the insert.

Bouquets are flowering branches of compatible pollenizer varieties which are placed in containers of water and situated throughout the orchard to provide a source of pollen for cross-pollination. Honey bees visit these bouquets, collect the pollen from the pollenizer variety and then distribute it to the main variety throughout the orchard. To increase the effectiveness of bouquets:

- Cut branches from a pollenizer with only the king bloom open (for apple).
- Maintain fresh bouquets by changing them often.
- Use large bouquets. Branches up to four feet in length are best.
- Place bouquets in buckets or large drums filled with water.
- Hang bouquets in or near every tree, preferably near the bloom to be pollinated.

Pollen also may be distributed by hand brush to individual blooms. However, this method is very labour-intensive. An airgun applicator may be used for applying pollen to blossoms. This is less labour-intensive than hand pollination. The airgun application method has been developed and utilized successfully in Washington State.

<u>Directing Bees to Crops</u>

Directing bees to target crops is difficult if the flowering plants have little or no pollen or nectar available, or if crops are less rewarding than nearby forage. Best results are obtained when the odour of the target crop is incorporated into the colony's food stores. Although spraying sugar syrup directly on crops may increase numbers of bees, it seldom increases yield. Pollen odours contained in pollen extracts may attract bees to crops but more data are required before this method can be recommended.

Certain synthetic bee pheromones may be useful for attracting bees to crops, resulting in improved pollination (See Section IV.(iii))

Reducing Competition

Although honey bees are one of the major insect pollinators, they can pose special management problems because they may desert the "target" crop for more attractive, or "rewarding", plants in the same area. Cover crops (e.g. dandelion (*Taraxacum officinale* Weber), white clover *(Trifolium repens* L.), and wild mustard (*Sinapis arvensis* L.) which often grow beneath fruit trees can be eliminated or mowed when in flower to avoid competition. However, some authorities believe that cover crops retain bees in an orchard and thus bees may, in time, switch to the target crop. The questions underlining these two viewpoints urgently require answers.

In addition, several field trials in Ontario have indicated that dandelions in apple orchards are not major competitors for honey bees during apple bloom. Dandelions and other ground vegetation harbor an important pest of apple, the tarnished plant bug (*Lygus lineolaris*). Not mowing the sod during bloom may reduce the risk of tarnished plant bugs being disturbed and migrating into apple trees where they can cause economic injury to buds and fruitlets.

V. MANAGEMENT OF ALTERNATIVE BEE POLLINATORS

Although honey bees are the most important pollinator in the service of agriculture, alternatives exist for various crops. In Canada the most-used alternative pollinator is the alfalfa leafcutting bee (*Megachile rotundata* (F.)). Its culture is now a multi-million dollar business in the Canadian prairies because of its efficiency in alfalfa pollination. In Japan, orchard bees (*Osmia* spp.) are used extensive and effectively in apple pollination, and may be useful in other locales and for other orchard crops. Bumble bees (*Bombus* spp.) have become an attractive alternative pollinator for greenhouse tomato and pepper production in Europe and Canada, and more recently, they have been tested as potential pollinators of cranberries, blueberries and ginseng. Various bees and flies have been used effectively for experimental pollination in plant breeding. Despite the potential wealth of alternative pollinators in the Canadian landscape, little has been done to promote their usefulness. As a result there remains great opportunities in Canada for developing management schemes for other pollinators such as blueberry bees, other leaf-cutting bees, squash bees, and various flies.

The management of alternative pollinators is as varied as the pollinators themselves. Successful management requires extensive knowledge of the insects concerned. For beekeepers, their basic understanding of honey bee management is a firm foundation for expanding into alternative pollinators. The most well-known alternative pollinator in Canada is the alfalfa leafcutting bee, and management systems for this pollinator are well defined. The management of orchard bees is common practice in Japan and is slowly being adopted elsewhere. For bumble bees, the recent success in using European species for greenhouse tomato pollination in Europe has spurred advances and success in Canada using North American species. There remains great opportunity in Canada for developing management of other alternative pollinators such as blueberry bees, other leafcutting bees, squash bees, and various flies for specialty crops.

i) Leafcutting Bees

The alfalfa leafcutting bee, Megachile rotundata (F.), is the most important pollinator of alfalfa in Canada and is increasing in importance worldwide (Figure 8). It can also be used to pollinate many other forage legume species such as sainfoin, clovers, milkvetch and birds-foot trefoil. With good management the bees can increase alfalfa seed yields by as much as 20 times. Large numbers of leafcutting bees (20,000 to 30,000 per acre or 50,000 to 75,000 per hectare) are needed to pollinate the crop. For this reason, the loose-cell system of leafcutting bee management was developed. This system places the optimum number of bees on the crop at the appropriate time to obtain a high seed set and an adequate return of viable bees for the following year.

The loose-cell system enables easy removal of bee cells from laminated, grooved nesting materials made of pine wood or polystyrene, for storage over the winter without destroying the nesting material. The system was developed to control the potential build-up of populations of natural parasites of the bees (cuckoo bees, chalcidoid wasps, blister beetles) and efficient use of cold storage and incubation facilities to synchronize bee emergence with the beginning of flower bloom. The development and emergence of bees can be regulated more easily by using controlled incubation facilities than by relying on field conditions. Techniques to synchronize the emergence of the bees with flowering have been easier to develop than techniques to control the blooming of the crop.

Figure 8. The alfalfa leafcutting bee is the most important pollinator of alfalfa in Canada and is becoming increasingly important worldwide.

The alfalfa leafcutting bee is a solitary nesting bee by nature, although it is gregarious. At the nests, each female makes her own nest by cutting, transporting, and placing suitable leaf material in the tunnel to form thimble-shaped cells, collecting provisions of pollen and nectar, and laying eggs in the cells. She has little interaction with other females of either her own or the daughter generation.

The management system which has been devised permits beekeepers to take samples of cells they produce to estimate accurately numbers of intact cocoons, female bees, parasites, and disease. These estimates allow leafcutter beekeepers to improve their beekeeping practices. The estimates also provide quality guidelines when the bees are sold.

ii) Orchard Bees

Orchard bees have been managed for apple pollination in Japan for 35 years. Research in the United States attests to the potential in North America of a native species, Osmia lignaria propinqua Cresson, the blue orchard bee. These bees, like leafcutting bees, nest in wood tunnels. Artificial domiciles made from paper drinking straws, or similar paper tubes, inserted into boxes or plastic pipes to exclude light and pests, are used commercially. The bees start to forage at 13-15oC and are highly efficient pollinators. Maximum pollination in isolated orchards can be reached with as few as 250 female bees per acre (625 bees per hectare). Because orchard bees land directly on the sexual columns of the flower they are more likely to pollinate apples than honey bees which often sidework the flowers and fail to contact the stigma.

iii) Bumble Bees

Bumble bees (genus *Bombus*) are important pollinators of native plants and a wide variety of crops. Several characteristics make them useful crop pollinators: 1) long tongues; 2) ability to forage at low temperatures; and, 3) ability to harvest pollen from buzz-pollinated flowers (eg. blueberries, cranberries and tomatoes). As a consequence of these charactersitics bumble bees are most effective as pollinators of crops with long or trumpet-shaped flowers (eg. red clover), crops blooming during cold weather (eg. fruit trees), and buzz-pollinated crops. The blossoms of buzz-pollinated crops have anthers which require rapid vibration before they will release their pollen grains. Bumble bees are especially efficient at performing this type of vibrational pollination (Figure 9).

Figure 9. Bumble bees have relatively long tongues which makes them expecially useful as pollinators of crops with long or trumpet-shaped flowers.

There are about 40 species of bumble bees in Canada. The bees produce annual colonies that reach a peak size in mid-late summer of 50-150 workers, depending on conditions and the species. The life cycle begins in spring with overwintered, mated queens that emerge and search for suitable nest sites (typically abandoned rodent nests). After a nest site is found the queen collects pollen and nectar and lays her first brood of worker eggs (usually 6-8). About 3 weeks later the first workers emerge and the colony then produces several successive broods of workers over the summer. By mid- to late summer, colonies produce new queens and males. The new queens mate and, after spending some time "fattening up", dig into the soil to winter. Any remaining workers and males die in the fall.

Bumble bees often are rare in areas of intense agriculture because of pesticide usage, lack of suitable nesting sites and insufficient food plants to sustain the colony over the active season (May-October). Wild populations can be encouraged by leaving undisturbed areas around crops such as, fence rows, that provide suitable nesting sites (e.g. under logs or in old mouse and vole nests). Providing suitable habitat for bumble bees may also increase rodent populations, requiring protection of fruit trees with plastic wraps. Even more important than increasing the number of nest sites is ensuring adequate food plants. Because bumble bees do not store food for more than a few days, a steady uninterrupted progression of plants over the season is essential to support colonies when crops are not in flower. Plants that are good nectar and pollen producers for bumble bees over the season include willows (*Salix* spp.), snowberry (*Symphoricarpos albus*. (L.) Blake), wild mustard (*Sinapis arvensis* L.), dandelion (*Taraxacum officinale* Weber), apples (*Malus* spp.), pears (*Pyrus* spp.) , cherries (*Prunus* spp.), strawberries (*Fragaria* spp.), blueberries (*Vaccinium* spp.), locusts (*Robinia* spp.), lilacs (*Syringa* spp.), honeysuckle (*Lonicera tatarica* L.), raspberries (*Rubus* spp.), milkweeds (*Asclepias* spp.), basswood (*Tilia americana* L.), vetches (*Vicia* spp.), clovers (*Trifolium* spp.), sweet clovers (*Melilotus* spp.), jewelweeds (*Impatiens* spp.), goldenrods (*Solidago* spp.) and asters (*Aster* spp.). Part of the progression of food plants may be a sequence of crops such as orchard trees, followed by mustard, alfalfa and clover.

Wild populations also can be augmented by commercially reared bumble bees colonies but this can be expensive, and colonies are vulnerable to wax moths, parasitic bumble bees, skunks and raccoons. At the present time domesticated bumble bees are too expensive to be used as pollinators of most field crops. However, with further research and development, it may soon be feasible to use commercially reared bumble bees for pollination of some crops such as cranberries, blueberries and red clover. Commercially reared colonies currently provide excellent pollination of greenhouse crops such as tomatoes (Figure 10a,b) .

VI. POLLINATION REQUIREMENTS OF SPECIFIC CROPS

i) Introduction

Pollination and Fertilization

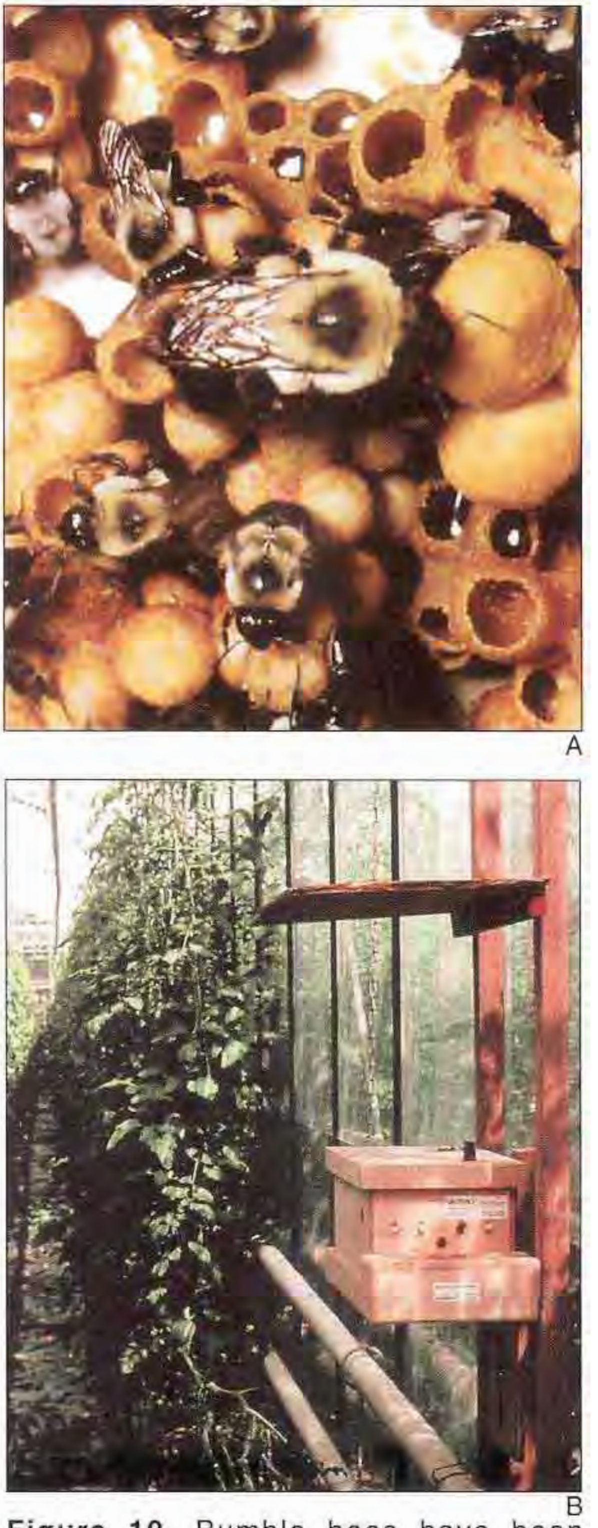
Pollination can be defined as the transfer of viable pollen from an anther to a receptive stigma of a compatible flower. At the appropriate time during the blossom period, the anthers open, releasing pollen. In many plants, the stigma is receptive at the time of pollen release. Viable pollen from a compatible plant of the same species contacts and adheres to the receptive stigma. There it germinates, and sends a pollen tube down through the style tissue and into the ovary. Inside the pollen tube, the generative cell divides to form two sperm cells. After the pollen tube enters the ovary, it grows towards and enters an ovule where it penetrates the embryo sac and finally the egg (Figure 11). When one sperm cell unites with the egg, fertilization occurs, resulting in the formation of a seed. The other sperm unites with another cell to begin formation of the endosperm (e.g. tissue surrounding the embryo of a seed). The resultant seed initiates subsequent growth and fruit development. Once fertilization occurs, it usually is the ovary wall of the blossom that swells to form the fruit. Two conditions must exist for fertilization to be successful: 1) the pollen must be viable; and, 2) the pollen must be compatible.

Cultivar Compatability

There are a number of terms frequently associated with pollination in the literature. A plant may be referred to as self-fertile or self-compatible if fruit can be produced, in the absence of pollen transfer, from one cultivar to another or between plants (i.e. receptive to its own pollen). A plant of this type may not necessarily be self-pollinating and could require a pollinating agent, such as an insect, to facilitate the transfer of pollen from the anthers to the stigma within the flower or between flowers on the same plant or between plants of the same cultivar. If the plant is not receptive to its own pollen, but is fertilized only when pollen comes from another plant or variety, it is referred to as self-sterile. Red Delicious and Golden Delicious apples are primarily self-sterile, but when they are interplanted and cross-pollinated, fertilization can occur and fruit will be set. These two apple clones are considered to be cross-compatible. Plants are considered to be cross-incompatible if they are not receptive to the pollen of another plant. The terms self- and cross-pollination also can be somewhat confusing. The transfer of pollen from the anther of a flower of one clone to the stigma of another flower of the same clone is referred to as self-pollination, whereas the transfer of pollen from the anther of a flower of one clone to the stigma of another flower of a different clone is cross-pollination.

ii) Tree Fruits

The main tree fruits grown in Canada are apples (*Malus* spp.); peaches (*Prunus persica* (L.) Batsch.; pears (*Pyrus communis* L.); sour and sweet cherries (*Prunus cerasus* L. and *Prunus avium* (L.)); prunes and plums (*Prunus* spp. and *Prunus domestica* L.); apricots (*Prunus armeniaca* L.); and, nectarines (*Prunus* spp.). Most of these tree



A

B

Figure 10. Bumble bees have been domesticated and are now commercially reared for use as crop pollinators: **a)** an internal view of a bumble bee nest; **b)** a bumble bee colony situated in a greenhouse for pollination.

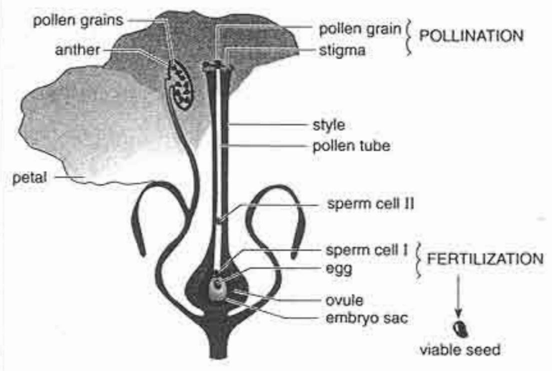


Figure 11. An illustration of the basic principles of pollination and fertilization.

fruit crops are dependent on insect pollination to some extent (Appendix I) and honey bees are considered to be their primary insect pollinators.

The movement of this cross-compatible pollen is provided by the pollination activities of insects such as honey bees and alternative pollinators including *Osmia lignaria propinqua* Cresson, the blue orchard bee. If pollenizer varieties are not interplanted within orchards, cross-compatible pollen can be dispensed to honey bees through the use of pollen-inserts attached to the entrance of colonies situated in the orchards. The honey bees then disperse the cross-compatible pollen from the pollen insert to the main apple cultivars while foraging in the orchard.

The apple flower cluster consist of 6 blossoms on 1- to 3-year woody shoots. The "king" bud, the central flower in the cluster, opens first and generally produces the choicest fruit. Growers should make sure that the king blossom is pollinated soon after opening. Pollination of the king blossom can be insured by providing the recommended number of honey bee colonies per acre (hectare) of orchard (Appendix II) and by making sure that the hives are moved to the orchard when 10% of king buds have opened.

Most peach and nectarine cultivars are self-fertile and do not require honey bees or other insect pollinators to produce fruit. However, providing honey bees for the pollination of peaches and nectarines does seem to improve fruit quailty in regards to size and shape. The flowers of both peach and nectarine are highly attractive to honey bees and other pollen- and nectar-collecting insects.

Sweet cherry cultivars are considered to be self-sterile and require cross-pollination by insect pollinators to produce fruit. Honey bees find sweet cherry blossoms more attractive than sour cherry blossoms primarily because the nectar of sweet cherries is much richer in sugar (55%) than that of sour cherries (28%). The pollen of both types of cherries is attractive to honey bees. Sour cherries are generally self-fertile and set fruit with their own pollen, but only after it is transferred from the anther to the stigma of the blossom by pollinating agents such as honey bees. It is recommended that pollination of either sweet or sour cherry cultivars occur as soon after the release of pollen from the anthers as possible. To insure that this occurs honey bee colonies should be moved into sweet cherries on the day of or one day before the first blossoms open. Colonies should be moved into sour cherries at least one day after blossoms have begun to open primarily because the nectar is less attractive than in sweet cherries and more blossoms need to be open to keep the honey bees from leaving the orchard in search of a more attractive crop.

Many pear cultivars are self-sterile and set good crops only when pollinating insects are available in sufficient numbers. However, the nectar produced by pear blossoms is not attractive to honey bees because of its low sugar content (8-10%). Therefore colonies should not be moved into pear orchards until 30% to 50% of the blossoms are opened.

In general, most apricot cultivars are self-sterile and require pollination by honey bees to assure a good fruit set and yield. However, it is not necessary to have large populations of honey bees present in apricots in order to provide adequate pollination.

Prunes are plums that, because of their high sugar content, can be dried without having their stones removed. All prune and plum cultivars require large populations of honey bees to carry out adequate cross-pollination. The blossoms of both prune and plum trees are usually attractive to bees all day but more so in the morning.

Citrus tree fruits such as oranges, grapefruits, lemon and limes are not grown in Canada but are considered important tree fruits crops in the southern United States and in other tropical and subtropical regions throughout the world. The pollination requirements of citrus fruits are quite diverse but all seem to benefit from the presence of honey bees during the pollination period.

iii) Small Fruits

Small fruits (berries) cultivated in Canada include: strawberries, raspberries and blackberries (Family: Rosaceae); blueberries and cranberries (Family: Ericaceae); currants and gooseberries (Family: Saxifragaceae); and grapes (*Vitis vinifera* L.). Insect pollination is beneficial to all except grapes.

Flowers of crops in the family Rosaceae typically have numerous stamens surrounding the dozens to hundreds of pistils. Nectar, often plentiful, is produced from glands at the base of the petals. Pollen is released from longitudinal sutures in the anthers. Because of their abundant, easily available nectar and pollen, the flowers are highly attractive to pollinators. When adequately pollinated, most ovules develop. This requires four to six honey bee visits per flower pistils mature over a period of several days. Poor pollination in these crops results in malformed fruit.

Strawberries (*Fragaria* x *ananassa* Duchesne) are the most widely cultivated small fruit in the world. The succulent, edible portion is actually the swollen receptacle, but the true fruits are the small seeds. In some locations growers depend on wind, natural pollinators and self-pollination for pollen transfer. However, honey bees can be beneficial in improving fruit quality and often are brought into strawberry fields during bloom.

Red raspberry (*Rubus idaeus* L.) and blackberry (*Rubus* spp.) are multiple fruits resulting from the union of many drupelets. Most commercial red raspberry cultivars are self-fruitful, but do require insects for pollen transfer, especially during poor weather. Blackberries do not require insects for pollen transfer, but the presence of bees results in more uniform pollen dispersal and more marketable fruit.

Crops in the family Ericaceae, such as blueberries and cranberries, are the only commonly cultivated native North American fruits. Highbush blueberry (*Vaccinium corymbosum* L.) is a shrub, but lowbush blueberry (primarily *Vaccinium angustifolium* Ait.) and cranberry (*Vaccinium macrocarpon*

Ait.) are low growing woody plants. Blueberry flowers have fused petals shaped like an urn, while in cranberry blossoms five separate petals reflex backward in the mature flower. A ring of 8 or 10 stamens surrounds the single pistil. Nectar is produced at the base of the corolla, and pollen is released from pores in the anthers by bumble bees and other solitary bees that vibrate the blooms during foraging (e.g. buzz pollination). Honey bees also enhance pollination, but are not as efficient because they are incapable of buzzing the anthers.

Many varieties of highbush blueberry and cranberry are self-fertile and are typically grown in large solid stands of one cultivar. However, lowbush blueberry is self-sterile, requiring the planting of different lowbush blueberry clones in each field for cross-pollination. Fruit sets of at least 80% are required for a profitable commercial crop of highbush blueberry. Acceptable commercial yields in cranberry and lowbush blueberry require that 33% and 50% of the flowers set fruit, respectively.

Currants and gooseberries are of minor importance in Canada. Although red currants (*Ribes sativum* (Rchb.) Syme) and gooseberries (*Ribes uva-crispa* L.= *R. grossularia* L.) are self-fertile, black currants (*Ribes nigrum* L.) are self-sterile and require pollinizing cultivars. The small, cup-shaped, dull-coloured flowers require bees for pollen transfer.

iv) Forage Legumes

Seed production of forage legumes requires or benefits from cross-pollination. With the exception of alfalfa (*Medicago sativa* L.), honey bees are used as a managed pollinator for these crops.

Alfalfa

Alfalfa seed has been produced in Canada for many years, primarily in the prairie provinces. Early records of seed production indicated tremendous annual yield fluctuations caused by variations in weather, insect pest populations and the presence or absence of natural pollinators.

The alfalfa leafcutting bee *(Megachile rotundata* (F.)) was introduced into Canada in 1962 as a managed pollinator of this crop. When honey bees probe alfalfa flowers for nectar, the floret opens exposing the sticky stigmatic surface and the tripping mechanism associated with the anthers. The tripping mechanism often hits the foraging honey bee. Honey bees may assist in pollinating alfalfa; however they quickly learn to avoid the tripping mechanism of the flower by probing it from the side and between the petals, taking the nectar without tripping the floret. Alfalfa leafcutting bees, in contrast, trip each floret visited, and for this reason are used for alfalfa seed production in Canada and the United States. Attempts have been made over the years to simulate tripping by mechanical means, such as dragging tires, ropes, sacks, or harrows behind tractors or using the downdraught from low flying helicopters. No mechanical process has produced results as reliable as those of the leafcutting bee.

Leafcutting bees are placed at intervals throughout the seed field in domiciles containing nest materials. Current recommendations for pollinator stocking rates are 8,000 bees per acre (20,000 bees per hectare), assuming an average of 39% females in the population. Growers vary this rate from 6,000 to 16,000 bees per acre (15,000 to 40,000 bees per hectare), depending on the potential for seed yield of the field and the availability of bees. Most growers own their own leafcutting bees. Some custom pollination also occurs, with the beekeeper providing the bee management and receiving the returning bees, along with a share of the alfalfa seed crop, while the field management is conducted by the grower, who receives the remainder of the seed crop.

Clovers, Bird's-foot Trefoil, and Sainfoin

Other major forage legumes grown in Canada for seed production are red clover (*Trifolium pratense* L.), alsike clover (*Trifolium hybridum* L.), white clover (*Trifolium repens* L.), white sweet clover (*Melilotus alba* Desr.), yellow sweet clover (*Melilotus officinalis* (L.) Pall.), bird's-foot trefoil (*Lotus corniculatus* L.) and sainfoin (*Onobrychis viciifolia* Scop.). All of these crops require cross-pollination for seed set. Unlike alfalfa, the florets of the clovers, trefoil and sainfoin do not have a tripping mechanism, so honey bees readily work the florets and come into contact with the anthers and stigmas, thus moving pollen from one blossom to another. The florets range in shape from being tubular (e.g. red clover) to quite open (e.g. sweet clover).

Of these crops, red clover has a floral tube that is so long that the honey bee's tongue cannot always reach the nectar within the tube. If the honey bees find it too difficult to extract the nectar, they may lose interest in the crop, especially if there are other attractive nectar sources nearby. In this case pollination and seed yield suffers. If this situation arises growers would have to depend on local populations of bumble bees to enhance the pollination activities of honey bees.

The florets of alsike, white and sweet clovers, bird's-foot trefoil and sainfoin, are short enough that the honey bee's tongue can easily reach the nectaries within the floret. Honey bees maintain their populations in fields of these crops, and are consistently reliable pollinators.

The recommended number of honey bee colonies for pollination is at least two colonies per acre (five colonies per hectare). The recommended number of colonies should be used to insure maximum seed yield, especially for pedigreed seed production. Alternatively, leafcutting bees may be used in these crops at a stocking rate of 20,000 adults per acre (50,000 adults per hectare).

v) Annual Legumes

Field peas (*Pisum sativum L.*), broad and field beans (*Vicia faba* L.), soybeans (*Glycine max* (L.) Merr.) and lentils (*Lens culinaris* Medic.) are grown in Canada. Unlike forage legumes, which are biennial or perennial, these crops are annual, and the seed crop is destined for human consumption.

Field peas are self-fertile and self-pollinating. Self-pollination in field and garden pea flowers occurs in the bud stage before the flower opens. Therefore insect pollinators are of no benefit. Soybeans also self-pollinate within the bud and young flower and require no insect pollination for seed set.

Although broad and field beans are considered to be self-pollinating, the lack of adequate cross-pollination (i.e. inbreeding) can result in a progressive loss of the ability to set seed and a reduction in yield. Honey bees are highly recommended for the pollination of beans.

Lentils are grown extensively in western Canada. They are self-fertile and primarily self-pollinating, and appear to be completely unattractive to honey bees and other native bee pollinators.

vi) Oilseed Crops

The main oilseed crops grown in Canada are the Polish and Argentine types of canola (rape) (*Brassica rapa* L. = *B. campestris* L., and *B. napus* L.), yellow or white mustard (*Brassica hirta* Moench), sunflower (*Helianthus annuus* L.), and flax (*Linum usitatissimum* L.).

Canola and Mustard

In 1994, approximately 14.4 million acres (5.8 million hectares) of canola (rape) and about 800,000 acres (320,000 hectares) of mustard were grown in Canada. Seed set in these crops can benefit from bee visitation. Pollinating agents such as wind and other insects also are effective; some self-compatibility also occurs. It is recommended that colonies be placed in yellow mustard (*Brassica hirta* Moench), and the Polish canola *(B. rapa = B. campestris)* variety to maximize seed yield for pedigreed seed production (Appendix 2). The literature is ambiguous whether or not Argentine canola *(B. napus)* varieties benefits from insect pollinators; some authors indicate a yield increase with bee visitation, but others believe that insects are not necessary for good seed yields.

Beekeepers consider canola (rape) to be a major nectar producer and therefore a primary source for the large honey yields in the prairie provinces. Alfalfa leafcutting bees also survive and reproduce using canola as their primary floral source.

Recently, hybrid canola seed production has been initiated in the prairie provinces. Honey bees and alfalfa leafcutting bees are used in cross-pollination for hybrid seed production. Preliminary work indicates that up to six honey bee colonies per acre (15 colonies per hectare) are required for optimum seed production, and beekeepers receive a fee for these pollination services.

Sunflower

About 140,000 acres (56,000 hectares) of sunflower are grown in Canada. The original cultivars grown in North America were self-incompatible and required cross-pollination. For these open-pollinated varieties it was recommended that honey bees be placed throughout the sunflower field to insure adequate pollination (Appendix 2). However, virtually all sunflowers now grown in Canada are varieties that are largely self-compatible, and thus do not require cross-pollination for seed set. There is some indication that honey bees still enhance pollination and seed set in these hybrids, but growers at present do not pay for pollination services. From the beekeepers' point of view, hybrid sunflowers result in good honey crops in some years but small to insignificant crops in other years. It is not clear which environmental and genetic conditions affect nectar yield. To optimize honey production it is necessary to have the colonies in the field even before the sunflowers bloom because the florets open and dry up fairly quickly.

Flax

Approximately 1.5 million acres (600,000 hectares) of oilseed flax are grown in Canada. Products from this crop are linseed oil for industrial uses, and linseed meal for livestock feed. Flax is primarily self-pollinating. Flax provides nectar and pollen to visiting insects, and bee pollination may increase seed yields. However, under Canadian prairie conditions flax is not considered to be an attractive bee plant nor a useful honey producer. In addition,seed yields in flax do not increase when honey bees are used to pollinate this crop. Consequently, honey bees are not recommended for pollination of flax.

vii) Vegetable Crops

The consideration of pollination requirements for vegetable crops should be viewed under two broad categories: vegetable seed production and vegetable "fruit" production.

The commercial production of vegetable seed is a specialized agricultural operation that is limited to a few producers. Although the specific pollination requirements for individual species and their cultivars are unclear, it is agreed that almost all of the common vegetable seed crops benefit from insect pollination. Some of the more common vegetables for which insect pollination is important include: asparagus, beets, the cole crops (broccoli, brussels sprouts, cauliflower, cabbage, radish, turnip etc.), carrot, celery, lettuce, onion, and parsnip.

Because vegetable seed crops are often grown in small plots, the need for pollination may be satisfied by naturally occurring pollinators. However, honey bees should be supplied to larger commercial plots of 5-10 acres (2- 4 hectares) (Appendix 2). Some crops may require more bees than normal, especially in large plantings. Onions, for example, are unattractive to bees and require 5-15 colonies per acre (13-38 colonies per hectare) to insure adequate pollination.

Many vegetable crops benefit from insect pollination. The Cucurbitaceae is the most important vegetable crop family that requires insect pollination, and includes pumpkin and several varieties of squash, musk melon, watermelon, cantaloupe and cucumber. The number of honey bee colonies that should be placed in commercial plots of these vegetables is dependent on plot size and the availability of other pollinators (Appendix 2 - Stocking Rates).

viii) Nuts

In recent years, there has been increased interest in both commercial and personal-use plantings of nut tree orchards in Canada. Nut producers have been diversifying their plantings using new varieties of northern nut cultivars and hardy clones. The most common nut crops being cultivated include the heart nut, a type of Japanese walnut; the Persian walnut; the Chinese chestnut; and selected clones of hazel-filbert hybrids. Interest has also increased in northern pecan, hardy almond and Chinese-American sweet chestnut hybrids.

Cross-pollination is desirable for most nut species. In some species, such as the pecan, cross-pollination is required but for others, such as the chestnut, it is strongly recommended because the female flower and male catkin mature at different times on the same tree. Some species, such as the Butternut, are considered to be self-pollinated.

Mixed plantings of nut tree varieties are common to facilitate cross-pollination. In most cases, cross-pollination results primarily from wind, but bees and other pollinating insects are known to visit both male and female flowers and insect pollination does occur. The importance of insect pollination to most nut crops increases during inclement weather, especially if heat and drought occur during the flowering period. The use of honey bees for pollination improves the chances of achieving maximum production and should be encouraged.

Almonds (*Prunus amygdalus* (L.) Bartsch) benefit substantially from honey bee pollination. For maximum pollination, it is recommended honey bee colonies be placed in almond orchards during flowering.

ix) Greenhouse Pollination

Insects are utilized for the pollination of a number of greenhouse crops such as cucumbers, melons, strawberries and bell peppers. Although honey bees are often used for greenhouse pollination they tend not to forage well indoors and colony strength can rapidly dwindle. To maintain the pollination efficiency of honey bees in greenhouses colonies need to be closely monitored and regularly fed pollen to stimulate brood rearing, and sugar syrup for energy requirements.

Older forager bees, when introduced with their hive into a greenhouse, tend to become disoriented and often congregate in high corners away from the plants requiring their pollination services. However, young bees that begin their foraging under greenhouse conditions are less likely to become disoriented and are more efficient pollinators. Leaving open ends in greenhouses (as in plastic tunnel houses) provides honey bees with an opportunity to forage on the greenhouse crop or on plants outdoors. Some situations call for the rotation of hives into and out of greenhouses on a weekly or biweekly basis to allow colony strength, lost in the greenhouse, to be regained outside. Hives for greenhouse pollination may vary from mini-hives containing 5,000- 7,000 bees, to single brood chamber hives containing 10 frames or 24,000 bees. Several small hives usually result in better pollination than one large one. Colonies generally take a few days to settle into their surroundings in a greenhouse, following introduction.

Bumble bees are now well established as the pollinator of preference for greenhouse tomatoes in Europe and Canada. Native Canadian species are excellent tomato pollinators. The culture of bumble bees is becoming well developed in Canada, and it is expected that these bees will become increasingly available commercially as beekeepers and growers expand the greenhouse and field crops that can be pollinated commercially by bumble bees.

Other bees, such as leafcutting and *Osmia* spp. bees, also can be used in greenhouses for seed production, but they are not widely used commercially. These bees and various flies (blowflies, houseflies, and flower flies) are used for vegetable seed production in commercial operations in several countries.

VII. PESTICIDE HAZARDS AND BEE POLLINATORS

i) Introduction

Chemical pesticides are important tools in agricultural production, but their use is sometimes incompatible with insect pollination. Correct choices of pest control materials, proper application techniques, and cooperation between beekeepers, growers and pesticide applicators are necessary to minimize potential problems. Awareness and implementation of the principles of integrated pest management will lessen dependence on calendar spray schedules and optimize spray timing to reduce hazards to pollinators.

Pesticides can be classified according to the type of pest they control (insecticides, herbicides, fungicides, etc.). However, many are non-specific toxins that affect more than target pests, making them hazardous to pollinators. For example, paraquat is a herbicide that is also highly toxic to many other organisms, including insects and mammals.

ii) Pesticide Toxicity and Honey Bees

Insecticides pose a great danger to bees. In fact, honey bees are sometimes more susceptible to poisoning than are insect pests. Factors that influence the relative hazards of insecticides are discussed below.

Chemistry

The major chemical classes of insecticides are organophosphates (e.g. diazinon, Guthion®), carbamates (e.g. Sevin®, aldicarb), synthetic pyrethroids (e.g. permethrin, fenvalerate), and organochlorines (e.g. DDT, chlordane). In addition to these, other compounds do not fit into discrete chemical classes but are classified according to their mode of action (e.g. insect growth regulators) or origin (botanicals such as rotenone and pyrethrum; microbial insecticides such as *Bacillus thuringiensis,* or B.t.).

Insecticides belonging to the same chemical class often share similar chemical properties that determine toxicity, persistence, and overall hazard. However, there are some compounds within each class that do not share common properties and present hazards that are difficult to predict. It is important to know the properties of the chemicals being used to assess their potential danger to bees. For example, dichlorvos (Vapona®) is an organophosphate that is often formulated into solid strips and released slowly for long-term insect control. However, Vapona® also has a high affinity for wax and must never be used in buildings where honeycomb is being stored.

Acute Toxicity

Toxicity following short-term exposure is usually expressed as LD50: the "lethal dose" that kills 50% of the treated insects in a specified period of time (usually 24 hours).

Lower LD50 values indicate more toxic insecticides (i.e. it takes less material to kill 50% of the insects). LD50 is usually expressed as micrograms (g) of insecticide per insect, or in terms of concentration as parts per million (ppm= one part insecticide in one million parts tissue).

Residual Activity

Most pesticides remain toxic in the environment for a period of time following application. This characteristic of pesticides is termed residual activity and it varies depending on temperature, humidity, exposure to direct sunlight, and other environmental factors. Residual activity and acute toxicity combined give a good relative measure of hazard. A highly toxic insecticide with short residual activity can be used with relative safety if applied at the proper time, such as in the evening after foraging has ceased. Conversely, a moderately toxic material possessing long residual activity can remain hazardous for extended periods.

Formulation

Most pesticides require formulation before they are useful for pest control. Commercial products contain the active ingredient in combination with solvents, dusts, emulsifiers, stickers, and other inert ingredients. Formulation greatly influences the hazard of an insecticide to pollinating bees. Dusts/microcapsules are more hazardous than wettable powders, which are more hazardous than emulsifiable concentrates. Granular formulations are the least hazardous to bees. Dusts and microcapsules are particularly toxic because they are approximately the size of pollen grains and can be picked up by foragers and transported back to the colony. Some formulations reduce the hazard by including stickers which decrease the risk of bees picking up material from plant surfaces.

Most insecticides are nerve poisons that are effective via both contact and oral exposure. Bees encounter these toxins in the field by walking on surfaces covered by spray residues, flying through drifting spray droplets, or consuming contaminated water. Only foraging workers contact sprays in these ways; hive bees and brood, as well as the queen, contact insecticides only when foragers carry toxins back to the hive. Colony exposure to low doses of insecticide may have serious long-term consequences, including depletion of hive bees followed by starvation or brood chilling, poor egg laying and eventual queen supersedure, or death of the entire colony in extreme cases. Sublethal insecticide doses also affect individual bees by shortening their life spans and disrupting their ability to communicate locations of floral nectar and pollen sources.

Another possible route of exposure is through contamination of nectar with systemic insecticides that are taken up by the plants. This problem has occurred following mis-timed applications of dimethoate. Proper timing of these sprays is vital to prevent serious bee kills.

Worker bees exposed to insecticides exhibit a variety of poisoning symptoms, many of which are common to more than one insecticide class. Symptoms include aggressiveness, erratic movements, regurgitation of stomach contents ("wet bees", often seen in organophosphate poisoning), trembling or spinning on the back, and inability to fly with the appearance of being chilled ("crawlers", often caused by poisoning from Sevin®). Dead bees also can be observed in piles at the hive entrances in cases of severe poisoning by relatively slow-acting toxins. Highly toxic, fast acting materials such as synthetic pyrethroids usually kill the bee before it can return to the colony.

iii) How to Avoid Pesticide Poisoning

Cooperation between beekeepers, growers, and pesticide applicators is the most important safeguard against bee poisoning. In particular, an understanding between grower and beekeeper that each contributes to the other's success go a long way towards solving problems.

The best protection for hives is to place them in areas that are isolated from insecticide applications. This is often impossible if the hives are used to provide pollination services or if they are situated in areas with commercial crops. Unmarked colonies should never be left near orchards or fields likely to be sprayed. Leave your name, address, and phone number posted in print large enough to be read from some distance away so you can be contacted regarding upcoming sprays.

If pesticide spraying is imminent, move the colonies out of the area if feasible. If not, cover the entire hive with burlap or other similar material, pulling out and securing the edges like a tent. It is essential that an internal source of fresh water be provided to allow the bees to cool the colony during its confinement, which can be up to 48 hours after the application of some highly toxic materials. More information on these procedures can be obtained from your local extension agent.

help prevent losses by following proper spray procedures. Always read and understand the information on the pesticide label, and never apply insecticides to crops in bloom. If possible, spray in the evening after foraging has ceased. If several registered products are available, use the material that is least hazardous to bees if this is consistent with other pest management considerations. Use liquid formulations instead of the more hazardous dusts when appropriate. In orchards, mow cover crops to remove dandelion blooms before applying insecticides.

If poisoning is evident, collect a sample of dead bees in a glass jar as soon as possible. Keep frozen and label with the date and as much other information as possible. Find out what was sprayed from the grower/applicator, and report the incident to the appropriate government agency. This information is essential to minimize future poisoning incidents and/or to support damage claims. Feed poisoned colonies pollen supplement and sugar syrup to stimulate brood rearing.

Less information is available concerning pesticide effects on alternative pollinators, particularly at sublethal doses. Alfalfa leafcutting bees can be protected by storing nests in a cool room or basement during spraying. Nests can be moved at night, and bees are almost completely inactive at 15oC (60oF). Nest shelters also can be designed to be closed or covered for short periods during the spray operation. Other pollinators such as bumblebees can be protected by conserving nesting sites in hedgerows and adjacent uncultivated land. Herbicides should not be applied to such areas unless absolutely necessary for noxious weed control.

IX. APPENDIX 1

The Value of Honey Bee Pollination in Canada

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Agriculture and Agri-Food Canada
Market and Industry Services Branch
Horticulture and Special Crops Division
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INTRODUCTION

The purpose of this report is to update the estimate of the economic value of honey bees as crop pollinators and to assess the cost/benefit ratio of pollination services. The report was last undertaken in August 1992 utilizing crop values based on 1990 data from Statistics Canada. This report utilizes crop values based on 1998 data.

METHOD

Estimation Formula

To estimate the dollar value of honey bee pollination to Canadian agriculture, a study developed by Willard S. Robinson and his coworkers at Cornell University was adopted (Robinson et al. 1989). In their study, they estimated that the annual value of honey bee pollination to agriculture in the United States was as high as $US 9.3 billion in 1987. The study was subsequently updated to an estimate of $US 14.6 billion in 2000. The following formula was used:

The value of honey bees to agriculture = V x D x P

where

V : annual value of the crop attributable to honey bee activity

D : **dependency of the crop on insect pollinators**

P : proportion of **(-effective-)** insect pollinators of the crop that are honey bees

The dependancy factor "D" was calculated according to the following formula for crops where data could be found in studies on crop pollination:

$D = (Y_o - Y_c)/Y_o$

where

Y_o : open pollinated yield or yield in cages with bees provided

Y_c : yield in cages without insects

In using the dependency factor, only the value of the yield above what would be obtained in the absence of honey bees is considered, not the entire value of the crop. In the case of crops that benefit from insect pollination in more ways than increases in yield, such as improved quality and uniformity, an arbitrary value of 0.1 was added to the calculated D-value.

Except when a P-value **for** a particular crop could be found in the literature, Robinson et al. (1989) assigned P the value of 0.8. This value was based on the widely accepted estimate that honey bees account for at least 80% of all pollinators. For crops that normally have a presence of bee hives for pollination or honey production, a coefficient of 0.1 was added to the P-value to reflect the higher density of honey bees.

The value of the "D" and "P" factors vary among cultivars, regions and crop management practices. In the absence of scientific data for the wide range of crops and varieties grown in Canada, a process of consensus was initiated to arrive at a reasonable estimate for "D" and "P" values. An initial draft of the 1992 report which used the assumptions of Robinson et al. (1989) for the "D" and "P" values was circulated to Canadian apiculturists, plant scientists and horticulturists. This was followed by a series of interviews, to adjust the "D" and "P" values to generally accepted values for Canada, considering an average for each crop and assuming that honey bees were generally used for many crops even though alternative pollinators could possibly be more effective if they were available. The exception to this assumption is the lower "P" value for alfalfa because of the extensive use of leaf cutter bees for that crop.

In the case of fababeans, the "P" value was arbitrarily fixed to be equal to 0.8 and the "D" value was determined to be 0.5 from research data found in Pesson and Louveaux (1984). This means that 40% of the crop value is directly attributable to honey bees.

Selected Crops

The crops selected for this report are those commercially grown in Canada and are known to be dependent on insect pollination or to benefit from insect pollination. Crops have been considered only if farm value data were available, or were computable from production and price data. This excluded minor crop seed production. Furthermore, unlike the work of Robinson et al. (1989), only crops that were assessed to be directly dependent on pollination were considered. Crops like asparagus or alfalfa and clover hay which only benefit from pollination for seed were disregarded. The dollar value estimation is based on the 1998 crop value as published by Statistics Canada.

Assessment of the cost/benefit ratio of pollination services

Although most honey in Canada is produced from mutual benefit placement, particularly for crops like clover, buckwheat and canola, a large number of hives are rented from beekeepers for high value horticultural crops. Provincial apiarists were contacted to obtain recent figures on the number of rentals of colonies in their region, the crops for which beehives were rented and the rental fee.

Data from Quebec were based on a survey conducted by "le Bureau de la statistique du Québec" in 1998. All other provinces could provide only an estimate of the number of rentals and the rental fees. For this reason, it was decided to assess a cost/benefit ratio only for blueberry and apple production in Quebec.

The cost/benefit ratio is calculated as follows:

$b/c = V_{hb}/pf$

where

b/c = cost/benefit ratio

V_{hb} = value of honey bee pollination to a crop

pf = total amount of fees paid for pollination services for a crop

RESULTS

Value of honey bee pollination to Canadian agriculture

The estimated total value to Canadian agriculture is estimated to be about $782 million (Table 1). This is approximately eight times greater than the annual farm value for honey and wax, which had a value of $93.5 million in 1998. The value of honey bee pollination represents 21% of the total farm value of approximately 26 selected crops.

Provincial values for pollination (Tables 4 and 5) provide an estimate of the benefit of honey bees to pollination in each province. Provinces with high production of highly dependent crops show the highest values even though they do not have the highest populations of honey bees. This explains the higher demand for colony rentals in Ontario and British Columbia. (Table 2).

Cost/benefit ratio of pollination services

Approximately 93,000 rentals of honey bee colonies for crop pollination took place in 1998, mostly for apple, blueberry and canola production Quebec, Ontario and Alberta (Table 2).

The estimation of a cost/benefit ratio for apples in Quebec indicated that for each dollar spent in rental fees, producers realized a gain of $185 (Table 3). Because of low blueberry production in Quebec due to a killing frost in the Spring of 1998, the cost benefit ratio was approximately $5 compared to $41 in 1990. Quebec apples had a cost benefit ratio of $185 in 1998, compared to $192 in 1990.

CONCLUSI0N

The 1998 value of honey bees as pollinators for Canadian crops was assessed to be $782 million, up from $444 million in 1990. This estimate is conservative, as many minor crops were omitted and as values for "D" and "P" may be estimated lower than the actual value. Therefore, the vital importance of honey bees to agriculture, not only as honey producers, but also as pollinators, is clearly demonstrated.

The cost/benefit analysis, using data from Quebec, showed that each dollar invested in pollination services produced very attractive returns to apple producers, while corresponding figures for blueberries were down significantly due a killing frost at blossoming. The rental of honey bee colonies is an important management tool to assure the highest possible yields and quality of product.

Table 1: Estimation of the Value of Honey Bee Pollination in Canada - 1998					
Crop	DEPENDENCE ON INSECTS	HONEY BEE PORTION	DEPENDENCE ON HONEY BEES (%)	Production Value ($'000)	Honey Bee Contribution ($'000)
Tree Fruits					
Apples	1.00	0.85	85	161533	137303
Apricots	0.70	0.80	56	1031	577
Sour Cherries	0.70	0.90	63	256	161
Sweet Cherries	1.00	0.90	90	7709	6938
Nectarines	0.35	0.80	28	4557	1276
Peaches	0.35	0.80	28	27165	7606
Pears	1.00	0.90	90	13551	12196
Prunes & Plums	0.80	0.90	72	3875	2790
Berries					
Grape	0.10	0.10	1	58555	586
Kiwis	0.90	0.90	81	328	266
Blueberries	1.00	0.90	90	56626	50963
Raspberries	0.90	0.80	72	21313	15345
Strawberries	0.30	0.80	24	51156	12277
Cranberries	1.00	0.90	90	28395	25556
Cucurbits					
Cucumbers	1.00	0.90	90	10468	9421
Melons	1.00	0.80	80	560	448
Pumpkin	1.00	0.60	60	5947	3568
Squash and Zucchinis	1.00	0.60	60	4145	2487
Oilseeds					
Canola/Rapeseed	0.20	0.90	18	2512354	452224
Sunflower	0.20	0.80	16	19699	3152
Mustard	0.20	0.80	16	1519	243
Soybeans	0.10	0.50	5	652000	32600
Forage legume Seeds					
Alfalfa Seed	1.00	0.10	10	9500	950
Clover Seed	1.00	0.70	70	1229	860
Pulses & Other Crops					
Fababeans	0.50	0.80	40	1920	768
Buckwheat	0.80	0.80	64	1534	982
TOTALS				**365,6925**	**781,542.64**
Sources: Statistics Canada 22-003 Feb 2000, Provincial Ministries of Agriculture, Bureau de la Statistique de Quebec, Provincial Apiculturists					

Table 2: Canada 1998 Honey Bee Colony Rentals For Polination Services				
Province		Crops	Colony rentals (Number)	Rental Fee $
Nova Scotia	NS/NE	app,bl,bh,s,cr,cc	16100	$45 - $90
PEI/IPE	PEI/IPE			
New Brunswick	NB			
Quebec	QU	b	14173	$58
Quebec	QU	c	414	$54
Quebec	QU	s	760	$38
Quebec	QU	r	179	$40
Quebec	QU	app	3335	$33
Ontario (spring)	ON	app	12000	$40
Ontario (summer)	ON	c	3000	$90
Manitoba	MAN	c/r	840	$ 75 - $ 108
Manitoba	MAN	c/r Hybrid in Tents	260 five-frame nucs	$ 40 - $ 60
Saskatchewan	SASK	c/r	4200	$ 110 ¤
Alberta	ALB	c/r	40000	$ 108 ¤¤
British Columbia	BC/CB	app	6300	$ 40 - $45
British Columbia	BC/CB	b,c,s,r,app	1500	$ 35 - $ 45
British Columbia	BC/CB	c/r	300	$110
British Columbia	BC/CB	c	800	$ 40 - $ 45
British Columbia	BC/CB	cr	1800	$ 80 - $ 90
British Columbia	BC/CB	p	800	$ 40 - $45
British Columbia	BC/CB	r	2000	$ 40 - $45
CANADA		All crops	92661	

Colony Rental Notes:
All values estimated by the Provincial Apiculturists except for Québec where the values are from the Bureau de la statistique de Québec.
¤ - Saskatchewan stocking rate of 3 hives/acre
¤¤ - Alberta has an additional moving allowance for long moves

Table 2 Continued						
Crop Abreviations						
Tree Fruits		fruit de verger		Cucurbits		cucurbitacées
Apples	app	pomme		Cucumbers	c	concombre
Apricots	ar	abricot		Melons	me	melon
Sour Cherries	csr	cerise acide		Peppers	pr	poivron
Sweet Cherries	csw	cerise		Pumpkin	pk	citrouille
Nectarines	n	nectarines		Squash and Zucchinis	sz	courge et zucchini
Peaches	pc	pêche		tomatoes	tom	tomate
Pears	pr	poire				
Prunes & Plums	pp	prune		Oilseeds		oléagineux
				Canola/Rapeseed	c/r	colza/navette
				Sunflower	sf	tournesol
Berries		la baie		Mustard	ms	graine de moutard
Grape	g	raisin		Soybeans	sb	soja
Kiwis	k	kiwi				
Blueberries	b	bluet		Forage legume Seeds		légumineuse fourragère
lowbush	bl	bluet sauvage		Alfalfa Seed	al	luzerne
highbush	bh	bluet cultivé		Clover Seed	cl	trèfle
Strawberries	s	fraise				
Cranberries	cr	canaberge		Pulses & Other Crops		
Raspberries	r	frambois		Fababeans	fb	haba
				Buckwheat	bw	sarrasin

Table 3: 1990 and 1998 Estimation of the Cost/Benefit Ratio for the Pollination of Two Horticultural Crops Based on Quebec Statistical Data

Crop	Crop Value ($'000)	Dependence on Honey Bees (1=100%)	Honey Bee contribution ($'000)	Pollination Fees Paid ($'000)	Cost/Benefit Ratio ($)
1998					
Blueberry	$4,395.00	0.9	$3,956.00	$816.80	$4.83 *
Apples	$22,665.00	0.9	$20,399.00	$110.30	$185.00
* Due to frost 1998 was an abnormally poor year for blueberry production in Quebec					
1990					
Blueberry	$9,443.00	0.9	$8,499.00	$207.60	$41.00
Apples	$19,927.00	0.9	$19,804.00	$103.30	$192.00

Table 4: Estimation of the Provincial Values of Crops Affected by Honey Bee Pollination in Canada - 1998										
CROP VALUE DATA 1998 x $1000	Newfoundland Crop Value	Nova Scotia Crop Value	PEI/IPE Crop Value	New Brunswick Crop Value	Quebec Crop Value	Ontario Crop Value	Manitoba Crop Value	Saskatchewan Crop Value	Alberta Crop Value	British Columbia Crop Value
Tree Fruits										
Apples		12700		1800	22665	85315				39053
Apricots						290				741
Sour Cherries										256
Sweet Cherries						2652				5057
Nectarines						3715				842
Peaches						23460				3705
Pears						8950				4601
Prunes & Plums						3365				510
Berries										
Grape					405	42725				15425
Kiwis										328
Blueberries	920	16300	1730	7967	4395	2160				23154
Raspberries	55	278	35	255	4415	3505	195	35	210	12330
Strawberries	915	2405	805	1745	15050	17430	1410	305	2350	8741
Cranberries		X			X	X				28395
Cucurbits										
Cucumbers					8450					2018
Melons										560
Pumpkin					940	2210	100			2697
Squash and Zucchinis					1845	2130	170			
Oilseeds										
Canola/Rapeseed						20480	622296	1022883	846695	

Sunflower							19699			
Mustard							1519			
Soybeans						652000				
Forage legume Seeds										
Alfalfa Seed							9500			
Clover Seed							1229			
Pulses & Other Crops										
Fababeans							1920			
Buckwheat						1094	440			
Sources : Statistics Canada 22-003 Feb 2000, Provincial Ministries of Agriculture, Bureau de la Statistique de Quebec, Provincial Apiculturists										
X : Confidential										

Table 5 : Estimation of the Provincial Values of Honey Bee Pollination in Canada – 1998											
CROP VALUE DATA 1998 x $1000	DEPENDENCE ON HONEY BEES (%)	Newfoundland Honey Bee Contribution	Nova Scotia Honey Bee Contribution	PEI Honey Bee Contribution	New Brunswick Honey Bee Contribution	Quebec Honey Bee Contribution	Ontario Honey Bee Contribution	Manitoba Honey Bee Contribution	Saskatchewan Honey Bee Contribution	Alberta Honey Bee Contribution	British Columbia Honey Bee Contribution
Tree Fruits											
Apples	85		10795	0	1530	19265	72518	0	0	0	33195
Apricots	56		0	0	0	0	162	0	0	0	415
Sour Cherries	63		0	0	0	0	0	0	0	0	161
Sweet Cherries	90		0	0	0	0	2387	0	0	0	4551
Nectarines	28		0	0	0	0	1040	0	0	0	236
Peaches	28		0	0	0	0	6569	0	0	0	1037
Pears	90		0	0	0	0	8055	0	0	0	4141
Prunes & Plums	72		0	0	0	0	2423	0	0	0	367
Berries			0	0	0	0	0	0	0	0	0
Grape	1		0	0	0	4	427	0	0	0	154
Kiwis	81		0	0	0	0	0	0	0	0	266
Blueberries	90	828	14670	1557	7170	3956	1944	0	0	0	20839
Raspberries	72	40	200	25	184	3179	2524	140	25	151	8878
Strawberries	24	220	577	193	419	3612	4183	338	73	564	2098
Cranberries	90		0	0	0	0	0	0	0	0	25556
Cucurbits			0	0	0	0	0	0	0	0	0
Cucumbers	90		0	0	0	7605	0	0	0	0	1816
Melons	80		0	0	0	0	0	0	0	0	448
Pumpkin	60		0	0	0	564	1326	60	0	0	1618
Squash and Zucchinis	60		0	0	0	1107	1278	102	0	0	0

Oilseeds			0	0	0	0	0	0	0	0	0
Canola/Rapeseed	18		0	0	0	0	3686	112013	184119	152405	0
Sunflower	16		0	0	0	0	0	3152	0	0	0
Mustard	16		0	0	0	0	0	243	0	0	0
Soybeans	5		0	0	0	0	32600	0	0	0	0
Forage legume Seeds			0	0	0	0	0	0	0	0	0
Alfalfa Seed	10		0	0	0	0	0	950	0	0	0
Clover Seed	70		0	0	0	0	0	860	0	0	0
Pulses & Other Crops			0	0	0	0	0	0	0	0	0
Fababeans	40		0	0	0	0	0	768	0	0	0
Buckwheat	64		0	0	0	0	700	282	0	0	0
Sources : Statistics Canada 22-003 Feb 2000, Provincial Ministries of Agriculture, Bureau de la Statistique de Quebec, Provincial Apiculturists											
X : Confidential											

X. APPENDIX 2

Recommended honey bee colony stocking rates for crops discussed in this publication

CROP	LATIN NAME	POLLINATOR REQUIREMENTS	No. COLONIES REQUIRED per acre (per hectare)
Apples	*Malus* spp.	honey bees	1.5-5 (4-12.5)*
Peaches	*Prunus persica*	self-fertile, honey bees optional	1 (2.5)
Sour Cherries	*Prunus cerasus*	self-fertile, honey bees optional	1-2 (2.5-5.0)
Sweet Cherries	*Prunus avium*	honey bees	1-2 (2.5-5.0)
Prunes	*Prunus* spp.	honey bees	1 (2.5)
Plums	*Prunus domestica*	honey bees	1 (2.5)
Apricots	*Prunus armeniaca*	honey bees	1 (2.5)
Nectarines	*Prunus* spp.	self-fertile, honey bees optional	1 (2.5)
Pears	*Pyrus communis*	honey bees	1-2 (2.5-5.0)
Grapes	*Vitus vinifera*	wind, self-fertile, no honey bees	0
Strawberries	*Fragaria x ananassa*	alternative bees, honey bees	0.5 (1.25)
Raspberries	*Rubus idaeus*	self-fertile, honey bees optional	1+(2.5+)
Blackberries	*Rubus* spp.	self-fertile, honey bees optional	1 (2.5)
Low-bush Blueberries	*Vaccinium angustifolium*	honey bees, buzz pollination by bumble bees also effective	1-4 (2.5 -10)
High-bush Blueberries	*Vaccinium corymbosum*	honey bees, buzz pollination by bumble bees also effective	2+(5.0+)
Cranberries	*Vaccinium macroparpon*	honey bees, buzz pollination by bumble bees also effective	1 (2.5)
Red Currants	*Ribes sativum*	self-fertile, no honey bees	0
Black Currants	*Ribes nigrum*	honey bees	1-2 (2.5-5.0)
Gooseberries	*Ribes grossularia*	self-fertile, no honey bees	0
Alfalfa	*Medicago sativa*	alfalfa leafcutting bees	6,000-16,000 bees (15,000-40,000 bees)
Red Clover	*Trifolium pratense*	bumble bees and honey bees	1-4 (2.5-10)
Alsike Clover	*Trifolium hybridum*	honey bees	1-3 (2.5-8.0)
White Clover	*Trifolium repens*	honey bees	1-3 (2.5-8.0)

White Sweet Clover	*Melilotus alba*	honey bees	1-3 (2.5-8.0)
Yellow Sweet Clover	*Melilotus officinalis*	honey bees	1-3 (2.5-8.0)
Bird's-Foot Trefoil	*Lotus corniculatus*	honey bees	1-3 (2.5-8.0)
Sainfoin	*Onobrychis vicifolia*	honey bees	1-3 (2.5-8.0)
Field Pea	*Pisum sativum*	self-fertile, self-pollinated, no honey bees	0
Bean	*Vicia faba*	honey bees	1 (2.5)
Lentil	*Lens culinaris*	self-fertile, no honey bees	0
Soybean	*Glycine max*	self-fertile, self-pollinated, no honey bees	0
Canola (Polish)	*Brassica campestris*	honey bees	1-6 (2.5-15.0)**
Canola (Argentine)	*Brassica napus*	self-fertile, however reports on pollinator requirements are conflicting	0
Yellow/White Mustard	*Brassica hirta*	honey bees	1-2 (2.5-5.0)
Sunflower	*Helianthus annuus*	self-fertile, no honey bees for new hybrid strains	0
Flax	*Linium usitatissimum*	self-pollinating	0
Almond	*Prunus amygdalus*	honey bees	2 (5.0)
Cole Crops: e.g. broccoli, cauliflower, brussels sprouts		honey bees	2-4+ (5.0-10.0+)**
Onion	*Allium cepa*	honey bees for seed production	5-15 (12.5-37.5)
Asparagus	*Asparagus officinalis*	honey bees for seed production	2 (5.0)
Pumpkins and Squash	*Cucurbita* spp.	honey bees	1-3 (2.5-7.5)
Muskmelon	*Cucumis melo*	honey bees	1 (2.5)
Cucumber	*Cucumis sativus*	honey bees in field plantings	1-3 (2.5-7.5)
Tomato	*Lycopersicon esculentum*	field=self-fertile and wind, no honey bees greenhouse=bumble bees	0

* Stocking rate for apples increases with the density of the planting (ie. standard, semi-dwarf, high density semi-dwarf, dwarf and solid block plantingswith pollen inserts)

** Seed production is enhanced if the highest recommended number of colonies is used.

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