Current status and agricultural utilization of insect pollinators in Korea

Hyung Joo Yoon and In Gyun Park
Applied Entomology Division, Department of Agricultural Biology,
National Academy of Agricultural Science, Suwon, 441-100 Korea
E-mail: yoonhj1023@korea.kr, smja2995@korea.kr

Abstract

This paper describes bumblebee rearing technology as well as the current status and agricultural utilization of insect pollinators in Korea. We investigated the use rate and number of commercial bees such as bumblebees and honeybees for the pollination of 10 major horticultural crops in Korea. The use rates of bumblebees and honeybees for 10 major horticultural crops were approximately 7.9% and 48.0% in 2009, respectively. The use numbers of bumblebees and honeybees as pollinators was more than 51,400 colonies and 305,216 hives, respectively, in 2009. The number of *Osmia* mason bees used as orchard pollinators was approximately 570,000 individuals in 2009. The value of commercial insect pollinators in 2009 was estimated at more than $45 million.

Key words: Insect pollinator**,** Bumblebee, Honeybee, *Osmia* mason bee

Introduction

Bees are important for pollination, and arguably, the most important activity of bees is their pollination of natural vegetation and agricultural plants including fruits, vegetables, seed plants, edible oil crops, garden flowers, fiber crops like flax and cotton, and major forage crops. The products of honeybees are of obvious benefit, but they are of trivial value compared to the profoundly important role of bees as pollinators. Bees are diverse and abundant, with 16,325 species identified throughout the world (Michener, 2000). However, the true number of bee species is actually unknown because not all have been given a name, and some have yet to be recognized or discovered. Insect pollination is both an ecosystem service and a production practice used extensively by farmers all over the world for crop production. We rely on bees to pollinate 87 of the 124 (70%) most valuable crops used directly for human consumption (Klein et al., 2007). The production of 84% of crop species cultivated in Europe depends directly on insect pollinators, especially bees (Williams, 1994). Worldwide, bees pollinate more than 400 crop species and in the United States more than 130 crop species (James and Pitts-Singer, 2008).

Pollination is an ecosystem service in that wild pollinators, in particular wild bees, contribute significantly to the pollination of a large array of crops (Morandin and Winston, 2005; Greenleaf and Kremen, 2006; Winfree et al., 2007, 2008). Commercially managed bees are also available for pollination services and are used in large commercial fields, small gardens, or enclosures such as greenhouses and screen houses. Although the general public gives honeybees much of the credit for pollination, managed bumblebees and solitary bees also have a great impact on certain commodities (Free, 1993; Dag and Kammer, 2001). Thus the economic benefit of insect pollination is clear for farmers, and the market for colony rental is now well developed and organized for honeybees in the United States (Sumner and Boriss, 2006) and Europe (Carreck and Williams, 1998) as well as for bumblebees all over the world (Velthuis and van Doorn, 2006). For the 100 crops used for human food worldwide, the total economic value of pollination throughout the world amounted to € 153 billion in 2005, which was about 9.5% of the value of the world agricultural production used for human food (Gallai et al., 2009).

Here, we discuss the current status and agricultural utilization of commercial bees such as bumblebees, honeybees, and mason bees as pollinators in Korea. We also describe year-round techniques for rearing the Korean native bumblebee *Bombus ignitus*.

Commercially managed bumblebees

The introduction of bumblebees into greenhouses for pollination has become widespread in recent years, and demand increases annually. Bumblebees provide farmers the opportunity to decrease their pollination labor costs and promise a good crop yield, both in quantity and in quality (reviewed by Velthuis and van Doorn, 2006). They are more effective than honeybees in cloudy weather and in small areas, such as a greenhouse. Bumblebees also tend to devote themselves mainly to the crops within the greenhouse, whereas honeybees are apt to escape en masse to the outside. Bumblebees are particularly effective at pollinating Solanaceae, including the tomato and eggplant. It has been estimated that the bumblebees sold in 2004 consisted of approximately 930,000 colonies of the Eurasian *B. terrestris*, approximately 55,000 colonies of the North American *B. impatiens*, and a few thousand colonies of the Eurasian *B. lucorum*, East Asian *B. ignitus*, and North American *B. occidentalis* (Velthuis and van Doorn, 2006).

The large bumblebee, *Bombus terrestris*, which is indigenous to Europe, has been artificially introduced in several parts of the world. Since 1988, *B. terrestris* has been available commercially in portable boxes for crop pollination (Mitsuhata, 2000). Colonies of *B. terrestris* have been imported into many countries, including Korea, Japan, China, Taiwan, Mexico, Chile, Argentina, Uruguay, South Africa, Morocco, and Tunisia (Dafni, 1998). There has been some anxiety associated with the introduction of *B. terrestris* into greenhouses because it is highly invasive, could potentially escape from greenhouses, and could have negative effects through competition (Ono and Wada, 1996; Velthuis and van Doorn, 2006) or genetic contamination by hybridization (Velthuis and van Doorn, 2006) with native bumblebees. The competitive displacement of native pollinators and the invasion of native vegetation by *B. terrestris* have already been recorded in Tasmania (Semmens *et al*., 1993). In Israel, the numbers of honeybees and solitary bees have declined with the range expansion of *B. terrestris* (Dafni and Shimida, 1996). *B. terrestris* has also colonized Japan, where it escaped from greenhouses in 1996 after its introduction in 1991 (Washitani, 1998). For this reason, the governments of Canada and the USA prohibit the introduction of foreign bumblebee species, and at present a native bumblebee *B. impatiens* is used for commercial pollination in North America (Velthuis and van Doorn, 2006). In Korea, *B. terrestris* was first introduced in 1994, and in early May 2002 to 2004, *B. terrestris* overwintering queens were caught in several regions (Yoon et al, 2009). We are studying the artificial year-round mass rearing of *B. ignitus*, a Korean native bumblebee, because this species is the most reliable native bumblebee for crop pollination (Yoon et al., 1999, 2002, 2003, 2004).

Establishment of year-round rearing of Korean native bumblebee *B. ignitus*

We investigated the optimum temperature and humidity, the effects of photoperiod and CO_2-treatment, the facilitating effects of helpers, and artificial hibernation of *B. ignitus* to establish year-round mass rearing of *B. ignius*. The experimental temperature and humidity conditions tested were 23°C, 27°C and 30°C at a constant humidity of 65% R.H., and 50%, 65% and 80% R.H. at a constant temperature of 27°C, respectively. The conditions 27°C and 65% R.H. were determined to be the most favorable environmental conditions for colony development of *B. ignitus* in indoor rearing (Yoon et al., 2002). We also investigated whether the developmental characteristics of foundation queens of *B. ignitus* would be affected by the first oviposition days. The results revealed that a queen with an early first oviposition day could make a stronger colony and could make the colony formation period shorter; therefore, the first oviposition day of foundation queen was proved to be a criterion for the selection of super colonies when *B. ignitus* is raised indoors (Yoon et al., 2004). To stimulate colony initiation, we investigated whether or not such helpers as worker bees, bee-cocoons and egg-cups, etc., have any effects on oviposition and colony foundation of the queen bumblebee, *B. ignitus*. Among the helpers tested, callow workers of *B. ignitus* and *B. terrestris* showed the most substantial effects on the oviposition rates, to 92% and 88%, respectively. A narcotized old worker, aged 10 days after emergence, showed similar effects to a callow worker on colony development. In the number of workers recruited to a foundation queen, two workers showed a better effect than one worker on colony development (Yoon and Kim, 2002).

The effect of photoperiodic regimes on the oviposition and colony development of *B. ignitus* queens was examined with 0L, 8L, and 16L under 27°C and 65% R. H. The light conditions (8L and 16L) were more suitable than the dark condition (0L) for oviposition and colony development for *B. ignitus* in indoor rearing conditions (Yoon and Kim, 2003). We investigated mating conditions as follows: photoperiod, illumination, and temperature during mating periods; care temperature of queen before mating; mating period; and number of queens per mating cage, to improve the mating rate of *B. ignitus*. Among photoperiodic regimes of 12L, 14L and 16L during mating periods, queens mated at 14L showed better results than at 12L and 16L in egg-laying characteristics and colony development. An intensity of 1000 lux was more effective than intensities of 100 lux or 2000 lux in mating *B. ignitus* queens. The most favorable mating temperature and care temperature of the queen before mating favorable for *B. ignitus* queens were 22-25°C and 19°C, respectively. The period needed to mate a *B. ignitus* queen was 3 days, and the number of queens suitable per mating cage of 55× 45× 65 cm was 30 (Yoon et al., 2007).

The effect of CO_2-treatment on interrupting diapause of *B. ignitus* was examined to provide a means for year-round rearing of the bumblebee. When mated young queens were exposed to 65% or 99% CO_2 for 30 min daily during two consecutive days, the oviposition rate increased to 75% and 77%, respectively. At the same time, the days needed before first oviposition shortened to 17-18 days in CO_2-treated queens, compared to 30 days in CO_2-untreated queens. CO_2-treatment on the second day after mating was favorable to oviposition and colony development. CO_2-treatment showed a positive effect on oviposition and colony development, but CO_2-treated queens still produced fewer progeny than over-wintered queens (Yoon et al., 2003). Artificial hibernation is essential for year-round rearing of the bumblebee *B. ignitus*, which undergoes one generation per year. It is known that keeping the queens at a low temperature for two or three months is an effective way to terminate their diapause and develop the colony. Temperature, time and surroundings for the queens during artificial hibernation were investigated. Among the tested temperatures, -2.5°C, 0°C, 2.5°C, and 5°C, the optimum temperature was 2.5°C, at which the survival rate after chilling of the queens was high and colony development thereafter was enhanced. The proper time to initiate chilling the queen was 10 to 14 days after adult eclosion, and the survivability of the queens after chilling was good. For the surroundings of the queen during artificial hibernation, we proposed the method of preserving them in a bottle filled with perlite and keeping it at approximately 80% R. H (Yoon, 2003).

Bumblebee as a pollinator

In 1994, 2,300 *B. terrestris* colonies were first introduced into Korea. We transferred more than 10 patents and 20 bumblebee rearing techniques to farmers for commercial rearing of bumblebees from 2004 until. Since then, many more producers have started commercial rearing of bumblebees. There are over 10 producers in Korea today. The total number of bumblebee colonies produced in 2009 was over 500,000, of which 35,000 colonies (70%) were produced by Korean bumblebee companies and 15,000 colonies imported from foreign sources (Yoon, H.J., personal communication, 2010). In 1994, the value of a bumblebee colony was $ 167. Now, 15 years later, is $ 67, which is more than 60% cheaper than in 1994.

We investigated the role of bumblebees used for pollination in greenhouse plants. The rate of use of bumblebees as pollinators for 10 major horicultural crops averaged 7.9%, which was calculated including paprika (60.9%), tomato (39.7%), pepper (16.2%), zucchini (5.2%) and watermelon (0.4%). There was no use of bumblebees as pollinators for yellow melon, strawberry, cucumber, melon and eggplant (Fig. 1). The number of colonies used for 10 horicultural crops in greenhouses was estimated to be 31,406, which included 96,733 for tomatoes, 13,780 for peppers, 3,362 for paprika, 1,352 for zucchini, 1,230 for watermelon. The number of bumblebee colonies used was estimated to be more than 51,400 (Fig. 2).

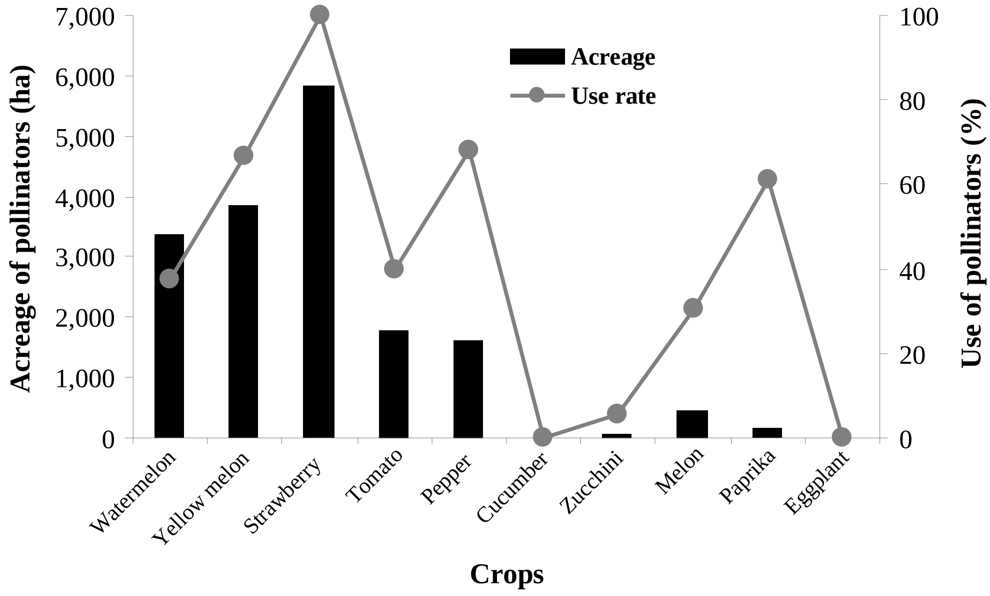


Fig. 1. Acreage and use rate of bumblebees and honeybees used for the pollination of 10 major horticultural corps in greenhouses, 2009.

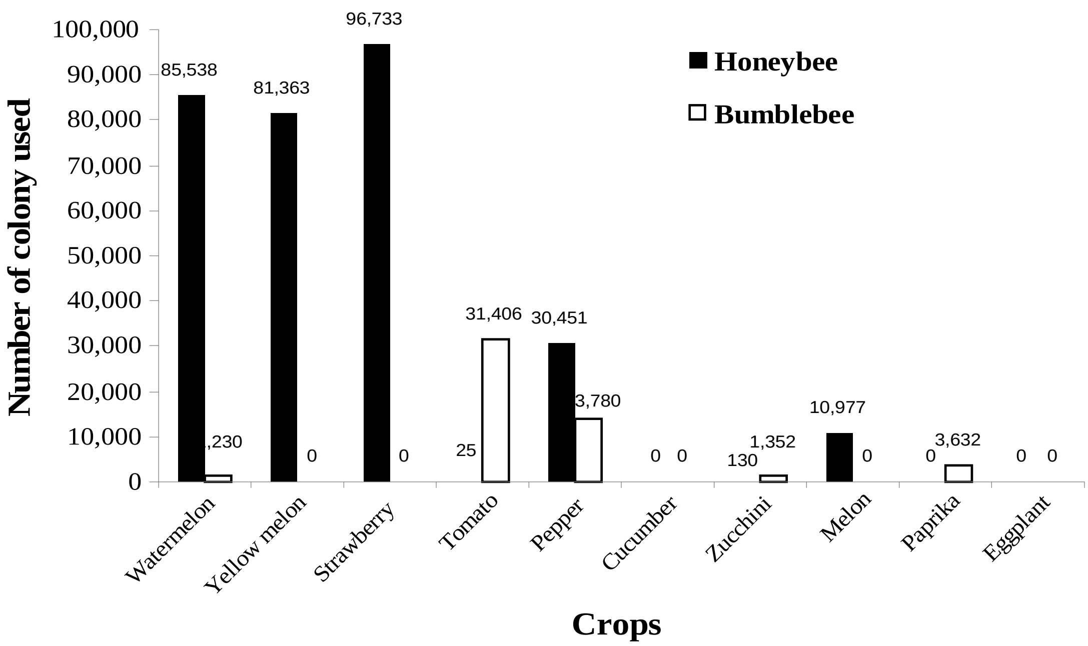


Fig. 2. Numbers of colonies of bumblebees and honeybees used for the pollination of 10 major horticultural corps in greenhouses, 2009.

Honeybee as a pollinator

The most widely used pollinator, and the one with the longest history of domestication, is the honeybee (Crane, 1990), probably utilized for at least 90% of managed pollination services. It has been recognized as an excellent pollinator of many plants, including many crops such as peach, almond, pear, apple, and melon. The main features that place honeybees ahead of other insects and other bees as pollinators are flower constancy, colony size, and recruitment behavior (Corbet et al., 1991). Although honeybees are excellent pollinators of many plants, they are not the best pollinators for all plants. They have short tongues and cannot reach the nectar in deep flowers. Honeybee hives are introduced into greenhouses mainly for pollination of “short”-blooming crops such as melons and watermelons for commercial purposes (Kirk, 2004). The acreages and values of insect-pollinated crops and the demand for insect pollinators are increasing year by year. Recently, however, the unexplained loss of honeybee colonies, referred to as colony collapse disorder, aroused considerable concern about managed bees and natural wild bees for crop pollination.

We investigated the current status of Korean beekeeping and the role of honeybees as pollinators. Korean beekeepers have reared two species of honeybees. One is the oriental honeybee (*Apis cerana*), which is a Korean native bee, and the other is the western honeybee (*A. mellifera*), introduced from overseas 100 years ago. The number of bee farmers was 34,102 in 2008: 13,883 (40.7%) farmers reared oriental honeybees, and 20,219 (59.3%) reared western honeybees (Fig. 3A). The number of hives peaked at 2,089,762 in 2005 and has declined to 1,858,574 (11.6% decrease) in 2008. The number of hives of western honeybees was 1,544,063 (83.1%), while that of oriental honeybees was 314,511 (16.9%). The number of beekeepers peaked at 52,555 in 1989 and was fallen to 41,039 in 2005 and declined to 34,102 in 2008, with a 5% decrease since 2005, while the number of beehives per beekeeper has steadily increased by 2.3% per year (Fig. 3B). Farmers rearing oriental honeybees manage a small business and prefer the apiculture. In the case of western honeybees, the number of beekeepers using fixed management was 12,671 (59.6%), and the number using moved management was 7,548 (37.3%) (Table 1). The amount of honey production has increased 3.2 fold over the last 20 years, and the value of honeybee production was almost $200 million in 2009.

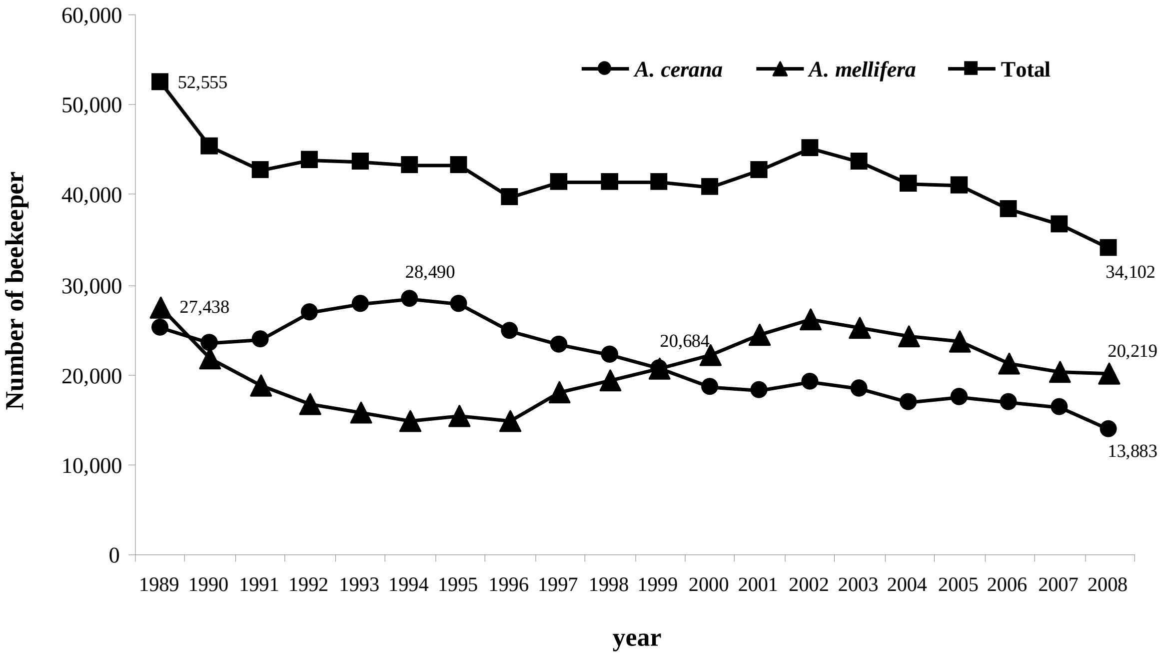
In 2009, the use rate of honeybees as a pollinator for 10 major horticultural crops in greenhouses was approximately 48.0%, which value was calculated with strawberry (100%), yelllow melon (66.5%), pepper (51.8%), watermelon (36.9%), melon (30.0%), tomato (0.2%), zucchini (0.2%), cucumber (0%), paprika (0%) and eggplant (0%) (Fig. 1A). The number of hives used for 10 horticultural crops in greenhouses was estimated to be 305,216, which included 96,733 for strawberry, 85,538 for watermalon, 81,363 for yelllow melon, 30,451 for pepper, 10,977 for melon, 130 for zucchini and 25 for tomato. The number of honeybee hives used as pollinators of outside crops, including many fruits and vegetables, was estimated to be more than 500,000 (Fig. 2). The value of honeybees as pollinators was estimated to be more than 8.5% to 15.0% of total Korean beekeeping products (Yoon, H. J., personal communication, 2010).

Table 1. Comparison of beekeepers and hives involved in fixed and moved management of the honeybee *Apis mellifera* in Korean apiculture

Year	Beekeeper (%)		Hive (%)	
	Fixed	Moved	Fixed	Moved
1990	84.7	15.3	62.1	37.9
1995	80.2	19.8	54.6	45.4
2000	75.3	24.7	43.6	56.4
2005	68.9	31.1	39.2	60.8
2008	62.7	37.3	42.1	57.9

Source: Ministry of Food, Agriculture, Forest and Fisheries, Korea, 2009.

A



B

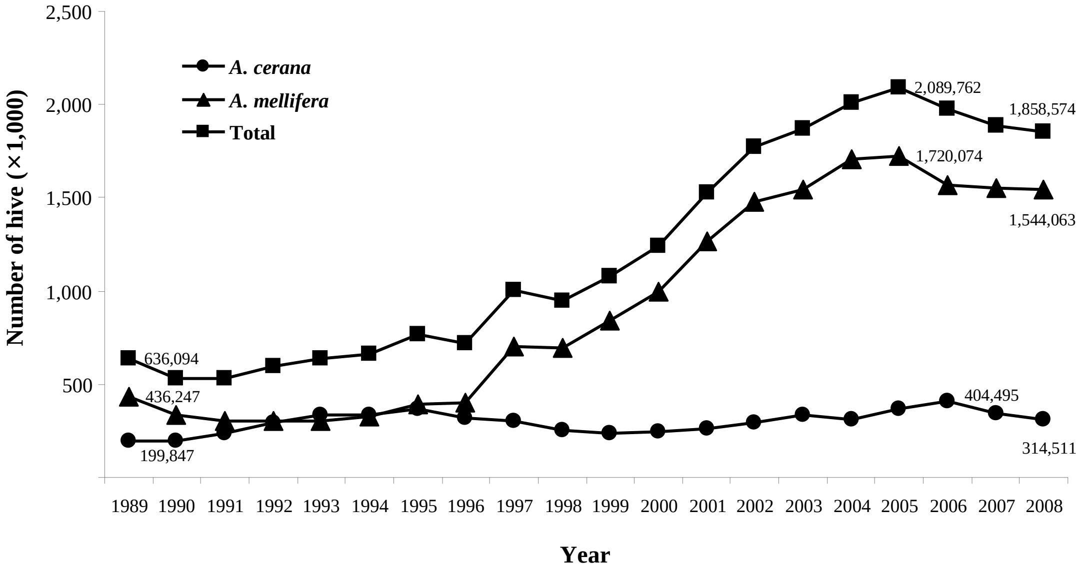


Fig. 3. The number of beekeepers (A) and hives (B) in Korean apiculture over 20 years (Ministry of Food, Agriculture, Forest and Fisheries, Korea, 2008).

Osmia mason bee as an orchard pollinator

The genus *Osmia* comprises more than 300 species, mostly in the Holarctic (Michener, 2000). Several *Osmia* species have been developed in different parts of the world to pollinate spring-blooming crops. *Osmia cornifrons*, the horn-faced bee, was developed as an orchard pollinator in Japan in the 1960s. Use of it has increased significantly increased from 10% of the total apple production area in 1981 to 50% in 1990, and it is being used on more than 70% of the apple acreage in 1996 (Yamada et al., 1971; Maeta, 1990, Sekita et al., 1996; Batra, 1998). In the late 1970s and early 1980s, *O. cornifrons* populations from Japan were introduced into the eastern United States, where the species is now becoming established as an orchard pollinator (Batra, 1979, 1998) and has also been tested on blueberries, several greenhouse crops (including strawberries, melons, and watermelons), and caged legume and mustard crops (Maeta, 1974; Maeta et al., 1990; Abel et al., 2003; Maeta et al., 2006). More recently, this species has been used in China (Xu et al., 1995). *O. cornifrons* was firstly introduced into Korea from Japan in 1992 and is now established as an apple pollinator.

We surveyed the current status of mason bees to augment *Osmia* bee use as pollinators of fruit tree in 2007 to 2009. The number of *Osmia* spp. produced in 2007 was 530,000, produced at two local organizations and by 34 farmers using mason bees, and reached 570,000 in 2009 (Fig. 4). *Osmia* bees collected by field traps were composed of five species, including *O. cornifrons* (68.1%), *O. pedicornis* (21.8%), *O. benefica* (9.5%), *O. Taurus* (0.3%) and *O. satoi* (0.3%). Five species of *O. cornifrons* and *O. pedicornis* were used as orchard pollinators, and more than 90% of them are being used for apples (Yoon H.J., personal communication, 2010). Mason bees were supplied from 1996 to 2003, and 71.1% of apple farmers first used them from 2000 to 2003. Most apple farmers expressed a positive intention to use mason bees for apple pollination. The advantages to the use of mason bees were improvement of regular shape and seed setting percentage, which were 62.1% and 23.7%, respectively. The problems were shortages of supply and low activity in bad weather. Also, 79.1% of farmers intend to use mason bees for apple pollination if the supply of mason bees supply is sufficient (Lee at al., 2010).

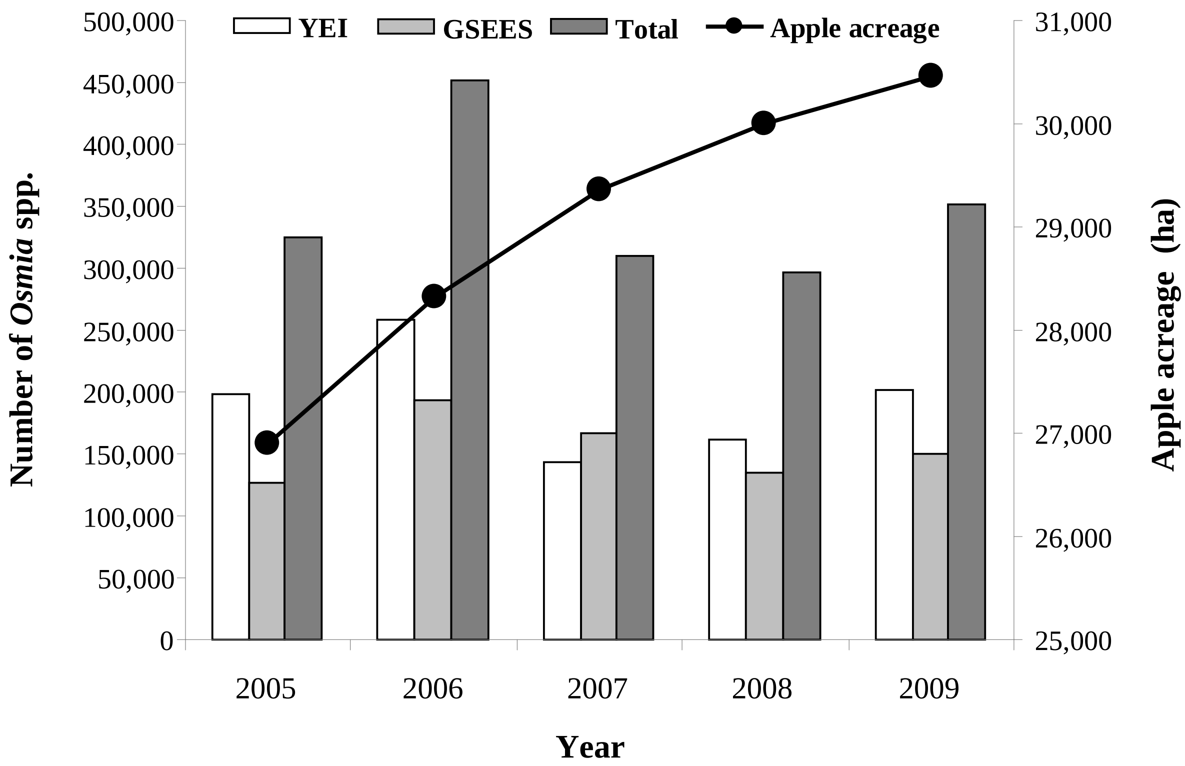


Fig. 4. Number of *Osmia* spp produced at two local oganizations in Korea from 2005 to 2009. Abbreviation: YEI, Yechon Entomology Institute; GSEE, Gyeongsangbukdo Sericulture & Entomology Experiment Station.

Conclusion

Bees are vital to the well-being of mankind. Products from pollinated plants, including fruits, vegetables, and seed crops, feed not only people but also livestock. Commercial bees, including bumblebees, honeybees and several nonsocial bees, provide farmers the opportunity to decrease their pollination labor costs and promise a good crop yield, both in quantity and in quality. However, managing bees can be problematic due to the dynamics of rearing organisms in close proximity and in controlled situations. We are pursuing better research about the domestic management of bees because disease epidemics can devastate or impair the production of commercial pollinators. The extent of our reliance on these species for pollination services is risky. Therefore, we must also concern ourselves with research on conservation and the enhancement of populations of wild pollinators to overcome corporate agriculture's horror at the prospect of stands of native flora as supplementary forage in the vicinity of crops.

References

Abel, C.A., R.L. Wilson and R.L. Luhman. 2003. Pollingation efficacy of *Osmia corniforence* and *Osmi lifnaria* subsp. *lignaria* (Hymenoptera: Magachilidae) on three Bassicaceae grown under field cages. Journal of Entomological Science 38: 545-552.

Batra, S.W.T. 1979. *Osmia corniforence* and *Pithitis smaragdula*, two Asian bees introduced into the United States for crop pollination. Fourth International Symposium on Pollination, (Special Miscellaneous Publication 1, 307-312). Maryland Agricultural Experiment Station.

Batra, S.W.T. 1998. Hornfaced bees for apple pollination. American Bee Journal 13: 364-365.

Carreck, N. and I. Williams. 1998. The economic value of bees in the UK. Bee World 79: 115-123.

Corbet, S.A., I.H. Chapman and J.L. Osborne. 1991. Bees and the pollination of crops and wild flowers in the European community. Bee World 72: 47-59.

Crane, E. 1990. Bees and beekeeping: Science, practice and world resources. Ithaca, NY: Comstock.

Dafni, A. 1998. The threat of *Bombus terrestris* spread. Bee World 79, 113-114.

Dafni, A. and A. Shimida. 1996. The possible ecological implications of the invasion of *Bombus terrestris* (L.) (Apidae) at Mt Carmel, Israel; in *The conservation of bees*. Matheson A.C. (ed.), pp. 183-200, The Linnean Society of London and The International Bee Research Association, London, UK.

Dag, A. and Y. Kammer. 2001. Comparison between the effectiveness of honeybee (*Apis millifera*) and bumblebee (*Bombus terrestris*) as pollinators of greenhouse sweet pepper (Capsicum annuum). American Bee Journal 141: 447-448. Free, J.B. 1993. The flower constancy of honey bees. Journal of Animal Ecology 32: 119-131.

Gallai, N., J.M. Salles, J. Settle and B.E. Vaissiere. 2009. Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. Ecological Economics 68:810-821.

Greenleaf, S. and C. Kremen. 2006. Wild bee species increase tomato production but respond differently to surrounding land use in Northern California. Biological Conservation 133: 81-87.

Klein, A.M., B. Vassiere, J.H. Cane, L. Steffan-Dewenter, S.A. Cunningham, C. Kremen et al. 2007. Importance of crop pollinators in changing landscapes for world crops. Proceedings of the Royal Society of London: Series B. Biological Sciences 274: 303-313.

Kirk, W.D.J. 2004. Plants for bees: Faba bean: *Vicia faba*. Bee World 85: 60-62.

Lee, M.Y., I.P. Hong, Y.S. Choi, N.S. Kim, H.K. Kim, K.G. Lee and M.Y. Lee. 2010. Present status of Korean beekeeping industry. Korean Journal of Apiculture 25: 137-144.

Lee, K.Y., H.J. Yoon, I.G. Park, C.R. Kwon and S.C. Lee. 2010. Survey on the current status of mason bees in apple orchard of Korea. Korean Journal of Apiculture 25: 53-61.

Maeda, Y. 1974. Preliminary report on the utilization of *Osmia cornifrons* for pollination of ladino clover in Japan. Kontyu 11: 4-5. [In Japanese.]

Maeda, Y. 1990. Utilization of wild bees. Farming Japan 24: 13-20.

Maeda, Y., S. Okamura and H. Ueda. 1990. Mame-do bachi, *Osmia cornifrons* (Radoszkowski) (Hymenoptera: Magachilidae) as a pollinator of blueberry. Report of Chugoku Branch, Odokou 32: 33-42. [In Japanese]

Maeda, Y., S.K. Nakanishi and K. Kitamura. 2006. Exploitation of systems to use a univoltine Japanese mason bee, *Osmia cornifrons* (Radoszkowski) (Hymenoptera: Magachilidae). throughout the year for pollination of greenhouse crops. Chugoku Kontyu 20: 1-7.

Michener, C.D. 2000. The bees of the world. Baltimore: Johns Hopkins University Press.

Mitsuhata, M. and M. Ono. 1996. Hybridization between Japanese and European bumblebees (*Bombus* spp.). Proceedings of the 7th International Pollination Symposium held in Lethbridge, Alberta, Canada.

Mitsuhata, M. 2000. Pollination of crops with bumblebee colonies in Japan. Honeybee Science 21: 17-25.

Morandin, L.A. and M.L. Winston. 2005. Wild bee abundance and seed production in conventional, organic, and genetically modified canola. Ecological Applications 15: 871-881.

Ono, M. and T. Wada. 1996. The world of the bumblebee. Japanese association for plant protection, p. 132, Tokyo, Japan.

Sekita, N., T. Watanabe and M. Yamada. 1996. Population ecology of *Osmia cornifrons* (Hymenoptera, Magachilidae) in natural habitats. Bulletin of the Amori Apple Experiment Station 29: 17-36.

Semmens, T.D., E. Turner and R. Buttermore. 1993. *Bombus terrestris* (L.) (Hymenoptera: Apidae) now established in Tasmania. Journal of Austrian Entomological Science 32: 346.

Sumner, D.A. and H. Boriss. 2006. Bee-economics and the leap in pollination fees. Agriculture and Resource Economics Update 9: 9-11.,

Velthuis, H.H.W. and A. van Doorn. 2006. A century of advances in bumblebee domestication and the economic and environmental aspects of its commercialization for pollination. Apidologie 37: 421-451.

Washitani, I. 1998. Conservation-ecological issues of the recent invasion of *Bombus terrestris* into Japan. Japanese Journal of Ecology 48: 73-78.

Williams, J.H. 1994. The dependence of crop production within the Euripean Union on pollination by honey bees. Agricultural Zoology Reviews 6: 229-257.

Winfree, R.T. Griswold and C. Kremen. 2007. Effect of human disturbance on bee communities in a forested ecosystem. Conservation Biology 21: 213-223.

Xu, H.L., L.L. Yang and Y.J.Kwon. 1995. Current status on the utilization of *Osmia* bees (Hymenoptera: Megachilidae) as pollinators of fruit trees in China. Korean Journal of Apiculture 10: 111-116.

Yoon, H.J., Y. I. Mah, M.Y. Lee, I.G. Park and M. Bilinski. 1999. Ecological characteristics of *Bombus ignitus* Smith in Korea. Korean Journal of Applied Entomology 38: 101-107.

Yoon, H.J., S.E. Kim and Y.S. Kim. 2002. Temperature and humidity favorable for colony development of the indoor-reared bumblebee, *Bombus ignitus*. Applied Entomology and Zoology 37: 419-423.

Yoon, H.J., and S.E. Kim. 2002. Facilitating effect of helpers on oviposition and colony development of bumblebee queen, *Bombus ignitus*. Korean Journal of Applied Entomology 41: 239-245.

Yoon, H. J. 2003. The method of artificial hibernation of the bumblebee, *Bombus ignitus*. The Research and Extension 44: 17-19.

Yoon, H.J., S.E. Kim, S.B. Lee and I.G. Park. 2003. Effect of CO_2-treatment on oviposition and colony development of the bumblebee, *Bombus ignitus*. Korean Journal of Applied Entomology 42: 139-144.

Yoon, H.J., S.E. Kim, Y.S. Kim and S.B. Lee. 2004. Colony developmental characteristics of the bumblebee queen, *Bombus ignitus* by the first oviposition day. International Journal of Industrial Entomology 8: 139-143.

Yoon, H.J., S.E. Kim, K.Y. Lee, S.B. Lee and I.G. Park. 2007. Mating conditions favorable for improving mating rate of the bumblebee, *Bombus ignitus.* International Journal of Industrial Entomology 15, 107-114.

Yamada, Y., N. Oyama, N. Sekita, S. Shirasaki and C. Tsugawa. 1971. The ecology of the megachilid bee *Osmia cornifrons* and its utilization for apple pollination. Bulletin of the Amori Apple Experiment Station 26: 39-77.