Chapter 2

Inadequate Pollination: The Major Cause of Declining Apple Productivity in the Region

The field surveys in selected apple growing areas of Bhutan, China, India, Nepal, and Pakistan clearly identified inadequate pollination as the major cause of declining apple productivity. Inadequate pollination not only reduces apple yield by causing poor fruit set, it also increases premature fruit drop and leads to poor fruit quality. Such fruit has poor market potential and fetches a low price, affecting the overall income of farmers.

Several factors contributed to the poor pollination. They included scarcity of pollinizer varieties in the orchards, insufficient populations of natural insect pollinators in the local environment, and changes in weather conditions during flowering. In India and China farmers were aware of the problem and the impact on apple productivity, but not in Bhutan, Nepal, and Pakistan. Farmers in the areas studied in India and China have already adopted different practices for managing pollination including the use of honeybees and hand pollination, but in Bhutan, Nepal, and Pakistan research and extension systems have yet to offer pollination management packages to farmers.

Factors Responsible for Inadequate Pollination in Apples

Pollinizer scarcity in the orchards

Many of the commercial varieties of apples planted by the farmers in the HKH region are self-incompatible and require cross-pollination with pollen from a compatible pollinizer variety. In order to ensure adequate pollination, it is necessary to plant sufficient pollinizer trees in such a position that each tree of the main variety has a pollinizer tree near it, so that pollen is available to its flowers. The optimum number and placement of pollinizers depends on several factors including the pollinizer variety, the main variety planted, and the number of pollinators. The standard requirement is for 20% of trees to be pollinizers, the normal minimum requirement is 11% if trees are planted in a strict geometrical arrangment (every third tree in every third row is a pollinizer) and closely spaced; some experts

A **pollinizer** (also spelt polliniser, pollenizer, and polleniser) is a source plant for compatible pollen that normally blooms at the same time as the target plant. For good yields, apples require a different variety of tree (for example Golden Delicious for Royal Delicious) as a pollinizer.

A **pollinator** is the agent that moves pollen from the anthers to the stigmas of flowers, thus enabling pollination. The most common pollinators are bees, but they can also be birds, butterflies, bats – and even humans.

Inadequate pollination may be the cause of ...

A.W. Jasra

... low fruit bearing

A.W. Jasra

... and premature fruit drop

recommend a proportion of 30-50% to achieve optimal pollination if the second variety has a market value (Mayer et al. 1985; Verma et al. 1997; Smith and Bradt undated; Deslauriers undated). It is equally important to select a pollinizer variety that blooms profusely and has a flowering period that overlaps with that of the commercial varieties.

Overall more than half of the farmers in the study areas had less than the minimum requirement of 20% pollinizer varieties in their orchards, most had only between 7 and 12%. The survey found the following situation.

In India, only 2% of farmers in the Shimla Hills, and Kullu Valley and none in Kinnaur met the standard requirement of 30% pollinizer trees in their orchards. About one quarter of farmers in Himachal Pradesh had between 20 and 25% pollinizer trees. It seems that in an attempt to have more trees producing commercial varieties of apple, and as a result of lack of knowledge about the importance of pollinizer–pollination systems, farmers have ignored the need to plant appropriate ratios of pollinizer apple varieties. In earlier times farmers grew

Pollination in apples

Apple flowers are hermaphrodite or bisexual, they have both male and female parts on the same flower, but most commercial varieties of apple can only be fertilised by pollen from flowers of a different, compatible, variety. In other words they are partially or completely self-incompatible. Pollination and fertilisation are a prerequisite for fruit set. To produce fruit, apples must be cross-pollinated and require pollinators to transfer pollen from the flowers of one tree to the flowers of another

Each apple flower has 5 sepals, 5 petals, 15–20 stamens with anthers producing pollen, and a pistil with a 5-chambered inferior ovary with 2 ovules in each chamber (or locule), 5 styles united at the base, and 5 stigmas. The same number of ovules must be fertilised in each chamber to produce a fruit of perfect shape and good quality. Generally, one ovule is fertilised in each chamber, rarely two. If the ovules in any one chamber are not fertilised, the fruit will be irregular in shape and size, reducing its market value.

a mixture of many varieties like Commercial, Golden, Jonathan, Red Gold, Red, and Royal Delicious. These provided pollen compatible with other varieties and there was generally good fruit set. In the early 1980s farmers started planting Royal Delicious on a large scale because of its high commercial value, and they slowly uprooted the other apple varieties – which could have been excellent pollinizers for Royal Delicious. During the past decade, the total apple-growing area has increased considerably, and all new orchards were planted only with Royal Delicious, although it is completely self-sterile and cross-pollination is essential. At the start of this trend there were still sufficient trees of the pollinizer varieties in the old orchards to ensure pollination, but over the last seven to eight years the problem has become serious.

The main reasons why farmers ignored the planting of pollinizers in China were market demand for a particular variety and scarcity of land. Apples from pollinizer varieties have a very low market value, and farmers do not want to sacrifice their land for a variety that does not bring them income. The farmers in China preferred to pollinate their apple flowers by hand, thus cutting down on the number of pollinizer trees needed.

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Inadequate pollination not only reduces yields but also causes low fruit quality

In Bhutan, farmers knew more about the need for pollinizers, and most farmers had planted pollinizer varieties – but the proportion was less than the recommended value (only 7-10%).

The farmers in Pakistan and Nepal knew little about managed pollination and planted few pollinizer trees. The majority of farmers in Nepal did not know which varieties were pollinizers or what the pollinizer proportion was in their orchards.

Whatever the reasons, the lack of appropriate proportions of pollinizer varieties in farmers' orchards is today one of the key factors in inadequate pollination of apples.

Declining populations of natural insect pollinators

Decline in the diversity and abundance of natural insect pollinators is the second most important factor affecting apple pollination, and thus productivity. A pollinator is the agent that transfers pollen between flowers. The known pollinators of apple trees include different types of insects like honeybees, bumblebees, solitary bees, and flies like dipterans and syphids (McGregor 1976; Free 1993; Verma and Chauhan 1985; Bangyu et al. 1997; Batra 1997a,b).

In recent years the diversity and populations of these natural insect pollinators have been declining for several reasons – including loss of food and nesting habitats due to clearance of forest and

grassland for agricultural purposes and indiscriminate use of pesticides. Changes in climate might also be affecting insect numbers. In all the study areas, farmers mentioned that in the past there were more insects like wild bees, butterflies, and moths during the apple-flowering season but that now most of them have disappeared. The majority of farmers identified pesticide use as the main cause of loss of natural insect pollinators. But increase in the amount of marginal land taken over for agriculture, and concomitant loss of wild habitat, must also have contributed. The increase in orchard area per se was also thought to play a role, with the natural populations of insects being too small to pollinate the newly-developed large areas of apple crops. This problem is less well understood than some others. The problem can be simply summarised as 'less insects available to pollinate more crops'. The scarcity of natural insect pollinators, and lack of replacement by 'managed' pollinators like hive bees, is another major cause of inadequate pollination in apples in the HKH region.

Changing climatic conditions

The third major reason suggested for pollination failure is climate change. Weather plays an important role in determining the success or failure of pollination as it affects both pollen production and the activities of pollinating insects (Verma et al. 1990). A drop in temperature or rainfall when apples are in flower can have an adverse effect on pollinator activity. Rain falling on the flowers can wash away the pollen grains, and hail can damage the flowers resulting in pollination failure and a decline in fruit set. The farmers in the study areas had observed an increase in bad weather conditions during the apple-flowering period in terms of the occurrence of frost, rain, hailstorms, and low temperatures.

Apple Pollination Management Today in the Survey Areas

Inadequate pollination is a relatively new problem in the HKH region and little research has been done on options to address it. In two of the HKH areas studied, Himachal Pradesh in India and the Maoxian Valley in China, productivity had dropped so severely that farmers and institutions were compelled to search for a solution. It was in these areas that the problem of insufficient pollination was first recognised, and it is here too that farmers and institutions have started investigating and testing pollination management options. The different approaches being tried are described briefly in the following.

Apple pollination management in Himachal Pradesh, India

Thanks to the efforts of government institutions, the majority of apple farmers in Himachal Pradesh are now well aware of the apple pollination problem and the factors responsible for it. They are trying different ways to improve pollination. Management efforts include planting different varieties of pollinizers, increasing the proportion of pollinizer trees, and increasing the number of pollinating insects in the orchards.

Managing the pollinizers

Now that farmers have become aware of the need for pollinizers to ensure yield and quality of apples, they are trying to increase the pollinizer proportion in the orchards, either by replacing some trees of the main variety with pollinizers, or by grafting pollinizers onto the main trees.

Grafting is sometimes necessary because grafts produce flowers more quickly than newly-planted trees. The most common varieties of pollinizer used are Commercial, Golden, Red Gold, and Tydeman's Early Worcester. Crab apple (wild apple) varieties are also being promoted as pollinizers. Crab apple varieties have considerable advantages: the trees are small and take up less space in orchards, they produce a good quantity of flowers, and they have long flowering periods of more than a month and are thus available to provide pollen to any variety, whether early or late blooming (Partap 1998).

It takes newly-planted pollinizer trees a minimum of four to five years to produce flowers, and grafts two to three years. As a short-term solution, farmers are practising 'bouquet pollination' – flowering pollinizer branches are cut and hung on the trees of the main variety, with the base placed in plastic bags filled with water to keep them fresh

Managing pollinators (hiring honeybees for pollination)

Many farmers in the valleys covered by the surveys are using honeybees (both *Apis cerana* and *Apis mellifera*) to increase the number of pollinating insects in their orchards. Some farmers keep their own honeybee colonies while others rent them from the Department of Horticulture, the University of Horticulture and Forestry, or private beekeepers. The present fee (2001) for renting honeybee colonies is IRs 300 (US $7.50) per colony for two weeks.

Increasing the pollinizer proportion ...

... crab apples placed between commercial trees

... grafting pollinizers onto trees of the main variety

... hanging pollinizer bouquets on trees of the main variety at the time of flowering

Preparing pollinizer bouquets ...

... putting pollinizer branches in plastic bags

... filling the bags

An additional IRs 500 (US $12.50) is charged as a refundable security deposit giving a total of IRs 800 (US $20). *Apis mellifera* is the main bee species provided. The colonies are kept in movable-frame hives. At present, Himachal Pradesh is the only place in the whole of the HKH region where a well-organised system has been established for hiring and renting honeybee colonies. A number of pollination entrepreneurs (beekeepers who rent honeybee colonies for crop pollination) have now started up in the state to complement the official services.

One problem that has arisen is that there are not enough colonies available for all the farmers who want to rent them. The State Government is now making efforts to encourage farmers to keep their own honeybee colonies for pollination. For this, the government has created a special section, 'The Beekeeping Development Office' (BKDO), under the Department of Horticulture. This office supports the sale of *Apis mellifera* colonies at a subsidised rate of IRs 300 (US $7.50) per colony – the market price is greater than IRs 2000 (US $50).

In addition to increasing the number of insect pollinators by renting or buying colonies of honeybees, some farmers are trying to save the populations of existing pollinators by making judicious use of carefully selected less toxic pesticides and spraying outside the apple flowering period.

Pollination entrepreneurs ...

... honeybees being transported to apple orchards

... colonies of honeybees being used for pollination

Apple pollination management in Maoxian Valley, China

A different approach is being followed in Maoxian County in China. Here, hand pollination of apples has become common practice. Since orchards are small, families try to pollinate their orchards themselves by training all members of the family (men, women, and children) making it a community effort (Partap and Partap 2000). Farmers also share days or hire labourers for the pollination of their apple orchards. These 'human pollinators' have been termed 'human bees' (Partap and Partap 2000). People do the work that could otherwise be done by honeybees. The advantage is that by far fewer pollinizer trees need to be planted, thus utilising the scarce land resources to a maximum for producing commercial varieties of fruit.

In hand pollination the anthers are picked from the flowers of the pollinizer varieties when the flowers are at the balloon stage (partially open) and then dried to release pollen grains, usually by spreading them out in the sun for a day or two, but sometimes in a cardboard box with an electric bulb, or even using an electric blanket. The pollen grains are stored in a cool, dry place and remain viable for three to four days. Pollen is mixed with a little white flour or skimmed milk powder and applied to the flowers of the main variety within two days of the flowers opening. Farmers normally apply pollen with the help of a hand-made brush, the filter side of a cigarette, or a pencil rubber. The farmers pollinate three out

Pollen is collected from the flowers of the pollinizer variety at the 'balloon stage'

Farmers in Maoxian County usually dry pollen by spreading it out in the sun ...

... some use electric blankets

Farmers apply dried pollen to the stigmas of flowers using hand-made brushes, cigarette, pencil rubbers, even camel hair brushes...

... they climb up the trees and use brushes with long sticks to pollinate distant flowers

of the five flowers in each apple inflorescence. Hand pollination is carried out three times in a season so as to cover some of the late flowers. The process is repeated in hundreds of apple orchards every year.

Apple pollination management in Pakistan, Bhutan, and Nepal

In Pakistan, Bhutan, and Nepal farmers are not yet aware of the importance of pollination or of the pollination crisis in their orchards, thus there are no clear management strategies.

In the Balochistan Province of Pakistan, apple productivity has been fluctuating and declined sharply in 1997-1998. Farmers are facing apple pollination problems both as a result of a lack of appropriate proportions of pollinizer trees and a lack of natural insect pollinators, but most apple growers are not aware of the source of their problems.

In Bhutan the apple orchard area is increasing but the yield per hectare is either static or declining. In the past there were adequate populations of natural insect pollinators, including wild honeybees (*Apis laboriosa).* The latter have survived because over 60% of land is forested and religious taboos mean there is no honey-hunting. However, the area of apple orchards has increased considerably during the past decade, with apple trees replacing forests on sloping land because Bhutan's agricultural policy prohibits fruit farming on flat irrigated cropland. This loss of natural forest is affecting the populations of natural insect pollinators and thus natural apple pollination. The process of decline of natural insect pollinator populations has just started and is expected to become more serious in the future. Already, despite religious taboos and the paucity of bee colonies, some farmers have started to keep bees for apple pollination.

In Nepal, farmers grow apples in a number of remote areas like Jumla, Mustang, and Solukhumbu. In Jumla, despite very poor yields, farmers were completely unaware that they had a pollination problem. They first realised that pollination was acting as a limiting factor in 1999 when ICIMOD

started its survey on apple pollination issues in collaboration with a local non-governmental organisation (NGO), the Surya Social Service Society (4S). In 2000, 4S organised an awareness-cum-training course on pollination problems and management for selected apple farmers of Jumla in collaboration with the Department of Agriculture of His Majesty's Government of Nepal (HMGN) and ICIMOD. Since April 2000, some leading farmers in Kholikot and Mahatgaon have started keeping honeybee colonies in their orchards.

Looking Ahead: Solutions to the Pollination Crisis

Pollination of self-incompatible crops like apple requires the presence of pollinizer trees and of pollinators, mostly insects. The problem of planting sufficient pollinizers lies outside the scope of this book, which focuses on pollinators. However, increasingly, departments of horticulture are becoming aware of this problem, which is important for many fruit crops not only apple, and activities to address the problem are underway.

Once sufficient pollinizer trees are present, the most important concern is to ensure that pollen transfer actually takes place. There are different ways of managing this including the use of honeybees (*Apis* spp.), rearing and using pollinators other than honeybees, and hand pollination.

Honeybees for pollination and the significance of honeybee diversity

For apples, one of the most practical approaches to increasing the number of pollinators is to use honeybees. Research has shown that pollination by honeybees increases fruit set, enhances fruit quality, and reduces fruit drop in apple trees (Dulta and Verma 1987). Honeybees are also the most efficient pollinators among insects because they can be managed in sufficient numbers and show flower constancy (Free 1964, 1966; McGregor 1976). The hive-kept species of honeybees (*Apis cerana* and *Apis mellifera*) are of great value because they can be moved to orchards where and when necessary. At present, pollination using honeybees is the most cost-effective method for pollinating apple and other fruit crops.

The HKH region is one of the richest in honeybee species diversity in the world. There are five species of honeybee: three wild species that cannot be kept in hives – the giant honeybee (*Apis dorsata*), the little bee (*Apis florea*), and the rock bee (*Apis laboriosa*) – and two hive species – the Asian bee (*Apis cerana*) and the introduced bee (*Apis mellifera*). All honeybees are good crop pollinators, but because the wild species' cannot be kept in man-made hives they cannot be transported to the sites where bees are needed. The honeybee species' diversity in the HKH region holds much potential for wider use in managing crop pollination in ways suited to the conditions in specific areas. In particular, the native hive honey bee *Apis cerana* offers clear advantages as a pollinator in remote and higher altitude areas.

Advantages of Apis cerana for crop pollination in high altitude areas

Both *Apis cerana* and *Apis mellifera* are excellent pollinators of mountain crops (Verma and Partap 1993; Partap and Verma 1992; 1994; Partap and Partap 1997, 2001). However, *Apis mellifera* performs better when daytime temperatures are relatively high, and temperature fluctuations are low, whereas *Apis cerana* is cold resistant and can perform well even when

daytime temperatures are relatively low, on cloudy days, and at higher altitudes with marked temperature fluctuations. In mountain areas, *Apis cerana* is a better pollinator of vegetable and fruit crops during spring and early winter than *Apis mellifera*. The race of *Apis mellifera* introduced to the HKH region is generally found to be more suitable for beekeeping under the warm agro-climatic conditions of the low hill and plains areas. In higher altitude areas, the native hive bee, *Apis cerana,* offers considerable advantages for beekeeping, whereas introduction of *Apis mellifera* can be problematic (ICIMOD 2002). Some of the advantages and disadvantages are summarised in the boxes.

If beekeepers introduce *Apis mellifera* to higher altitude areas for summer honey production, the exotic bee replaces the hardier native species, and the overall pollination of early crops is adversely affected. It can also lead to cross-infections that weaken the bees of both species. This has been shown in the mountain areas of Pakistan, where *Apis mellifera* has been introduced on a large scale for honey production – and the yield and quality of produce from early blooming mountain crops has been greatly reduced as a result of the lack of pollination (AKRSP, personal communication). At higher altitudes, *Apis mellifera* displaces the native bee without replacing its special pollination capabilities, and doesn't itself perform well.

Notwithstanding, *Apis cerana,* tends not to be popular among beekeepers (particularly commercial beekeepers), because of its lower honey yield. The institutions promoting beekeeping in the HKH region have so far focused exclusively on honey production rather than pollination, and have promoted the introduction of *Apis mellifera*, despite the considerable advantages of *Apis cerana* for pollination at higher elevations. Studies indicate, however, that some high mountain races of *Apis cerana* can match *Apis mellifera* in both behaviour and honey production. Activities are underway to select improved species, which will increase support for *Apis cerana* beekeeping.

When all these points are considered, it seems that *Apis cerana* should be promoted in higher altitude areas, and *Apis mellifera* and/or *Apis cerana* in the more accessible lower regions,

Advantages of beekeeping with *Apis cerana* in mountain areas

- Cold resistant, performs well at lower temperatures
- Available for pollination of early crops
- Flies in poor weather conditions
- Thrives on mixed, diverse crops
- No capital outlay, farmers can collect colonies from the wild and propagate them
- Minimum labour for maintenance, simple log hives can be used
- Relatively disease resistant
- Does not need feeding, fumigating, migration in winter
- Requires no external inputs, remoteness no problem
- Suitable for small-scale and stationary beekeeping

Problems with *Apis mellifera* at higher altitudes

- Poor tolerance of cold and widely fluctuating temperatures
- Requires migration to lower altitudes in winter
- Not available for pollination of early crops
- Requires intensive management practices with standardised equipment and external inputs
- Requires larger foraging grounds with monoculture-based agriculture
- Prone to diseases, parasitic mites, and wasps
- Introduces exotic diseases to which native (hive and wild) species are susceptible
- Less suitable and often unprofitable for small-scale and stationary beekeeping

particularly when bees are primarily kept for pollination. This will ensure better pollination of mountain crops and also help in conserving the indigenous species.

Decline of the native hive bee

Beekeeping with the native honeybee *Apis cerana* is a traditional household activity among several mountain communities. But the promotion of *Apis mellifera* over the past few decades has adversely affected indigenous *Apis cerana* beekeeping and led to the replacement of *Apis cerana* with *Apis mellifera* in many areas of the HKH region (Partap and Partap 1997). Studies carried out by ICIMOD have shown that at present there are only a few areas in the mountain districts of Nepal, India, China, and Pakistan where *Apis cerana* is being kept by beekeepers and farmers (ICIMOD 1998; Bangyu and Tan 1996).

Constraints to using honeybees for pollination in the HKH region

Hive bees can play an important role in pollination – and in areas like N. America, Europe, and Japan they are used extensively to ensure pollination of fruit and vegetable crops (see for example McGregor 1976, 2002; Morse and Calderone 2000). However, although beekeeping is common in the HKH region (stationary beekeeping with *Apis cerana* and migratory beekeeping with *Apis mellifera*), bees are only used specifically for pollination in a few areas. Beekeeping has only been promoted as an enterprise for honey production; neither the policies nor the institutions involved have focused on developing and promoting beekeeping for crop pollination. Considerably more research and development efforts will be needed before honeybees can be effectively promoted for pollination on a large scale in this region. The main constraints to using bees for pollination are lack of awareness among farmers, lack of beekeeping in horticultural development packages, scarcity of honeybee colonies, and lack of knowledge about honeybees' foraging behaviour.

Lack of awareness among farmers is one of the main problems. With a few exceptions, farmers in those areas of the HKH region where there is a pollination problem with apples are not aware of the value of honeybees for apple production. This is both because beekeeping has always been promoted exclusively as an enterprise for honey production, and because apple growing is a new activity and there is no indigenous knowledge on the needs for production.

Beekeeping from the perspective of crop pollination has been overlooked in agricultural development strategies for hill areas of the HKH region. Agricultural institutions offer different packages of practices for specific crops to promote high-value farming of cash crops. These packages suggest to farmers the kind of inputs needed to maintain sustainable yields of specific crops like soil preparation, irrigation, use of fertiliser, and pesticide spray schedules. However, beekeeping as an input to manage crop productivity has not yet been included. Thus farmers have no way of knowing how essential it can be. This weakness in the agricultural extension system needs to be addressed. Though a few farmers are aware of the value of beekeeping for crop pollination, in the HKH region there is no formal system for hiring and renting honeybee colonies of the sort prevalent in horticulturally developed countries of the world (see, for example, Morse and Calderone 2000).

Scarcity of honeybee colonies for pollination is the third major constraint on promoting honeybees for apple pollination. In the apple valleys where honeybees are being used for apple pollination, the number of honeybee colonies is far below that required for pollination of the whole crop in the area. In Himachal Pradesh about 78,000 ha are planted with apple trees. Theoretically some

230,000 colonies would be needed to pollinate the whole apple crop in Himachal (on the basis of 2-3 colonies of *Apis mellifera* or 3-5 colonies *of Apis cerana* needed to pollinate 1 ha of apple orchard). However, there are only about 10,000-12,000 honeybee colonies in all, and not all of them can be used for pollination. Thus, the available honeybees meet only 4-5% of the calculated total demand. It seems that the expansion of horticultural farming in Himachal has not been accompanied by a corresponding increase in the number of honeybee colonies (Nadda and Tiwari 1998). This highlights the fact that, in addition to raising awareness, training farmers, and creating the right policy environment, it is important to focus on ways of increasing the number of honeybee colonies in each area.

Lack of knowledge among farmers about the foraging behaviour of honeybees is another constraint hindering the use of honeybees in crop pollination. Even those farmers in the HKH who do know that they can use honeybees to increase apple pollination and yield don't always know how to use the bees. Few people know about the foraging or pollination behaviour of honeybees. For example, farmers in some villages in Himachal Pradesh, unaware that honeybees do not visit flowers during the night, had stolen colonies of honeybees from neighbouring orchards during the night and returned them early in the morning, in the hope that their apple trees would be pollinated.

Overcoming constraints to promoting honeybees for pollination

Diversification of mountain agriculture towards high-value cash crops requires pollination management since most commercial varieties of these high-value crops are cross-pollinated. Farmers have been looking at the ways in which institutions (government and non-government, private entrepreneurs, researchers) can help. The various suggestions are summarised below.

Raising awareness about the importance of using honeybees for crop pollination is the first step in promoting beekeeping for pollination

Horticultural extension

The first and most important step in promoting the wider use of honeybees for crop pollination is to include beekeeping as part of horticultural development efforts. Horticulture, especially apple farming, is being promoted in several areas of the HKH region. Official institutions offer packages of practices for each type of crop, but the importance of managing pollination to achieve a sustainable yield has been overlooked. Since pollination is essential for the production of fruits and seeds, crop pollination management should be included in horticultural development packages, with beekeeping for crop pollination as a 'double benefit approach'.

Influencing thinking

The second step is to change the general 'mindset' about honeybees and beekeeping, and to raise awareness about the importance of managed crop pollination. Traditional thinking is that beekeeping is for honey production, its role in crop pollination is rarely considered. Today, most government agencies are only engaged in promoting beekeeping for honey production. The move towards introduction of *Apis mellifera* to increase honey production is an example of this. Countries in Europe, the USA, and Japan have been using honeybees for pollination of crops such as apples, almonds, pears, plums, cucumbers, melons, watermelons, and a number of berries for a long time. In the USA the first colonies of honeybees (*Apis mellifera*) were rented for apple pollination in 1909 in New Jersey (Morse and Calderone 2000). In contrast, in the HKH region, renting of colonies for apple pollination only started in 1996, and is still restricted to a very few areas.

There is a need for a change in thinking about the value of honeybees as crop pollinators at many levels: policy, planning, research, beekeeping, and farming. The initial thrust of the pollination programme will need to raise awareness about the need for managing pollination through honeybees and to generate the knowledge and information needed to facilitate the formulation of strategies that will ensure the wider use of beekeeping for pollination. Honeybees should be seen as crop pollinators first, and as honey producers second. Changes in research and development investment policies may be needed to encourage this.

Training in orchard planning and management

A further important step is to train apple farmers in orchard planning and pollination management. Many farmers in mountain areas have insufficient knowledge about the best layout for orchards. More information is needed on appropriate pollinizer varieties, proportions of pollinizers, placement of pollinizers in relation to the main variety, and pruning and thinning of trees. Farmers also need to know about the importance of bees, and numbers and placement of bee colonies.

Increasing the number of colonies

The next step is to increase the number of honeybee colonies available for pollination. There are about 370,000 ha of apple orchards in the HKH region, theoretically these need about a million bee colonies to ensure optimum pollination. The actual number available is much lower. In our survey, farmers rated this as the major problem. Since beekeeping is not traditional in Bhutan or the Balochistan Province of Pakistan there are few colonies, and in China beekeepers are not willing to provide bee colonies to apple farmers for pollination, partly for fear of the effects of insecticide spraying. The number of colonies should be increased by multiplying the existing colonies through breeding and mass queen rearing. Such efforts will require more trained manpower and a large amount of scientific, management, and extension inputs.

Another part of increasing the number of honeybee colonies for pollination is to encourage private entrepreneurs to keep large numbers of honeybee colonies that they rent to farmers for pollination. In addition to the rental fee, these 'beekeeping for pollination entrepreneurs' can earn income through the sale of honey and beeswax. Such a system benefits both farmers and beekeepers. Pollination entrepreneurs have already become established in a few apple valleys in the region.

An apiary of Apis mellifera *in Kullu Valley, Himachal Pradesh, which rents honeybee colonies to farmers for apple pollination*

Promoting beekeeping

The final step is to encourage individual farmers, village communities, and commercial pollination entrepreneurs to rear and keep bees for pollination. Individual apple farmers could be encouraged to keep their own honeybee colonies for pollination if training is available and there is a supply of colonies. Honeybee entrepreneurship schemes need to be encouraged. Himachal Pradesh has recently started such a programme, as mentioned above. The government agency arranges sales of *Apis mellifera* colonies to apple farmers at a subsidised price and the State Department of Horticulture, and the University of Horticulture and Forestry provide training, and some honeybee colonies free of charge, to apple farmers.

Beekeeping for apple pollination can also be promoted at community and village level. The requirement of honeybee colonies for apple pollination is 2-3 colonies of *Apis mellifera* or 3-5 colonies of *Apis cerana* per hectare. Since landholdings are often small, individual farmers may need only 1-2 colonies of honeybees. In high elevation and inaccessible areas, and on a small-scale, only *Apis cerana* should be promoted, both because this bee is suitable for stationary beekeeping and for the other reasons summarised above. In accessible areas if *Apis mellifera* is kept, then the colonies need to be migrated to low hill or plains' areas during the winter season, and brought back at the time of apple flowering because there is no bee forage available in the winter and the *Apis mellifera* colonies are susceptible to cold. If farmers feed the bees with sugar during the winter months, the colonies are not strong enough early in the season when they are needed for apple pollination. It is not economic to migrate small numbers of bees; a truckload is needed. Thus farmers in these areas should be encouraged to migrate their colonies collectively. Community and village-level management of beekeeping can be a very useful way of ensuring both apple pollination and a good honey harvest.

Providing for increased bee numbers

Given the large number of honeybee colonies that will be required in areas with large acreages of crops; it is possible that the number of bees may exceed the present carrying capacity of an area. It may well be necessary to either increase the number of honeybee forage plants through new plantations and/or to promote migratory beekeeping as an enterprise. The latter would also help strengthen upland-lowland linkages.

Investment in crop pollination

Apples are only one example of a number of cash crops grown by the HKH farmers which require managed pollination for increased production and quality. Vegetable seed production is another

Institutional efforts to promote beekeeping for apple crop pollination in Himachal Pradesh

The Role of the Himachal Horticulture and Forestry University

- Strong scientific expertise available on honeybees, beekeeping, and pollination
- Field stations in apple-farming areas monitor problems related to horticulture and focus on problem-solving research
- On-farm research into and demonstration of the positive effects of beekeeping for apple pollination
- Special awareness programmes launched in apple-farming areas
- The Agriculture Science Centres, (the university extension centres) give beekeeping training on-demand to farmers and interested new entrepreneurs
- The university provides bee colonies for pollination; the Beekeeping and Horticulture Research Stations keep both *Apis cerana* and *Apis mellifera* for this
- Training and demonstrations on how to use bees for pollination

The Role of the Government of Himachal Pradesh Department of Horticulture

- Establishment of a Beekeeping Development Office for Pollination (BKDO), which maintains and rents honeybee colonies to farmers; *Apis mellifera* colonies sold at a subsidised rate (IRs 300 [US $7.5] per colony, against a market price of about IRs 2000 [US $50])
- Annual assessments of the demand for honeybee colonies by apple farmers, and arrangements for supply facilitated with private beekeepers
- Attractive financial support for starting a beekeeping enterprise for pollination
- Provision of honeybee colonies at a subsidised rate to promote their use for pollination

The Role of the Himachal Apple Growers' Association

- Platform for farmers to discuss emerging problems and to act as a strong pressure group to seek government intervention
- Raised the apple-pollination problem faced by farmers with the university and government and sought rapid solutions
- Raised awareness about the scale of the problem in the state and encouraged farmers to become beekeeping entrepreneurs for pollination; coordinated honeybee demand–supply aspects

crucial sector where pollination management is essential. It is necessary to evolve strategies to promote investment in research and development that will enhance the use of honeybees for pollination. This means developing area-based approaches, making full use of the existing diversity of honeybee species in the HKH region.

Strengthening research and extension systems

Beekeeping for crop pollination is a new activity in the HKH region. There are few institutions in the region with explicit mandates or expertise. Most institutions promote beekeeping as a cottage industry to increase family income through the sale of honey. Promoting the value of honeybees as reliable pollinators of apples and other fruit and vegetable seed crops will require special efforts to strengthen research and extension systems. In Pakistan, for example beekeeping with *Apis mellifera* for honey has been heavily promoted by the government, but crop pollination is not included on the agenda of the honeybee research and development agencies. The approach being taken in Himachal Pradesh is summarised in the box as an example.

Other options for pollination

Non-honey bees

Species of bumblebees and solitary bees like *Amegilla, Andrena, Anthophora, Ceratina, Halictus, Megachile, Nomia, Osmia, Pithis,* and *Xylocopa* are important pollinators of apple flowers in the

HKH region (Batra 1997b), but the natural populations of these bees are declining. In principle, many of these pollinators could be reared on a large scale and managed for the pollination of apple trees and other crops. In many developed countries various natural insect pollinators, including some species of bumblebees and solitary bees, are being reared and managed commercially for pollination of crops, particularly those that are less, or not effectively, pollinated by honeybees. Bumblebees, for example, are used for the pollination of potatoes and tomatoes, alkali bees and leaf cutter bees for the pollination of alfalfa, and various species of bumblebees and solitary bees for pollination of apple, almond, and other fruit trees, and cotton, mustards, lucerne, and berseem (Crane 1990). The solitary bee *Osmia cornifrons* Rad. is being managed on a large scale in Japan where it is used to pollinate one third of all apple crops (Batra 1995, Sekita 2001).

Some species of bumblebees and solitary bees are excellent pollinators of apple trees, and can be managed for their pollination. Batra (1997a) reported that the halictine bee (a solitary bee, *Lasioglossum (Evylaeus) matianensis*) is the predominant pollinator of apple trees at altitudes higher than 2600 m and that it can be managed simply by providing nesting sites.

According to Batra (1997b), there are two approaches to enhancing the pollination of fruit crops using solitary bees. The first is to manage the habitat around orchards to provide nesting sites for the native pollinators in the area. Making sunny plots by removing shady vegetation from any existing nest aggregations can increase the population of most species. This type of habitat management may take up too much space, however, and thus be too costly, and in many areas of the HKH, farmers (especially fruit growers) have already cleared the habitat required for these pollinators. Keeping native habitat may also interfere with orchard operations or provide a refuge for crop pests. The second approach is to keep populations of solitary bees in bee shelters and place them near the orchard. Shelters can be made from inexpensive materials. They take up little space and do not interfere with most operations or harbour crop pests. With these solitary bees, the adults are only active while the crops are in flower. After the flowers have been pollinated, the adult bees die and the dormant brood can be put into storage until the next pollination season, when the next generation of adult bees will emerge to help carry out crop pollination (Batra 1997b).

There is good potential for the managed use of non-*Apis* pollinators in the Himalayan region. There are thousands of hectares of land under cash crops that need cross-pollination. But owing to lack of expertise and institutional capability, the HKH countries have so far not been able to make real use of these pollinators. Batra (1997b) summarised the characteristics of solitary bees that make them useful as pollinators, these characteristics could be used as criteria for selection of natural insect pollinators to be reared and managed for fruit tree pollination (see box).

In cold and arid areas of the HKH region, for example Balochistan (Pakistan), Mustang (Nepal), and Lahul (Himachal Pradesh), where stationary beekeeping cannot be practised because of the prevailing cold and dry climatic conditions and lack of forage during the greater part of the year, managing non-honeybees for pollination is a good option. These areas have a number of different types of solitary bees. Since only two to three per cent of total land area is cultivated, a lot of space is available for these bees to hibernate. But major research and extension efforts will be needed

Characteristics of solitary bees that make them useful for pollination of fruit crops

Host Preference and Foraging Behaviour

- Solitary bees prefer fruit blossom and the brood can develop well on a diet of nectar and pollen
- An individual bee works rapidly, quickly dispersing a large amount of pollen
- The bees work across rows and among plants of different cultivars maximising cross-pollination
- The pollen is carried loosely in fine body hairs and is easily brushed onto stigmas of other flowers
- The bees have a short flight range and stay close to their nest in the orchard
- The bees forage in the cool, cloudy, windy, or rainy weather that is common in the spring in hill areas
- Both males and females visit and pollinate flowers

Life Cycle, Nesting Habits, and Manageability

- The period of adult activity naturally coincides with the time of fruit flowering
- The bees thrive in the climatic zones where fruit trees are grown
- They nest in inexpensive man-made or altered natural substrates and can find all their material needs in or near the crop
- They live in colonies or nests so that it is easy to manage a large population
- They are gentle, permitting human activities near their nests
- They are relatively free of parasites and predators or can be easily managed to eliminate them
- Each female makes many cells that produce next generation females, thus the population increases rapidly, and pollination is enhanced because females are better pollinators than males
- The bees can be mass reared, so that large numbers can be made available at the flowering time of the crop

Source: Batra (1997b)

before such insects can be reared and managed for pollination of crops in the region. At present, there are no government institutions or private entrepreneurs engaged in rearing and managing these insects for pollination purposes. Popularising the rearing and use of non-*Apis* pollinators in the HKH region will take many years.

Humans as pollinators

Hand pollination, although the most reliable method of ensuring pollination takes place, is expensive, laborious, and time-consuming and is unlikely to be sustainable in the long term, particularly as labour costs increase.

Making use of honeybee diversity: different approaches for different areas

The most promising approach to reversing the decline in productivity of fruit and vegetable crops in the HKH region is to introduce the approach of integrated pollination management. For apple crops, the most practical approach at present is to promote the use of honeybees.

There are various possibilities: beekeeping for pollination using *Apis cerana, Apis mellifera,* or a combination of the two, and promotion of wild honeybees. Which is best, depends on the particular conditions in an area. The most promising approaches in each of the different areas studied are summarised below.

Apis cerana and Apis mellifera beekeeping for pollination

A combined approach using both species might be most appropriate in the apple valleys of Himachal Pradesh, India, and Maoxian County, China, where apples and other temperate fruits have emerged as important cash crops. Traditional beekeeping with *Apis cerana* is common in these areas; farmers generally keep a few colonies around their houses in wall or log-hives. Equally *Apis mellifera* is

Beekeeping is common in Maoxian Valley but local institutions do not promote the use of honeybees for pollination

A commercial, migratory Apis mellifera apiary in a Juniper forest of Balochistan. The honeybees are not used for pollination

(A.W. Jasra)

also widely popular for honey production. Thus *Apis cerana* and *Apis mellifera* could be used to complement each other for pollination.

Apis mellifera beekeeping for pollination

In lower altitude hill areas of Pakistan the best approach is likely to be promoting the use of the *Apis mellifera* bees that are now kept for honey production for the pollination of apple crops. Migratory beekeeping for honey production with *Apis mellifera* has already been widely promoted by the Government of Pakistan, and *Apis mellifera* beekeeping is flourishing well in both hill and plains areas where sub-tropical fruit and vegetable crops are grown. But the bees are not being used for pollination. Hives are most commonly placed along the roadsides, in forest, or on wasteland – but not in the orchards. *Apis mellifera* is suitable for large-scale migratory beekeeping, and the colonies could be moved easily to areas requiring pollination services, for example where pollinator populations may not be sufficient and/or stationary beekeeping is not possible because of the cold winter conditions.

Apis cerana beekeeping for pollination

In Nepal the most appropriate approach for apple pollination is likely to be the promotion of *Apis cerana* beekeeping. Traditional beekeeping with *Apis cerana* is common in the mountain areas of Nepal where apples are grown, and these areas already have a gene pool of this bee. *Apis mellifera* can be more difficult to manage at these higher elevations. Introduction of *Apis mellifera* in the traditional isolated *Apis cerana* areas should be discouraged. In lower elevation areas with good access, *Apis mellifera* can be promoted for the pollination of other fruit and vegetable crops.

Wild bees for pollination

In Bhutan the best approach may be to focus on using wild honeybees for pollination. Three wild honeybee species are found in the HKH region: *Apis dorsata* and *Apis florea* in low and middle hill

areas and *Apis laboriosa* in high mountain areas. All are excellent pollinators of crops and wild plant species. They play an important role in improving farm productivity and conserving biodiversity. Their natural populations need to be maintained so that they can provide a needed pollination service for wild plants, as well as for apples and other crops. In Bhutan, support for ensuring populations of wild bees is likely to be more successful than encouraging beekeeping, the potential for which is restricted by religious taboos, as more than 60% of the land area is forested, wild bees are already widespread and play an important role in crop pollination, and religion prohibits honey hunting, which has helped natural populations of wild bees to increase.

Pratim Roy

Apis laboriosa (a wild honeybee species) is an important pollinator of apple crops in Bhutan

Conclusion

The declining productivity of fruit and vegetable crops, in particular apples, in the HKH region can be attributed to a number of factors, but among these pollination plays a major role. The approach outlined above for raising awareness of the problem and introducing integrated pollination management with bees on a large scale, should make it possible to arrest and reverse this decline, and restore faith in cash crops as a way of reducing poverty and supporting development in the region.