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The Human Pollinators of Fruit Crops in Maoxian County, Sichuan, China

A Case Study of the Failure of Pollination Services and Farmers' Adaptation Strategies

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The third dimension of mountain agricultural productivity, pollination, helps to maintain crop productivity and thus makes a great contribution to agricultural economy. In the absence of natural pollinators for a variety of reasons, farmers in Maoxian County of southwestern China employ "human pollinators" to pollinate apple and other fruit crops to secure yields. In 2001, we conducted a study to gain an understanding of the process and significance of hand pollination of apples, which revealed that 100% of the apples in Maoxian were hand pollinated. Because it was a unique approach developed by these Chinese farmers the authors were curious to revisit the site in 2011 to assess the sustainability of human pollination and see whether farmers had invented better alternatives. The findings suggest that, recently, Maoxian farmers have been working toward phasing out apples and replacing them with plums, walnuts, and loquats along with vegetables. These new fruit and vegetable crops are economically and ecologically more appropriate to them, because they do not require pollination by humans and also fetch a better price. However, hand pollination by human pollinators is still practiced with apples to a lesser degree, which indicates that all these farmers have yet to find satisfactory alternatives to this economically unsustainable practice.

Keywords: *Maoxian; apple; pollination; human pollinators; China.*

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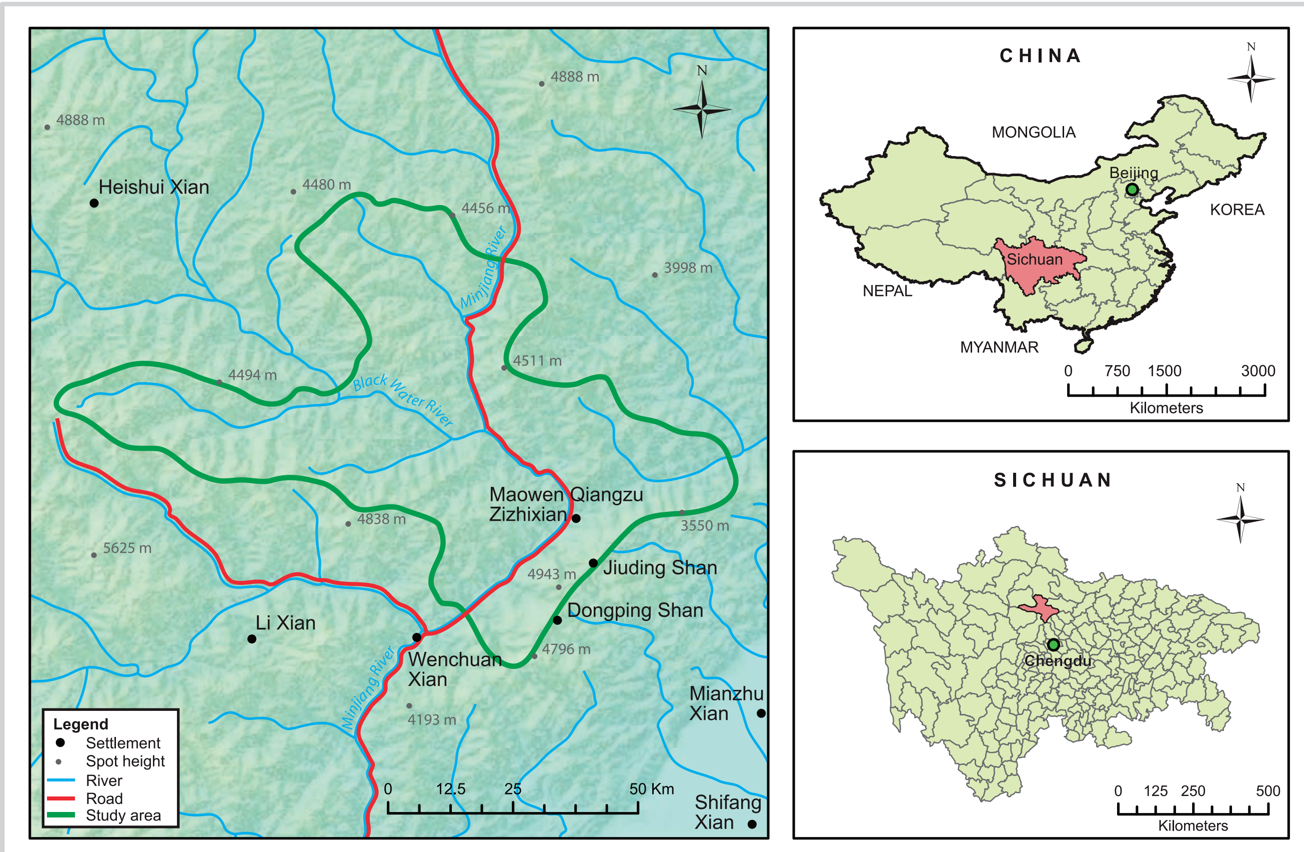
Introduction

The importance of pollinators and pollination in agriculture has been recognized for centuries (Kevan 1991; Buchmann and Nabhan 1996; Kevan and Phillips 2001; Partap 2003; Eardley et al 2006). Results of studies conducted in different parts of the world have shown that pollinators make a huge economic contribution to agriculture (Winston and Scott 1984; Matheson and Schrader 1987; Pimentel et al 1997; Carreck and Williams 1998; Morse and Calderone 2001; Ruijter 2002). Globally, the annual contribution of pollinators to agricultural crops has been estimated at about € 153 billion (US$ 206 billion; Gallai et al 2009). However, in the mountain areas of South Asia, specifically the Hindu Kush–Himalayan region, which comprises Afghanistan, Pakistan, India, China, Nepal, Bhutan, Bangladesh, and Myanmar, the lack of knowledge and understanding about the significance of crop pollination in sustainable crop production of cross-pollinated crops and the lack of institutional and farmers' initiatives to promote managed crop pollination is still a common feature. The authors of the present paper reflected on this state of affairs in their review study, *Managed Crop Pollination: The Missing Dimension of Mountain Agricultural Productivity* (Partap and Partap 1997). To further highlight the scale of the problem of declining pollinators, failing pollination, falling crop yields, and, consequently, strained farm economy, we did a field survey-based study in 2001 on pollination failure that led to problems in the apple-growing valleys in 5 countries: India, China, Pakistan, Nepal, and Bhutan. The study findings reported a growing decline of pollinators and consequent declining crop yields in apple crops in the apple valleys of China, India, and Pakistan.

During this survey, we found that, based on their knowledge and understanding about the problem, different approaches were adopted by farmers and institutions in these countries to solve the problem of pollination with apples. The apple farmers of Pakistan were not aware of pollination as a factor that determines productivity and, therefore, farmers who were facing acute decline in production were cutting the apple trees. Both apple farmers and institutions in Himachal Pradesh in India were aware of the problem and applied the ecologically appropriate solution of using honeybees as pollinators. In the apple valley of Maoxian, the area of the present study, the farmers also faced acute problems with natural apple pollinators and were using a unique,

FIGURE 1 Location of study area. (Map by Gauri S. Dangol, ICIMOD)



labor-intensive, and unsustainable technique of hand pollination by using "human pollinators," which was a massive scale effort during the 1990s. It was unimaginable in all respects, whether it concerned farmers' knowledge about pollen source management or pollen harvesting and processing. The skills and institutional arrangements of the farming community in Maoxian had evolved to support hand pollination on this massive scale. The costs involved also seemed unsustainable compared with the more appropriate solution of using honeybees and other bees for pollination.

We, therefore, were curious to revisit these apple farmers of Maoxian in China after a decade, in 2011, to determine the conditions that related to human pollinators of apples and check whether Maoxian farmers had developed any new innovations as alternatives to hand pollination of apples and apple farming in the valley, especially in the context of changes in local socioeconomic conditions and climate. In particular, we wanted to see if apples were still pollinated by "human pollinators," whether the practice of hand pollination of apples was sustainable, and whether farmers adapted to the pollinator crisis by using means other than "human pollinators."

Material and methods

Study area

This study was conducted in the Maoxian County in the northwestern Sichuan Province of China, between and 31°24′–32°17′3N; 102°56′–104°10′E (Figure 1). The altitude varies from 860 to 5230 m, and the total land area is 4075 km^2. Total cultivated land in Maoxian is only 6437 ha, that is, approximately 1.6% of the land area, and it is largely near villages or along river banks for reasons of irrigation access. Agriculture continues to be the major part of economy in the county, even while per capita cultivated land has dropped to 0.06 ha. The present agricultural system in Maoxian is characterized by diverse fruit crops including apple, plum, cherry, loquat, pear, walnut, peach, etc. and vegetables such as lettuce, cabbage, tomato, celery, onion, etc. While plums are the main fruit trees in most orchards at present, apples—the main crop of the past decades—exist only in some orchards (Table 1) and contribute only 30% of the total farm income (Du 1998; Huang and Chen 2003). The climate is warm temperate. Meteorological data collected from the county town of Maoxian located at an altitude of 1590 m revealed that the average mean annual

TABLE 1 Farming in different villages of Maoxian County, Sichuan Province.[a)]

	Village					
	Feng Mao	An Xiang	Jing Zhou	Le Du	Ping Tou	Shui Xi
Altitude of the area (m)	1419	1695	1595–1795	1534	–	1578–1633
Number HHs[b)] interviewed per village	11	4	12	7	9	7
Arable land per HH (ha)	0.26	–	0.15	0.13	0.13	0.34
Crops planted (% HHs)						
Apples only	0	0	0	0	0	12.5
Apples and plums	50	0	0	0	0	12.5
Apples, plums, and cherries	50	0	0	0	0	0
Apples, vegetables, and plums	0	100	0	0	0	50
Plums only	0	0	34	0	0	12.5
Plums and vegetables	0	0	22	100	100	12.5
Plums and cherries	0	0	11	0	0	0
Plums and peaches	0	0	11	0	0	0
Plums, grapes, and vegetables	0	0	11	0	0	0
Vegetables only	0	0	11	0	0	0
Average size of orchard (ha)						
Apples	0.08	0.16	0	0	0	0.04
Plums	0.16	–	0.11	0.13	0.13	0.23
Cherries	0.013	–	0.04	–	–	–
Loquats	–	–	–	–	–	–
Peaches	–	–	–	–	–	–
Number of trees per HH						
Apples	50	100	0	0	0	38
Plums	100	–	67	80	80	125
Cherries	8	–	13	–	–	–

TABLE 1 Continued.

	Village					
	Feng Mao	An Xiang	Jing Zhou	Le Du	Ping Tou	Shui Xi
Average annual HH income (Yuans/mu/y)						
Apples	4000	4000	0	0	0	4000
Plums	3000	0	3000	2000	2000	3500
Cherries	3000	0	3600	0	0	0

[a]15 mu = 1 ha; Yuans 6.4 = US$ 1.
[b]HH = household.

temperature is 11.2°C. July is the warmest month, with a mean monthly temperature of 20.8°C, and January is the coldest, with a mean monthly temperature of 0.4°C. Precipitation varies from 335 to 601 mm, and the mean annual precipitation is 490 mm, 77% of which falls from May to September. Mean annual relative humidity is 72%, ranging from 66% in January to 78% in September, with little variance throughout the year.

Data collection

A farmers' survey was conducted in April 2011 in the same or adjoining villages, including Feng Mao, An Ziang, Jing Zhou, Le Du, Ping Tou, and Shui Xi, where earlier studies were carried out in 2001. These villages, located at different altitudes in the valley, were selected to determine whether farmers at different altitudes were facing different degrees of pollination problems and changes in local climate. The survey questionnaire had questions about apple farming, pollinators and pollination issues, hand pollination needs and management approaches, shifts to other fruit crops, sources of farm income, better choices, and household economy. Information (quantitative as well as qualitative) was gathered from households with different amounts of land by interviewing any member of the family: husband, wife, parents, etc. Older family members were specially

TABLE 2 Pollination of fruit crops by farmers in different villages.[a]

	Village					
	Feng Mao	An Xiang	Jing Zhou	Le Du	Ping Tou	Shui Xi
Number of farmers using human pollinators for apples (%)	100	100	No apples	No apples	No apples	100
Number of farmers using human pollinators for cherries (%)	–	No cherries	100	No cherries	No cherries	No cherries
Number of person days needed for pollination of apples	5–6	5–6	NA[b]	NA	NA	2–3
Cost of hiring human pollinators (US$/person/d)	12.5	7.8–9.4	NA	NA	NA	15.6–18.75

[a]Yuans 6.4 = US$ 1.
[b]NA = not applicable.

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FIGURE 2 Farmers pollinating apple flowers in Feng Mao village. (Photo by Uma Partap)

chosen for gathering folk observations about the scale and pace of changes in agricultural systems and climate. A few beekeepers in the valley were also interviewed to understand access to beekeeping as a tool for managing fruit pollination in the valley and whether farmers are now using it. Secondary data on population, agriculture, average land holdings, and meteorology were accessed from literature and government sources.

Data analysis

Data were analyzed by using simple means and percentages; no special statistical methods or tests were used. Where surveys were conducted in different villages, overall averages for each village were used without being weighted for numbers of respondents.

Results and discussion

The status of human pollinators

Findings revealed that farmers continue to use human pollinators for hand pollination of apples, although at a reduced scale (Table 2). During the apple flowering season of 2011, countless numbers of people were seen working as human pollinators, pollinating apple orchards in the valley in some areas (Figure 2). Although those farmers with smaller orchards pollinated their trees themselves, the larger orchard owners employed laborers for this purpose. Hand pollination of apples in Maoxian on a large scale has been promoted since the late 1980s, and it was in its peak during the 1990s until the early 2000s. The findings revealed that, due to declining productivity and the falling price of apples as well as increased production costs particularly owing to the continuing need for hand pollination and rising costs and scarcity of labor (human pollinators), there has been a continuing decline in the contribution of apples to the household economy of Maoxian farmers. Apples are no longer the number one crop in the valley.

Problems that relate to pollination of apples were further compounded during this decade (2001–2011). With apples, pollination has to be accomplished within 5 days of blossoming. However, due to the migration of farm labor from the area, apple farmers are facing a serious scarcity of human pollinators. To cope with this

TABLE 3 Use of pesticides by farmers.[a)]

	Village					
	Feng Mao	An Xiang	Jing Zhou	Le Du	Ping Tou	Shui Xi
Number of farmers using pesticides (%)	100	100	100	100	100	100
Number of pesticide sprays per year	8	8	8	8	8	8
Types of pesticides used	Insecticides, fungicides, bactericides	Insecticides, fungicides, bactericides	NA[b)]	NA	NA	Insecticides, fungicides, bactericides
Time of pesticide sprays	Before and after flowering, not during flowering	Before and after flowering; not during flowering	NA	NA	NA	Before and after flowering; not during flowering
Farmers' awareness level about the harmful effect of pesticides on pollinators (%)						
Pesticides kill pollinators	50	100	44	100	–	75
Pesticides do not kill pollinators	50	–	–	–	–	–
Do not know	–	–	56	–	100	25

[a)]All the farmers use pesticides on apples, cherries, plums, and vegetables.
[b)]NA = information not available.

scarcity, farmers were hiring labor from other areas, which further escalated the cost of apple pollination. Usually, apple owners themselves collect and process flowers to build pollen stock, and the hired labor is engaged only for hand pollination. A person can pollinate 5–10 trees a day, depending on the size of the trees. Farmers pay the human pollinators US$ 12–19/person/d. They still believe that hand pollination is the only solution if they continue to grow apples.

Why Maoxian farmers needed human pollinators for apples

Our study indicated that an insufficient proportion of pollinizer trees in the orchards and the declining populations of natural insect pollinators in the surrounding localities have created a perpetual need for human pollinators in the apple orchards of Maoxian County. Visits to different villages and discussions with farmers revealed that there is a shortage of pollinators left in the area now to ensure adequate natural pollination of apple trees. About 4 decades of pesticide sprays by the farmers, 8 to 10 sprays of pesticides per season (Table 3), have contributed to a serious decline in pollinators (Partap and Partap 2002). That pesticide use is a major factor contributing to pollinator decline has been reported in several studies conducted in other parts of the world (Johansen 1977; Allen-Wardell et al 1998; Verma and Partap 1994; Partap and Partap 2002; Berezin and Beiko 2002).

The valley is also experiencing shrinking pollinator habitats due to a continuing increase in farmland area, at the cost of forests and grasslands. Results of several studies carried out in different parts of the world (Partap and Partap 2002; Aizen and Feinsinger 1994; Cane 2001; Berezin and Beiko 2002; Kremen et al 2002) revealed habitat loss as another very important cause of decline in pollinator populations. In Maoxian, loss of habitat that resulted in a decline in natural pollinator populations is driving the need for hand pollination. Our findings show that, in some areas of Maoxian, where natural vegetation is well preserved and pollinators are abundant, pollination of apples occurs naturally, which eliminated the need for hand pollination.

Furthermore, many commercial varieties of apples planted in Maoxian are self-sterile and require cross-pollination by pollen from a compatible variety (a pollinizer). The need for planting adequate proportions of compatible pollinizer trees in apple orchards among the commercial varieties has been reported in earlier studies (McGregor 1976; Free 1993). Liu and Zhang (2002) also attributed poor pollination of fruit crops in Maoxian to inappropriate placement of fruiting and pollinizer varieties, in addition to a low proportion of pollinizers.

TABLE 4 Beekeeping and use of honeybees by farmers for pollination of apples and other crops.[a)]

	Village					
	Feng Mao	An Xiang	Jing Zhou	Le Du	Ping Tou	Shui Xi
Number of farmers keeping honeybees (%)	50	50	11	0	0	12.5
Number of colonies per HH[b)]	6	2	2 (however, 1 beekeeper had nearly 100 *Apis cerana* colonies, whereas another had about 20)	–	–	3
Purpose of beekeeping	Honey production	Honey production	Honey production (also rented for pollination a few years earlier)	–	–	Honey production
Number of farmers renting honeybees for pollination (%)	There is no practice of renting honeybees for pollination.					
Number of beekeepers renting bees for pollination	Only 2 or 3 beekeepers in the whole valley sometimes rent bees to farmers for pollination; renting colonies is not a regular practice.					
Cost of renting bee colonies (Yuans/colony/season)	Rented 40 colonies for the pollination of cherry in 2010 at the rate of Yuans 300 (US$ 46.88) per day for 12 days, ie Yuans 90 (US$ 14.06)/colony/season.					
If not, why they do not rent the bees to farmers	Even though farmers offer good money, beekeepers are not interested in renting their bees for pollination because farmers use lots of pesticides that kill the bees, and they do not pay for any loss of bees.					

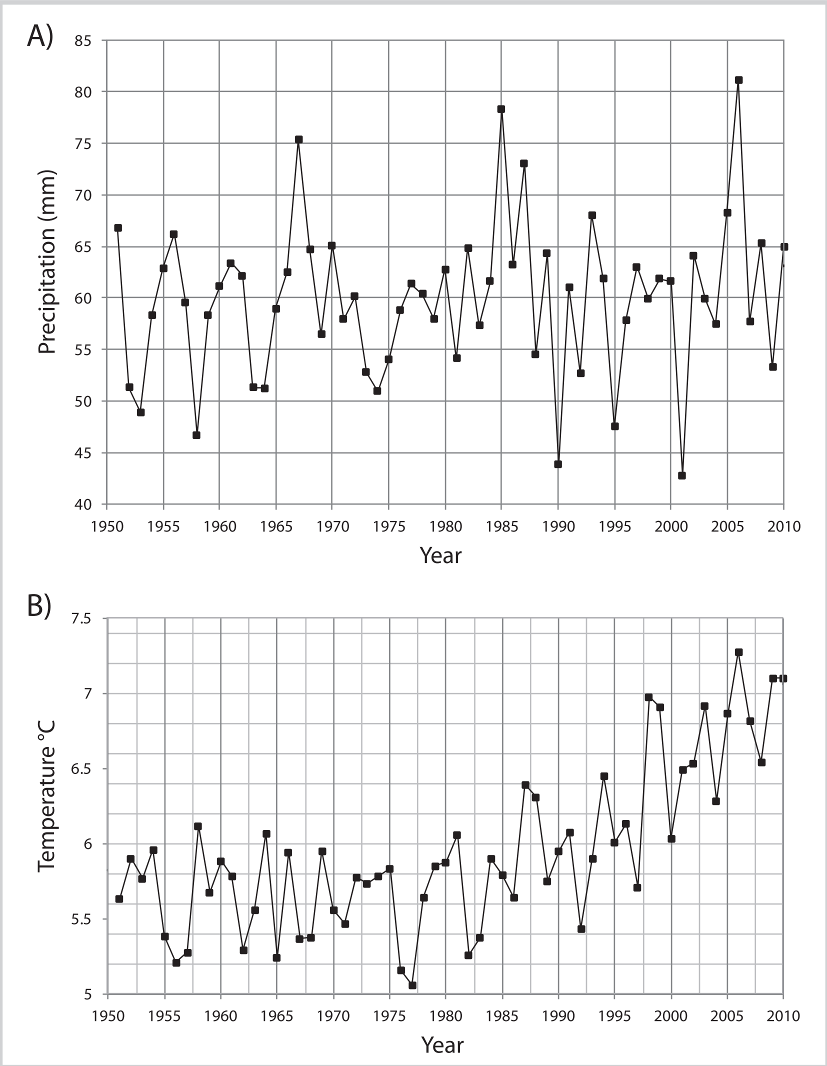
[a)]Yuans 6.4 = US$ 1.
[b)]HH = household.

Scientists recommend planting 25–33% pollinizer trees among the main variety for a satisfactory crop (Jindal and Gautam 2004). However, in most fruit orchards in Maoxian, pollinizer trees account for less than 10% of the trees. However, because land holdings are small in Maoxian, farmers do not want to plant pollinizer trees in their orchards because they have a low market value. The most obvious reason for this was the fact that the fruit produced by many of these pollinizer varieties has a low market value.

Analysis of our findings revealed that hand pollination of apples was driven by both ecological and economic considerations; ecological consideration, because pollination is a limiting factor in crop productivity; and economic, because apples were the main cash crop in the area. As mentioned earlier, pollinators that used to provide pollination services to crops in Maoxian are declining; and pollination as a free service provided by nature is no longer available free of charge. Therefore, it is necessary to increase pollinator intensity in the fields and orchards to ensure proper pollination: the "ecological dimension of crop productivity."

The intensity of pollinators in the orchards can be increased by using colonies of honeybees such as *Apis*

FIGURE 3 (A) Change in mean annual precipitation in Songpan from 1950 to 2010; (B) change in mean annual temperature in Songpan from 1950 to 2010.



cerana and *Apis mellifera* because they are known to be most effective as providers of pollination for agricultural crops (McGregor 1976; Deodikar and Suryanarayana 1977; Dulta and Verma 1987; Free 1993; Gupta et al 1993; Partap and Verma 1994; Singh et al 2000). The local government of Maoxian County tried but failed to promote beekeeping for pollination. It was not a pleasant experience for the beekeepers, either. They lost many colonies due to heavy pesticide use by farmers and were not compensated for the loss. This acted as a discouraging factor in facilitating the use of ecologically and economically sustainable methods of apple pollination. Consequently, hand pollination remained the only option that farmers knew (Table 4). Moreover, because apples had an important role in the economy of the area, it was important to make efforts to ensure the yield and quality of this crop. With no other option available for ensuring pollination, hand pollination was promoted to secure yield and fruit quality.

Why Maoxian farmers are adopting alternatives to apple farming

Large-scale community-based hand pollination of apples and other fruit crops is unique to China. However, farmers and institutions have begun to believe that it is not a sustainable option, as revealed by the findings of this study. The increasing costs of hand pollination compared with the low income from apples have forced Maoxian farmers to look for alternative farming options. Migration of local people (human pollinators of apples) to cities in search of better jobs has led to increased labor scarcity and has multiplied the cost by a factor of approximately 10. Although, in 2000, human pollinators were available for US$ 2/person/d, presently, the cost of

FIGURE 4 Mixed fruit farming in study area. An orchard with apples, cherries, plums, loquats, and vegetables in Feng Mao village. (Photo by Uma Partap)

hiring them varies from US$ 12–19/person/d, which has led to a substantial increase in the cost of producing apples. This, coupled with the falling market prices for Maoxian apples, has been the key factor that compelled farmers to look for other crops.

Our study revealed that climate change–induced changes in local weather have resulted in frequent rains, low temperatures and cloudy weather, as observed in Maoxian County during the apple flowering season, which delays flowering and also affects pollination by natural pollinators where they are present (Partap and Partap 2002; Tang et al 2003). Most of the responding farmers reported fluctuations in local weather. The striking feature of the local weather changes was that temperature changed within a short time, from very hot to very cold or vice versa. Snowfall has been decreasing, but freezing rains have increased; the time of snowfall has also changed. Another change was an increase in precipitation during the month of April, which caused continuing low temperatures in spring. The reports from a weather station also indicate an increase in mean annual precipitation and mean annual temperature (Figure 3A, B). Research conducted elsewhere by Fitter and Fitter (2002) and Miller et al (2007) showed that weather is the key factor that influences pollination of crops. Abnormal weather, such as cold temperatures, rain, and hailstorms, during the blooming period can negatively affect pollination. Temperature is reported to have a large impact on pollination interactions and is known to affect flowering in crops and plants (Arft et al 1999; Inouye et al 2003). Air temperature of 17–18°C is considered optimal for apple flower blooming.

Therefore, weather has also been a significant contributing factor in farmers' decision-making about the use of human pollinators. In clear weather, one-time hand pollination is sufficient, and hired laborers work for just 1 or 2 days but under cold and cloudy weather conditions. When the blooming period lengthens, repetitive pollination is necessary, which requires more days for human pollinators, which adds to the cost of managed pollination. The present findings reveal that fluctuation in local weather wherever human pollination is still practiced, has led to the hiring of more human pollinators so as to accomplish the pollination task in fewer days. Changes in weather have thus become another key factor that contributes to the necessity of maintaining hand pollination of apples, with the accompanying increase in input costs.

Farmers' innovations in adaptive strategies

In answer to the question of how farmers are adapting to the pollination crisis in the face of the increasing costs for human pollinators and climate change, our findings revealed that a major shift in the cropping pattern is occurring in the area. Apples, the major cash crop of the area in 2001, are now being phased out. Farmers are replacing them with other fruit crops, such as plum, loquat, and walnut. Many farmers have already replaced apples; others are in the process of doing so. As a result, mixed plantation orchards have become a common sight in the area (Figure 4). Apples have been completely phased out from Jing Zhou, Le Du, and Ping Tou, 3 of the 6 villages where this study was undertaken (Table 2). Discussions with farmers revealed that the increasing costs of production, including for human pollinators, were one of the reasons that led farmers to replace apples by alternative self-pollinated fruit crops.

This shift in fruit crop farming includes both ecological and economic considerations. In the present decade, the farm gate price of apples has dropped substantially, to between just US$ 0.16/kg and 0.19/kg, but production costs have continued to rise. However, other fruits fetched better prices, for example, plums, US$ 1.9–2.5/kg; cherries, US$ 4.7–6.3/kg; and loquat, US$ 1.6–2.3/kg. Moreover, the cost of production of these crops is much lower compared with apples, and they produce good yields without being essentially cross-pollinated. Therefore, investment in human pollinators is not required, and farmers do not have to worry about finding pollinators. To increase their farm income, farmers also adopted intercropping of vegetables, such as lettuce, cabbage, Chinese cabbage, tomato, celery, and onion, along with other fruit trees, which shows that, in this mountain valley of Maoxian, both ecological and economic factors combined to encourage farmers to innovate by finding new ways of cropping and suitable crops to sustain their livelihood.

Conclusion

For apple farmers in Maoxian, pollination continues to be a limiting factor in productivity, and managing it through human pollinators has been upsetting the cost–benefit ratio of apple farming. By 2011, apple farming and the use of human pollinators had been considerably reduced in the valley and is now limited only to those villages or areas where farmers either have not been able to find suitable alternative options or those nearer the forest areas that still benefit from some degree of natural pollinators. Changes in fruit farming from apples, a crop that essentially requires cross-pollination, to fruit crops and vegetable crops that are not necessarily cross-pollinated, are part of the farmers' adaptation strategy.

The clear message of this study is that pollination is a key factor in apple productivity and pollinators are essential in providing this service. Therefore, other areas dependent on the apple economy need to ensure that pollination is well understood as a key limiting factor in productivity and that steps are taken to manage it in sustainable ways that maintain populations of pollinators and their habitats rather than adopting unsustainable techniques such as human pollinators.

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