Impact of losing pollinator diversity: A case study in Taiwan

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Abstract

Mango (*Mangifera indica* Linnaeus) has become the third most important fruit crop in Taiwan at the turn of the 21st century. While enjoying the economic benefit due to an increase in the genetic diversity and diverse produce of mango, Taiwan suffered great economic loss due to unfruitfulness and shy cropping of mango during the period from 1975 to 1990. In this paper, we present our results of analysis of mango production data, interviewing mango growers, and reviewing relevant literature and demonstrate that loss of pollinator diversity might have played a significant role in mango crop failure. This conclusion is supported by the fact that mango crop yield was back to normal after an alternative pollinator of mango, i.e. the oriental latrine fly (*Chrysoma megacephala*), was successfully introduced and mass-reared in mango orchards in early 1990s. The impact of losing functional diversity of pollinators and relying on an alternative pollinator to mango industry was discussed. A restoration program on pollinator diversity is recommended to maintain a functional diversity of pollinators in mango orchard.

Introduction

Although mango (*Mangifera indica* Linnaeus) is native to southern Asia (Mango Fruit Fact, 1996), its cultivation in Taiwan can be traced back to as early as 1561 when the Dutch introduced it from Java, Indonesia into the island (Yang,1959b). Five American varieties of mango were introduced from Florida, United States by specialists of the Sino-American Joint Commission of Rural Reconstruction (JCRR, 1948-1973) in 1954 (Yang, 1959; Wang and Tseng, 1965; Chang et al., 1979) and the beginning of cultivation of these new varieties in the 1960s had a revolutionary effect on mango production in Taiwan. Since then, more than 70 introduced mango varieties have been cultivated in Taiwan (Yang, 1959b; Wang and Tseng, 1965; Chang et al., 1979). In addition, at least 6 locally bred varieties, including Jin-Hwang or Chiin Hwang which is the first local breed developed in 1976 (Hwang, 1986; Lee, et al, 1997), Tainong No. 1, Yu-Win No.6, etc., have been grown by farmers and sold in the market (Chiou, 2010). Mango became the third most important fruit crop in Taiwan at the turn of the 21st century (Yen, 2002). The annual yield of mango reached 212,875 m.t. (Taiwan Agricultural Yearbook) and the value of mango produce exceeded NTD4,600 million in 2001 (Yen, 2002), both have increased by two orders of magnitude within a 55-year period. Recently, the popular Irwin mango has been selected by the Council of Agriculture as one of the country's four “flagship export products.” It is evident that Taiwan has benefited greatly from the genetic diversity of mango.

While enjoying the economic benefit due to an increase in the genetic diversity and diverse produce of mango, Taiwan, particularly Yujing of Tainan County which is the most important mango production area in Taiwan, suffered great economic as well as social and environmental loss due to unfruitfulness and shy cropping of mango during the period from 1975 to 1990. The impact and the underlying causes of this crop failure have never been analyzed.

In this paper, we collected and analyzed data on mango plantation and yield from Taiwan Agricultural Yearbook, interviewed mango growers in Yujing to understand the historical background of mangoes crop failure and how this problem was solved, and reviewed literature in an attempt to demonstrate the loss of pollinator diversity might have played a significant role in mango crop failure. We then analyzed the impact of loss and recovering of pollinators to mango industry in Taiwan. We also tried to analyze the cost and benefit of relying on a single alternative pollinator in mango production.

Four stages of mango production

Based on data of mean annual yield per hectare, sizes of planted and harvested area, and annual yield of mango from Taiwan Agricultural Yearbook (renamed as Taiwan Agricultural Statistics Yearbook since 1999) from 1945 (after World War II) to 2009, 4 stages of mango production can be recognized in Taiwan and in Tainan County (Fig. 1, Table 1), i.e. Stage 1 (1945-1964) or the beginning stage, Stage 2 (1965-1974) or the expanding stage, Stage 3 (1975-1992) or the fluctuating stage, and Stage 4 (1993-2009) or the stabilizing stage.

I. Beginning stage

Between 1945 and 1964, mango cultivation was not very popular. Mean annual yield per hectare of mango in Taiwan was less than 10,000 kg/ha (7737.9 ± 1802.2 kg/ha). The total plantation of mango per year averaged 425.3 ± 61.4 ha (range: 317 - 580 ha, Taiwan Agricultural Yearbook) and the annual yield rarely exceeded 5,000 m.t. (average: 225.5 ± 921.4 m.t., range: 1,806 - 4,882.7 m.t.) (Fig. 3). This trend was basically a continuation of that in the last decade of the Japanese colonial era. At the time, the planted area was the same as the harvested area until 1963 when two statistics appeared in the Taiwan Agricultural Yearbook, namely the planted area and the harvested area, indicating an increase of young plantation of mango (Fig. 2).

II. Expanding stage

Between 1963 and 1974, the differences between the sizes of planted area and that of the harvested area gradually enlarged at a rate of several hundred hectares per year (from 1963 to 1969) to several thousand hectares per year (from 1970 to 1974) and reached its peak in 1974 (4600 ha, Fig. 4). Meanwhile, the mean annual yield per hectare increased drastically to 10,000-20,000 kg/ha (13585.1 ± 3492.5 kg/ha) and the annual yield tripled from 5,269 m.t. in 1964 to 17,645 m.t. in 1967 (Taiwan Agricultural Yearbook, Fig. 3) when new plantation began to set fruits. By 1974, the planted area of mango exceeded 10,000ha, the harvested area exceeded 5,000 ha, and the annual yield jumped to a record high of 59,898 m.t. (Taiwan Agricultural Yearbook, Fig. 2, Fig. 3).

III. Fluctuating stage

Between1975 and 1992, mean annual yield per hectare fluctuated between 5,000 -10,000 kg/ha (average: 7326.5 ± 2354.5 kg/ha), with fruit crop failure occurring in some years. The coefficient of variation (CV) of mean annual yield per hectare at this stage was the highest (32%) among the 4 stages. The rate of increase in both planted area and harvested area dropped (Fig. 2), and the difference between the sizes of planted and harvested area gradually reduced to its lowest point in 1988 (roughly 1500 ha), indicating that a weaken incentive to plant more mango trees, but the annual yield often exceeded 100,000 m.t. (Fig. 3).

IV. Stabilizing stage

Between 1993 and 2009, mean annual yield per hectare stabilized around 10,000 kg/ha (10623.4 ± 1066.0 kg/ha). The sizes of both planted area and harvested area slowly declined (Fig. 2) and the annual yield mostly exceeded 200,000 m.t.. The CV of average yield per hectare at this stage (10%) was the lowest among the 4 stages, indicating a rather matured mango cultivation which guarantees stable mango production each year. The difference between planted area and harvested area reduced continuously to less than 500 ha (Fig. 4), indicating a saturation of mango plantation.

Mango production in Tainan County where mango planted area, harvested area, and annual yield accounted for 50.2% (range 39.9% - 67.6%), 52.1% (range 40.6% - 75.6%), and 51.0% (range 18.7% - 85.6%) of those of Taiwan respectively in the past 65 years showed similar trend (Fig. 1, Table1). In fact, the correlation coefficient of mean annual yield per hectare between Taiwan and Tainan County was as high as 0.95 (Fig. 1).

At Stages 1 and 2, mean annual yield per hectare in Tainan County was 8085.7 ±2410.0 kg/ha and 15812.2 ± 4217.2 kg/ha, respectively, both were higher than that of Taiwan. Of the total yield of 59,898 m.t.in Taiwan in 1974 (stage 2), 74.4% (44,537/59,898) was produced from Tainan County (Taiwan Agricultural Yearbook, Fig. 3), particularly from Yujing area..

At Stage 3, however, mean annual yield per hectare in Tainan County was only 5715. ± 2795.4 kg/ha, much lower than that of Taiwan. At Stage 4, mean annual yield per hectare in Tainan County was 11811.8 ± 1613.3 kg/ha, higher than that of Taiwan again (Table 1). In short, the mean annual mango yield per hectare in Tainan County was higher than that of Taiwan at all stages but Stage 3 (Table 1). In most (37) of the past 65 years, mean annual mango yield per hectare in Tainan County was higher than that of Taiwan, but it happened only in one of the 17 years at Stage 3 (Fig. 1). In addition, the CV of mean annual yield per hectare in Tainan County at Stage 3 was close to 50%, reflecting an even wider fluctuation than that of Taiwan (Table1). The annual mango yield of Tainan County was particularly low, comparing to the rest counties in Taiwan, during the period from 1983 to 1986 (Fig. 3).

Factors causing unfruitfulness and shy cropping at Stage 3

In 1974, when annual yield of mango reached a record high of 59,898 m.t., the government set Yujing area of Tainan County where nearly three quarters of mango in Taiwan were harvested as the Mango Special Crop Region (Chang et al., 1979), in hope to contributing significantly to local economy and raising the income of the farming community. Ironically, in the following year, mango yield of Taiwan dropped 27.8% to 43,293 m.t. (Taiwan Agricultural Yearbook, Fig. 3), though the sizes of planted and harvest area kept increasing (Taiwan Agricultural yearbook, Fig. 2). Mango yield reduction in Tainan County, particularly in Yujing area, was astonishing: dropped almost 50% from 44,537 m.t. in the previous year to 29,243 m.t. in 1975 (Taiwan Agricultural Yearbook, Fig. 3).

In 1975, mango growers in Yujing area gather together and put pressure on government to find out the underlying cause of mango unfruitfulness and shy cropping. In the following years, the government spent more than 10 million NT dollars to build roads, bridges, mechanical pesticide spraying facilities and water supply facilities, etc., in a total area of 1,100 ha at Yujing and surrounding township (JCRR. 1976-1977) in an attempt to improve the situation. The Improvement Programs lasted for more than a decade and facilitated many research projects from various disciplines such as horticulture, plant physiology, plant pathology and entomology. Despite extensive research on factors related to mango fruit set, few advances were made towards finding the resolution of reliable and increasing crop production. The annual mango yield continued to fluctuate widely until 1992 (Fig. 3). Consecutive bumper harvests were often followed by consecutive lean harvests at this stage (Fig. 1, Fig. 3). The annual yield reached a new record high of 152,062 m.t. in 1982 but sharply dropped to a record low of 28,618 m.t. the following year (Fig. 3).

Meanwhile, the annual mango yield of Tainan County in 1983, 1984, 1985, and 1986 was only 18.7%, 30.4%, 18.2% and 25.4% of that of Taiwan, respectively (Taiwan Agricultural yearbook, Fig. 3). According to Liu (1983), more than 80% of Irwin mango in Yujing was parthonocarpic and he concluded that this was due to abnormal climate (lower temperature, higher rainfall, and therefore less pollinator) during the flowering season. However, mangoes failed to set fruit even in years when climate was quite normal and trees showed very good flowering. More fertilizers and pesticides could not help any more fruit setting either. A long list of possible causes of mango unfruitfulness was suggested, e.g. biennial bearing for certain varieties, the percentage of perfect (hermaphrodite) flowers was too low to set fruits for most mango varieties, water stress, cold weather at flowering or anthracnose in flowers, poor site condition, poor nutrition of trees, trees were inadequately fertilized, poor tree management (i.e. too high a density of mango trees, over-crowded crown without pruning and thinning, allowing fruit setting in early age of trees), overuse and/or misuse of pesticides damaging mango foliage and flowers, etc. (Yang, 1959a; Chang et al., 1979; Lin, 1980; Hwang, 1986, 1987). After studying mango fruit setting in Yujing area for several years, Lin (1989) hypothesized that overuse of pesticides to control mango insect pests might have eliminated non-target insects, particularly pollinators of mango, thus hindered mango fruit setting. Lin (1989) then called for cautious application of pesticides, especially during the flowering season, so to maintain the function of pollinators. However, no research was conducted to examine this hypothesis.

Overuse and/or misuse of pesticides and pollinator disappearance

Originally, 7 insect pests of mango were identified in Taiwan, including mango shoot bores *Chlumetia transversa*, California scale insect *Aonidiella aurantii*, mango brown leafhopper *Idioscopus nivesparsus*, mango green leafhopper *I. clypealis*, mango psyllid *Microceropsylla nigra*, small yellow thrips *Scirtothrips dorsalis*, and oriental fruit fly *Bactrocera dorsalis* (Lee, 1979; Lo, 1991; Plant Protection Manual, 1982-2007). The two species of mango leafhopper are the most destructive pests during mango flowering stage. The leafhoppers feed on tender shoots and secrete a sticky substance that sooty molds can grow on (Wen and Lee, 197). In addition, mango red spider mite (*Oligonychus mangiferus*) has become a serious foliage pest in recent years (Lin and Chen, 2008).

Four pesticides and formulations have been recommended for controlling mango shoot bores, 2 for California red scale, 2-3 for mango psyllid, 1 for small yellow thrips, and 2 for oriental fruit fly (Plant Protection Manual, 1982-2007). However, the number of pesticides and formulations recommended for controlling mango leafhoppers started from 5 in 1982, 6 in 1986, 12 in 1994, 18 in 2000, 23 in 2002, 27 in 2004, to 30 in 2007 (Plant Protection Manual, 1982- 2007). It is likely that mango growers demanded more choices of pesticides and formulations to keep the pest population under control so that they could have higher mango production.

The loss of agricultural database due to the 921 earthquake in year 2000 made it impossible to trace the amount of pesticides sprayed in Yujing area during this period of time. However, Chang et al. (1979) noted that in 1975-1976,

> "*For controlling disease and insect pests, fungicides and insecticides were usually mixed in solutions for spraying at the same time and the concentrations of individual agent were usually much higher than the regulation permitted. Spraying of such mixed solution resulted in the damage of foliage, flower and fruit setting.*"

He considered the spraying of fungicides and pesticides injured mango trees physiologically and caused unfruitfulness and shy cropping of mango in Yujing. However, the overuse and/or misuse of pesticides not only interfered with the physiological process of mango tree but also caused local extinction of pollinators. Lin (1989) noted that overuse of pesticides probably wiped out mango pollinators in Yujing. One can find the pattern that consecutive bumper harvests followed by consecutive lean harvests repeats several times at Stage 3 of mango production (Fig. 1, Fig. 3). In the first years of such cycle, target pests were killed by pesticides and farmers enjoyed a bumper harvest. As non-target pollinators were also killed by pesticides to a point that pollination become impossible, farmers then suffered a collapse of yield. The yield will not recover before the functional diversity of pollinators was rebuilt from surrounding forest. The fluctuation of annual yield apparently was related to an unstable population or local extinction of non-target pollinators (Fig. 1, Fig.3). Unaware that the misuse of pesticides was the cause of shy cropping of mango in 1975, the government went on to subsidize more mechanical pesticide spraying facilities to mango growers in Yujing from 1976 and on (JCRR, 1976-1977; Chang et al., 1979) and this was not helpful to rebuild the functional diversity of pollinators and consequently the improvement of crop yield.

Discovering an alternative pollinator

While decline in fruit set was getting more pronounced year after year, some sharp-eyed mango growers noticed that mango trees around the garbage dump site continued to have high fruit set. Further observation indicated that abundance of oriental latrine fly (*Chrysoma megacephala*) at the garbage dump site may be related to the success of mango fruit set. Some farmers attempted to trap these flies and brought them back to mango orchards but the flies simply flew away. Gradually the mango framers developed ways to facilitate oriental latrine fly to stay in their mango orchards. They took visceral of chicken and/or hog to the dump site so that female flies laid eggs on the visceral. Days later, the visceral filled with maggots was brought to the mango orchards. The newly emerged flies then stayed in the mango orchards and reproduced more offspring on site. The very existence of abundant oriental latrine fly apparently helped pollination and mango fruit set, and brought the crop production back to normal (Wu, personal communication). This finding encouraged more mango growers to leave decayed visceral of domestic animals in their orchards in order to maintain a high population of oriental latrine flies. To cost down, the mango growers later replaced the visceral with fish, which was much cheaper in price, to attract the oriental latrine fly during mango anthesis. As the method was getting popular, the mango production in Yujing recovered in 1990 (Fig. 1, Fig.3). Field experiment showed that the oriental latrine fly was indeed an effective pollinator (Wu and Lin, 1994). In1991, the mango yield of Tainan County reached 42.5% of that of Taiwan and this ratio remained to be around 50% till now. The difference between the sizes of planted and harvested area increased for 4 consecutive years since 1989 until it reached a second peak in 1993 (roughly 2400 ha, Fig. 4), indicating the solution was useful and farmers were willing to plant more mango again. The drop of yield after 1993 was mainly due to climate and market factors (Wu, personal communication).

Cost of losing pollinator diversity

Cost of losing pollinator diversity can be tremendous. Prior to Stages 3, the value of mango produced in Tainan County was 77%, 73% and 79% of that of Taiwan in 1968, 1970 and 1972, respectively. However, the value of mango produced in Tainan County dropped to 68% of that of Taiwan at the beginning of Stage 3 in 1975 and further dropped to 60% in 1976. This percentage kept descending to 53% in 1980 and to 41% in 1981 (Taiwan Agricultural Yearbook). Statistics on annual mango value became unavailable after 1981.

Take year 1980 as an example, the total value of mango production in Taiwan was NTD1,067 million. If value of mango production in Tainan County remained to be 70% of that of Taiwan, the value would have been NTD747 million. The real value of mango produced in Tainan County that year was only NTD569 million. The difference between the expected value and the true value was NTD178 million. In other words, the mango crop reduction in Tainan County due to loss of functional diversity of pollinators in Yujing area was NTD178 million in 1980 alone. If we take a conservative estimate that Tainan County lost NTD100 million per year during Stage 3, then the total monetary loss due to loss of pollinator diversity would have been NTD1,800 million.

The finding of oriental latrine fly *C. megacephala* solved the problem of mango pollination and subsequent fruit setting and fruit production. Although the fly saved economic loss in Yujing, Yujing was filled with stinky smell of dead fish during the mango flowering season. Yujing people had to tolerate numerous oriental latrine flies flying around as well as to live with the smell for months. In addition, the oriental latrine fly is known for producing myiasis in humans and other animals and transmitting pathogens. It was reported as the most dangerous dipteran vectors of enteric pathogens (Greenberg, 1971, 1973) and the dominant vector of helminth parasite eggs

(Sulaiman et al., 1988, 1989).

To avoid the stinky odor, several formula of artificial diet for mass-rearing oriental latrine flies were developed (Hung et al., 1994; Hwang and Liu, 1994; Wu and Lin, 1994; Hu et al., 1995; Chen and Chen, 1997; Hung, 1997). Ingredients of the artificial diet for fly larva included bean powder, fish meal and chicken feed and the advantage of using this artificial diet was economic, convenient, clean, odorless, and satisfactory nutritional content for normal development of fly (Hung et al., 1994; Hwang and Liu, 1994; Wu and Lin, 1994; Hu et al., 1995; Chen and Chen, 1997; Hung, 1997). Mango growers in Yujing later accepted the odorless artificial diet to mass-rearing flies for pollination and the dead fish smell was no longer an environmental problem after 1900s. However, the potential risk of the oriental latrine flies carrying diseases or parasites as vectors, and the nuisance problems caused by flies to Yujing communities remain to be assessed and managed.

More importantly, relying on a single artificially reared pollinator for pollination, like hand pollination, is unnatural and may not be sustainable. Interview of mango growers indicated that not all mango varieties rely solely on oriental latrine flies for pollination (Wu, personal communication). As more mango varieties are introduced or developed, more diverse pollinators may be needed for successful fruit production. Low pollinator diversity may limit the chances of producing new fruit varieties. Furthermore, high population of flies may continue to compete out other potential pollinators and make rehabilitation of natural pollinators difficult.

Last but not the least, the impact of losing the original pollinator diversity on natural vegetation within and around mango orchard, thus the loss of ecosystem function, such as nutrient cycling, water and soil conservation, maintenance of ecosystem stability, etc., that may affect mango orchard management in the long run may never be known.

Recent development of mango production

As the mango cultivation practice mature, mango production stabilized and the demand for better quality and safer fruit product increased, more mango growers began to bag their fruits from the damage of insect pests. The bagging technique is labor intensive and the labor cost can only be covered if the produce is exported or sold in organic market. In fact, the recent opening of foreign market such as Japan, Europe, and China, encouraged more mango growers to follow the strict export regulation and reduce the use of pesticides. This bagging method is an environmentally friendly act toward recovering pollinator diversity.

However, reducing the use of pesticides alone is not enough. We recommend a more proactive approach to restore pollinator diversity in mango production system, which may include protection of remaining wildness, set refuge for pollinators in or around the mango production system, and reintroducing or restocking local pollinators.

Conclusion

In the past 6 decades, the society and economy of Taiwan benefited greatly from genetic diversity of mango. However, overuse and/or misuse of pesticide probably caused decline or loss of pollinator diversity and the failure of pollination in turn reduced mango production in Yujing, a key mango producing area in Taiwan. Mango growers suffered a great economic loss due to loss of functional diversity of mango pollinators during the period from 1975 to 1992. The finding and mass-rearing of an alternative pollinator, the oriental latrine fly *C. Megacephala*, have ensured a rather stable mango harvest since 1990s. However, in order to maintain satisfactory fruit production, Yujing suffered from the stinky smell of dead fish, and the nuisance and potential health risk caused by flies. The problem of smell was fortunately solved, though the nuisance problem and the health issue remain to be assessed and managed. The increased dependency on single pollinator increased the risk of stable harvest and limits the potential of growing new varieties. To manage the risk, a restoration program on pollinator diversity is recommended so to maintain a functional diversity of pollinators in mango orchard.

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Table 1. Mean annual mango yield per hectare in Taiwan and Tainan County and their coefficient of variation (CV) at 4 different stages.

Stage	Mean annual yield per ha in Taiwan (kg/ha)	CV	Mean annual yield per ha in Tainan (kg/ha)	CV
1 (1945-1964)	7737.9 ± 1802.1	23.3%	8085.7 ± 2410.0	29.8%
2 (1965-1974)	13585.1 ± 3492.5	25.7%	15812.2 ± 4217.2	26.7%
3 (1975-1992)	7326.5 ± 2354.5	32.1%	5715 ± 2795.4	48.9%
4 (1993-2009)	10632.4 ± 1066.0	10.0%	11811.8 ± 1613.3	13.7%

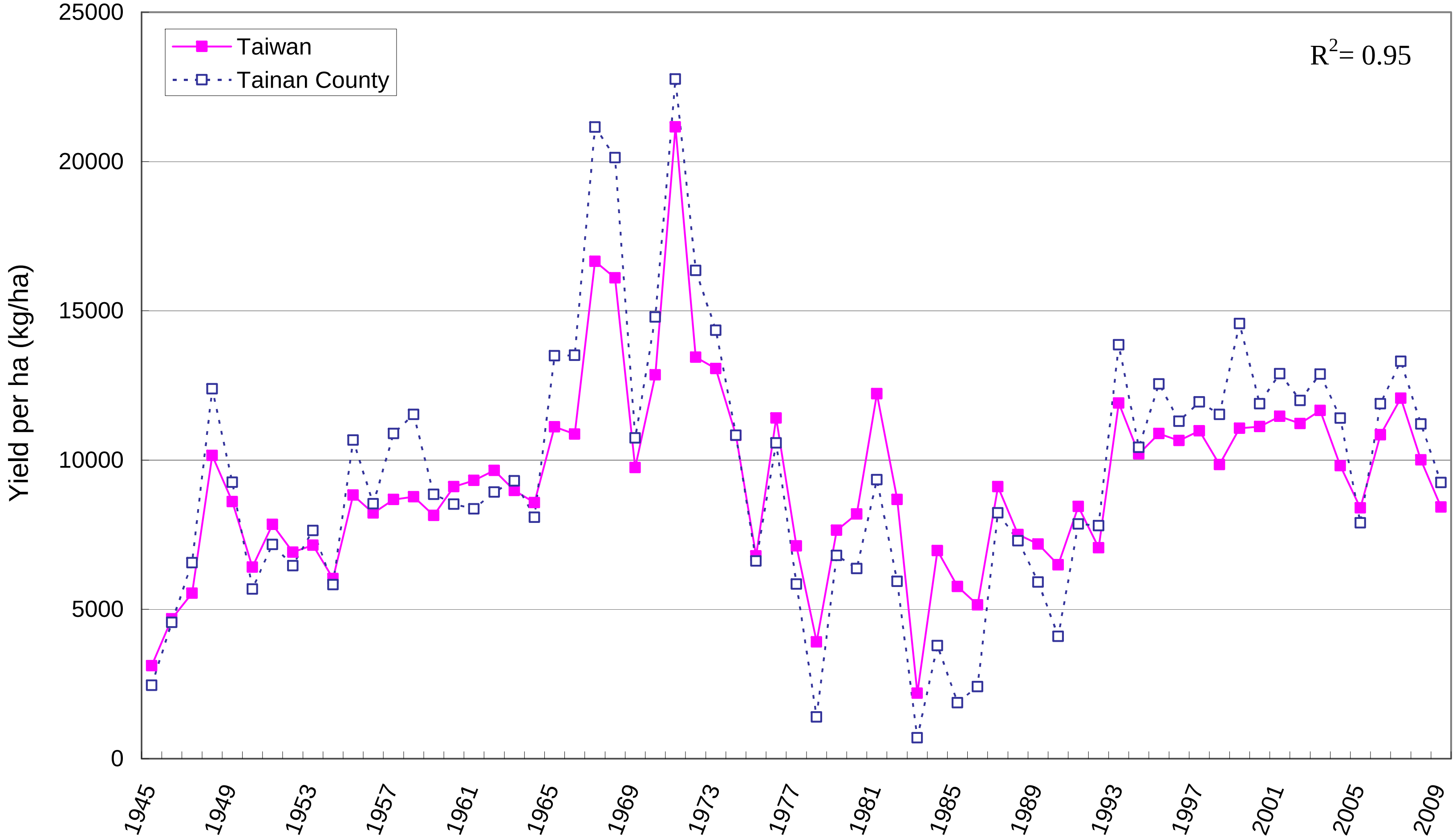

Fig. 1. Mean annual mango yield per hectare in Taiwan and Tainan County from 1945 to 2009.

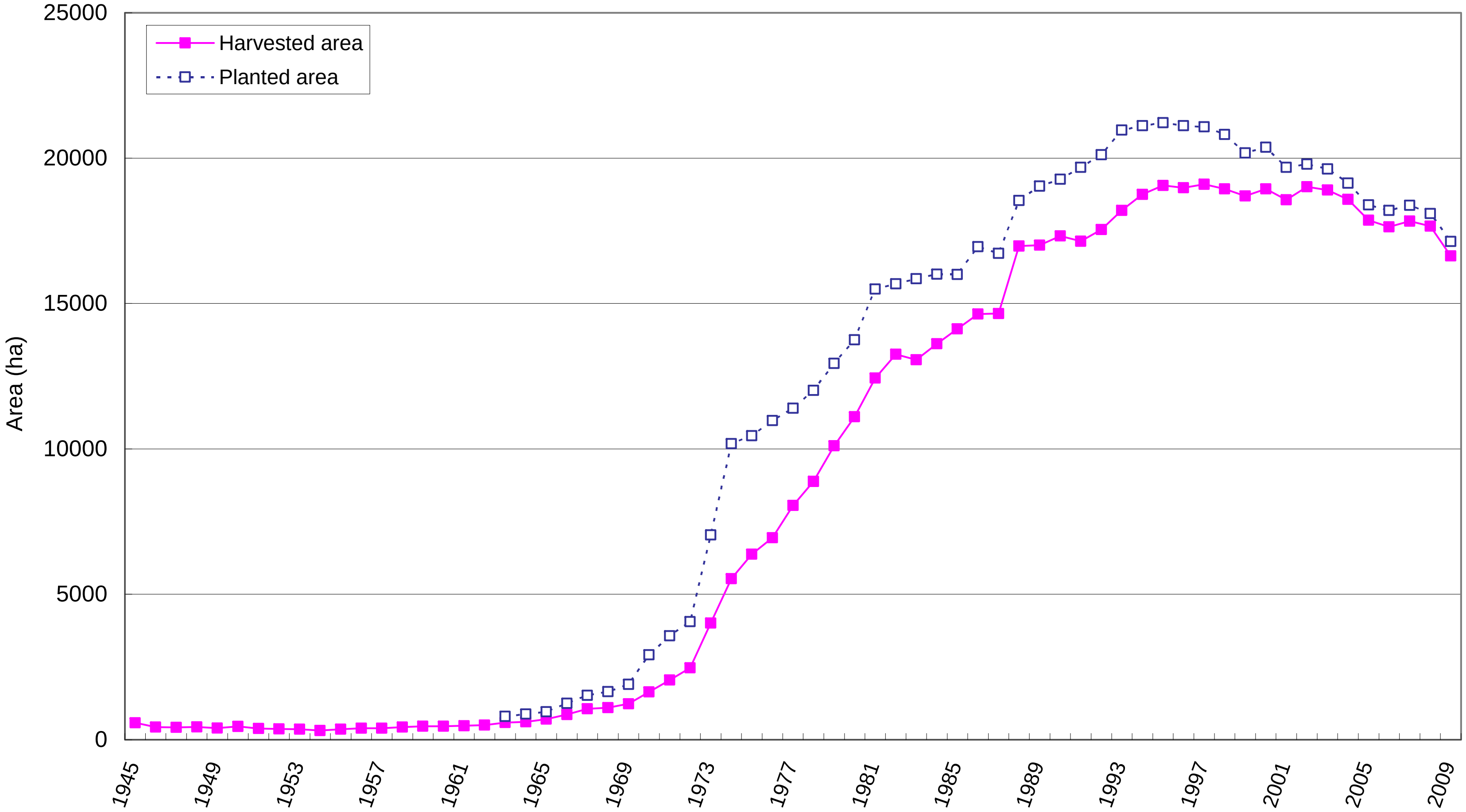

Fig. 2. Change of planted area and harvested area of mango in Taiwan and Tainan County from 1945 to 2009.

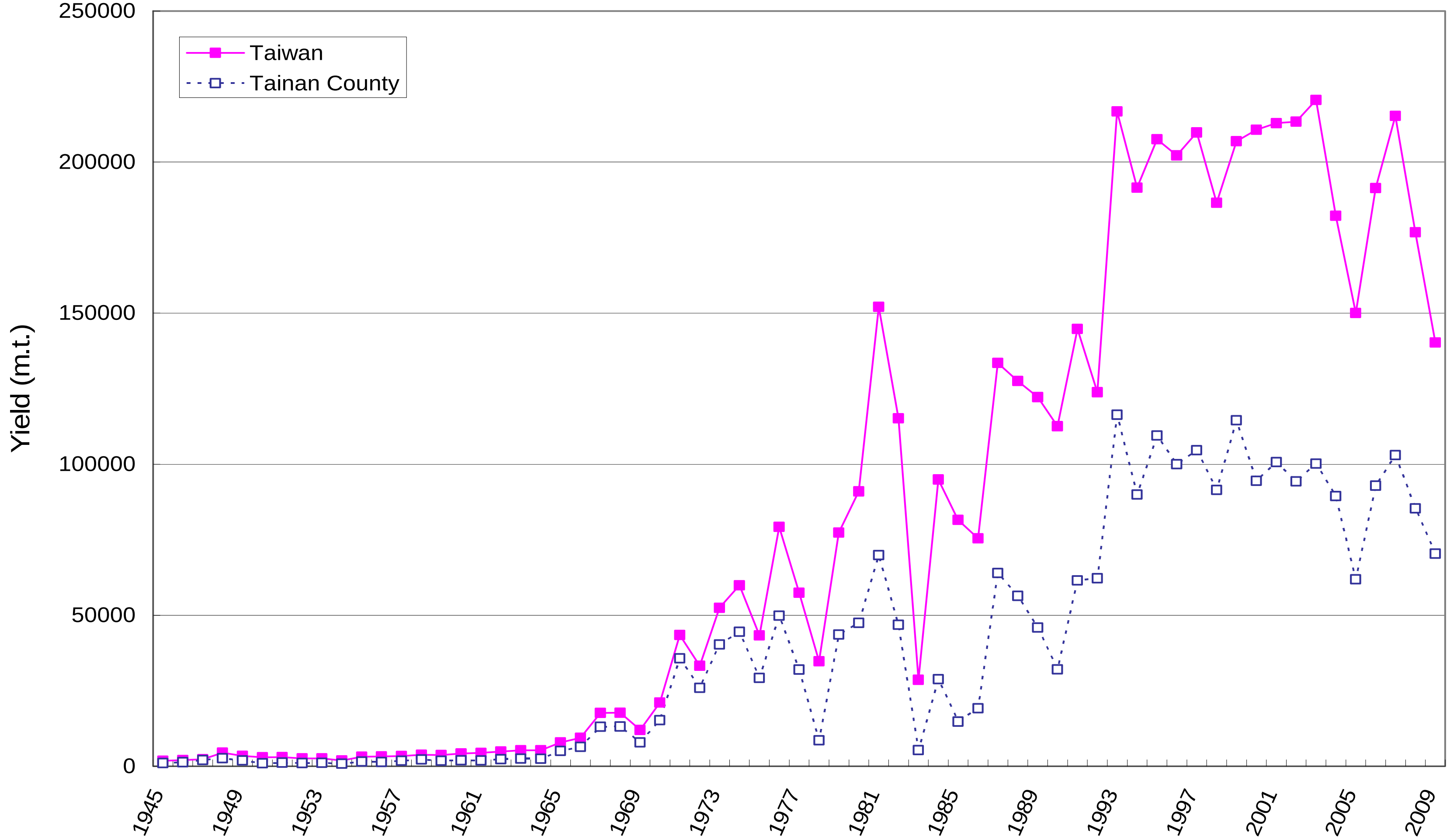

Fig. 3. Annual yield of mango in Taiwan and Tainan County from 1945 to 2009.

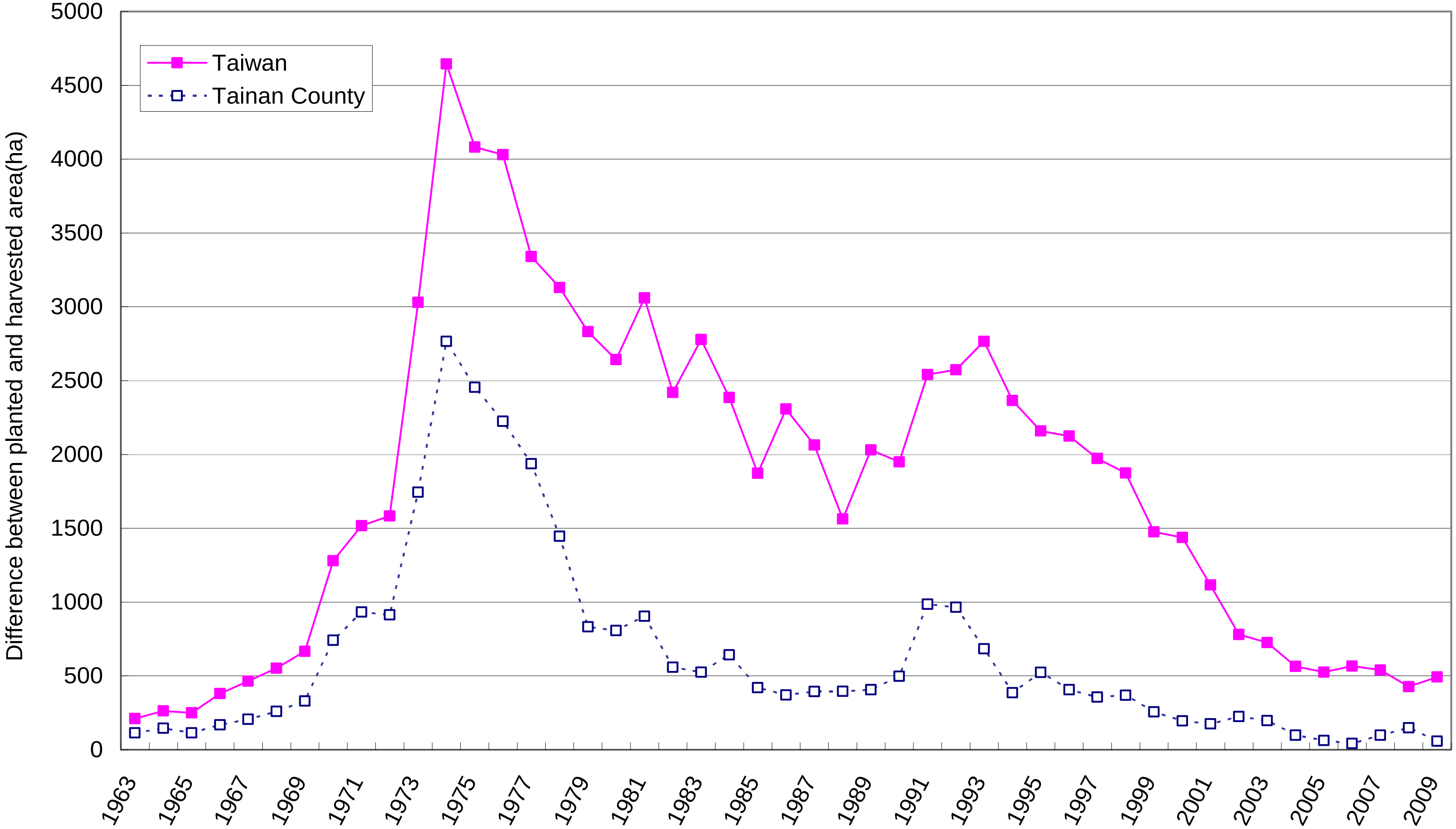

Fig. 4. Differences between the sizes of planted area and harvested area of mango in Taiwan from 1963 to 2009.