Tropical agriculture

The value of bees to the coffee harvest

The self-pollinating African shrub *Coffea arabica*, a pillar of tropical agriculture, was considered to gain nothing from insect pollinators[1,2]. But I show here that naturalized, non-native honeybees can augment pollination and boost crop yields by over 50%. These findings, together with world coffee-harvest statistics and results from field studies of organically shade-grown coffee, indicate that coffee plants would benefit from being grown in habitats that are suitable for sustaining valuable pollinators.

African honeybees colonized western Panama in 1985, where they naturalized. By 1997 they had become major pollinators of coffee growing near forests at 1,500 m above sea level[2]. Yields of *C. arabica* may therefore be higher near forest, which provides a good pollinator habitat[2]. In a study of 50 2-year-old plants in Panama in 2001, I observed that flowers were visited not only by native pollinators, but also by the naturalized honeybees.

Ripe berries resulting from open pollination of coffee flowers were heavier than those on control branches that had been bagged with fine-mesh material (from which pollinators were excluded), and were more abundant per flower (49% increase; $P < 0.01$, paired t-test). The open-pollinated fruit was, on average, 7% heavier, whereas a 25% increase in mass was recorded when African honeybees had exclusively dominated the flowers[2]. This suggests that the contributions to final berry weight and total yield[1,2] may differ for non-native honeybees and other, natural pollinators; however, bees consistently controlled over 36% of the total production.

Do bees control coffee harvests on a larger scale? Long-term data indicate that they do, although the results require detailed analysis. Almost 11 million hectares of coffee were harvested in 2001 (ref. 3). Cultivated areas of coffee in Ivory Coast, Ghana, Kenya, Cameroon and Indonesia have increased two- to fivefold in the past 41 years, although yields have decreased by 20–50%. El Salvador and Haiti, like other countries with intensive land usage and little natural habitat, show similar trends (Table 1)[3]. Pollinator loss is implicated in this decline, as sustained and aggressive cultivation may harm pollinators by removing their habitat.

A substantial increase in Latin American coffee yield partly coincided with the establishment of African honeybees in those countries[2,4], although there was no such change in the Old World, where honeybees originated (Table 1). This comparison underlines a possible cause-and-effect relationship between the presence of social bees and coffee yield.

Table 1 **Worldwide coffee yields and potential contribution by African honeybees**

New World	*1961–80*	*1981–2001*	*Old World*	*1961–80*	*1981–2001*
Costa Rica	9,139; 0.21	14,620; 0.09	Vietnam*	4,251; 0.44	13,380; 0.37
Bolivia*	7,686; 0.09	8,767; 0.09	Papua NG*	10,522; 0.19	11,561; 0.21
El Salvador†	9,996; 0.11	8,729; 0.10	Thailand*	3,509; 0.83	9,652; 0.24
Guatemala	5,488; 0.16	8,231; 0.11	Philippines*†	10,028; 0.20	9,593; 0.13
Colombia	5,920; 0.06	7,740; 0.16	Ethiopia	5,667; NA	8,797; NA
Honduras	4,096; 0.18	7,264; 0.14	Sri Lanka†	17,064; 0.24	7,869; 0.23
Nicaragua	4,566; 0.28	6,408; 0.23	India	5,904; 0.20	7,354; 0.21
Brazil	4,965; 0.25	6,283; 0.21	Malaysia	4,001; 0.19	7,288; 0.13
Peru	5,487; 0.09	5,740; 0.10	Kenya*	6,604; 0.15	6,055; 0.22
Mexico*	5,227; 0.12	5,116; 0.14	Tanzania	4,738; 0.11	5,432; 0.10
Haiti†	5,226; 0.04	5,024; 0.02	Indonesia†	5,716; 0.05	5,394; 0.08
Panama	2,347; 0.20	4,124; 0.14	Madagascar†	3,824; 0.08	3,576; 0.08
Dominican Republic	3,145; 0.12	3,949; 0.25	Cameroon*†	3,525; 0.19	3,141; 0.21
Ecuador*	3,089; 0.14	3,240; 0.25	Ivory Coast*†	3,393; 0.25	2,391; 0.30
Venezuela	1,938; 0.15	2,789; 0.16	Ghana	3,213; 0.57	2,136; 0.53
Mean‡	5,380	6,850		6,130.6	6,907
Standard deviation	2,413	3,057		3,776	3,346
Paired t-test	0.004			0.232	

Mean average coffee yield[3] (in kg ha^{-1}) and coefficient of variation for different countries in the New and Old Worlds are shown for two periods; 1981–2001 coincides with the continent-wide presence of feral African honeybees in tropical America. Paired t-tests (one-tailed) evaluate changes in both New World and Old World yields. NA, not applicable.
*Aggressive high-density cultivation. †Negative exponential trend in yield[3]. ‡Caribbean islands excluded.

Further comparison of yields from the Caribbean islands with those from Mexico and Central America suggests that social bee colonies, which exploit blooming coffee intensely, have two important effects. Such colonies, whether native or introduced, are virtually absent on Caribbean islands. On the mainland, African honeybees may replace native pollinators (primarily stingless, social bees) without affecting yields (paired t-test)[2–4] but they reduce the variation in yield, as indicated by the coefficient of variance (c.v., ratio of the standard deviation to the mean).

The c.v. magnitude for the islands had been the lowest in the region by a factor of two and has been stable for 41 years ($P = 0.27$, paired t-test). But after African bees arrived in Central America and Mexico, it dropped for those areas ($P = 0.02$, paired t-test), eventually reaching a value that is 23% less than for Caribbean islands. Moreover, the coffee yield of the islands has remained only half that of Central America and Mexico[3], indicating an absence of pollination and outcrossing benefits from bees[2]. The low c.v. in yield in Haiti, for example (Table 1), may be derived from low variance in self-pollination and scarce pollinators.

Recent saturation of the neotropics with feral honeybees, which compete with other flower visitors[4], has caused intensive exploitation of coffee and other flowering plants and has promoted pollination stability. However, although the island of New Guinea has no honeybees, its yields remain high (Table 1), partly because its native solitary bees pollinate the obligately outcrossing coffee plant *Coffea canephora* there[1,3]. *C. canephora* is grown in tropical lowlands and extensively in the Old World, but it is also wind-pollinated[1].

Declining yields can be offset by expanded cultivation or by increasing planting density, but such remedies are unstable (Table 1). Although shade conditions significantly improve the flavour of commercial coffee[5,6], coffee monocultures often lead to the removal of shade trees. The trend towards cultivating 'sun coffee' at high densities to boost yield[5,6] will eliminate sites for bee nesting and mask the erosion of pollinator populations, which is shown here to affect yield by 36%. Optimization of coffee harvests and agricultural flexibility in tropical countries in the long term will depend on a consideration of pollinator sustainability and habitat.

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1. Free, J. B. *Insect Pollination of Crops* 2nd edn (Academic, London, 1993).
2. Roubik, D. W. *Int. Workshop Conserv. Sust. Use Pollinators* (eds Kevan, P. G. & Imperatriz-Fonseca, V.) (Int. Bee Res. Assoc., Cardiff, in the press).
3. FAOSTAT online; http://apps.fao.org
4. Roubik, D. W. *Science* **201**, 1030–1032 (1978).
5. Muschler, R. G. *Agroforest. Syst.* **51**, 131–139 (2001).
6. Lyngbaek, A. E., Muschler, R. E. & Sinclair, F. L. *Agroforest. Syst.* **53**, 205–213 (2001).

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