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QUANTITATIVE APPROACH TO AVOCADO POLLINATION

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Abstract

New evidence from Israel indicates that yield in a healthy, efficiently managed avocado orchard, subject to no post-bloom weather-related catastrophes, is mainly a function of honey bee activity. The early-blooming avocado cultivars were found to be exposed to very low honey bee activity throughout most of their blooming period, and fruit set occurred only when bee activity increased to a high enough level. The trees along the plot's perimeter attracted higher bee activity, resulting in a higher pollination rate, and they bore more fruit than trees inside the plot. This effect was more pronounced when bee activity was lower. Pollination rates of five avocado cultivars were found to be positively correlated with honey bee activity. They averaged 60-80% pollinated stigmas with 6-10 pollen grains per stigma on days with 20 bees per tree or more, and only 2-10% pollination with 1-2 grains per stigma on days with less than 5 bees per tree. Cross-pollination rates were 50-75% of the above figures on trees adjacent to the pollen-donor cultivar, and much lower when the pollen donor was more than two rows away.

1. Introduction

Evidence accumulated over the last decade shows that in countries with a Mediterranean climate honey bees are the main avocado pollinator, and that pollination may be a limiting factor in avocado productivity (Bekey, 1989; Ish-Am & Eisikowitch, 1991, 1993; Robinson, 1989; Vithanage, 1986). However, no quantitative measurements have been performed of avocado fruit-set and yield dependency on bee density and pollination rate. This work was aimed at achieving quantitative correlations, under field conditions, between avocado flower and honey bee densities, pollination rate, fruitlet set and yield. These correlations could produce a tool for determining how many bees are needed to realize the orchard's yield potential, assuming no weather-related catastrophes.

2. Materials and methods

Observations were carried out during the blooming seasons of 1989-1992, in avocado orchards in the Western Galilee of Israel, both in the Kuren Valley (1-4 km from the Mediterranean coast, 30 m above sea level) and in the hill region (10 km from the coast, 300 m above sea level). Avocado flower and fruitlet densities were recorded in five medium-size inflorescences per tree, over five trees per studied cultivar. Bee density per tree (BPT) was measured on five trees per cultivar, by counting honey bees on the whole tree for I min, while walking around it. Pollination rate was measured using samples of 50 stigmas, which were collected every hour from five trees per studied cultivar. The harvested styles were placed on microscope slides coated with CMC gel containing methylene blue and were kept at 5ºC (Melamud H., personal communication). Pollen grains on the stigmas were later counted using a light microscope. Yield was measured by counting fruits on 20 trees per cultivar in the autumn.

Observations were designed to track the seasonal course of flower, bee and fruitlet densities (three observations a week throughout the blooming season) and to discover gradients of bee density, pollination rate and yield vs. distance from pollen-donor cultivar and/or plot edge. Statistical calculations were performed according to Sokal and Rohlf (1981).

3. Results

Monitoring throughout the season of flower, honey bee and fruitlet densities of the early-blooming avocado cultivars 'Ettinger' and 'Hass' revealed a clear discrepancy between the seasonal courses of flowering and honey-bee activity (Fig. 1). These cultivars received almost no bee activity throughout most of their blooming period, including their flowering pick. Fruitlets began to appear on the marked inflorescences only 3 days after honey bee density on the female-stage flowers reached at least three bees per tree. This only happened during the last 1-2 blooming weeks of these cultivars: a few fruitlets appeared on 'Ettinger' during the first blooming week, but were too few to be counted on the marked inflorescences.

All studied cultivars exhibited a significant positive correlation between pollination percentage (PP) and bee density (BPT), which best fit the exponentially ascending curve: BPT = k1*(1-Exp(-k2*BPT))+k3, where B is the function value for BPT=0, and k1+k3 is the function's maximum asymptote (Figs. 2,3). For each cultivar, the pollination curves yielded when a pollen-donor cultivar was near-by were higher than those with a more distant pollen donor, though the differences were smaller for curves of self- plus cross-pollination (at the end of a day's bloom) and bigger for curves representing cross- pollination only. The value of k3 was close to 0% for the cross-pollination curves and 3- 12% for the curves of self- plus cross-pollination.

On average, when bee density was low (5 BPT or less) the avocados achieved only 3- 10% self-pollinated flowers with 2-3 pollen grains per stigma (PGPS), and less than 4% cross-pollination with 1 PGPS (Figs. 4,5). However, when bee density exceeded 20 BPT, and a pollen-donor cultivar was close-by, they reached 50-70% self-pollination with up to 7 PGPS and about 50% cross-pollination with 4 PGPS, though only 20% cross-pollination with 1-2 PGPS when the pollen donor was more than two rows away.

Pollination gradient, related to distance from the plot edge, was studied in a homogeneous 'Reed' plot (19 trees by 29 rows), bordered by fallow fields on both its northern and southern sides, a plot of early-blooming avocado cultivars to the east (which had already completed their bloom), and a Nabal 'plot 30 m to the west. Honey bee distribution in the plot (Fig. 6) showed a significant preference for the perimeter trees over the trees inside the plot, with a minimum value in the fifth tree (p=0.013, Anova on data normalized by the maximum). Pollination rates revealed the same perimeter advantage (Fig. 7), with minima in the fifth to tenth trees (p=0.002, Anova on the percentage transformation).

Yields in this Reed' plot revealed a similar perimeter advantage (Fig. 8). The 1990 crop (7.4 tons per hectare) was carried almost exclusively by the perimeter trees, which held about 18 tones per hectare, whereas the inner-plot trees were almost empty (p=0.0001, two-way Anova). This crop resulted from a heavy bloom the previous year, coupled with very low honey bee activity (bee hives had not been stationed in the orchard), and the bees that did visit the heavy bloom were seen almost exclusively on the plot's perimeter trees. In 1990 the bloom was again very heavy, but this year bee hives were stationed in the orchard, resulting in a high bee density and a decrease in the perimeter advantage. The following year (1991) production was very heavy, 41.4 tons per hectare, with the perimeter-advantage effect being less significant ($p=0.002$). The 1991 bloom, occurring simultaneously with such a heavy crop, was very sparse, but was intensively visited by the bees. The next year, the crop was surprisingly heavy, 17.7 tons per hectare, with a clear effect of perimeter advantage ($p=0.0002$).

4. Discussion

The role of pollination as a limiting factor in avocado productivity has been questioned, since a blooming avocado tree carries some 50 000 new flowers every day, which could produce a high seasonal yield if only 1% of I day's bloom would set (Davenport, 1986). However, early qualitative observations in Israel found that fruitlet set in the field does not occur on days of low bee activity, with a pollination percentage of less than 20% (Eisikowitch & Melamud, 1982). The high positive correlations found here between bee density and both pollination rate and yield, throughout the blooming season (Fig. 1) and across the plot (Figs. 6,7,8), emphasize the dependency of avocado pollination, fruitlet set and yield on honey bees, and the importance of a high pollination rate for fruit set.

Shoval (1987) showed that although only one pollen grain penetrating the ovary is needed for fertilization, the rate of fertilization of pollinated flowers (actually, the rate of flowers with a pollen tube reaching the ovary) is strongly affected by the number of PGPS. In 'Hass' flowers that had been hand-pollinated by 'Ettinger' pollen, he found that 1-4 PGPS resulted in only 4% fertilization, and even 5-19 PGPS produced only 11% fertilization. Only at 20-30 PGPS was a substantial fertilization rate ensured. We found a significant positive correlation between pollination percentage and PGPS, in which high bee density corresponded to averages of 5-7 self-grains, and 4 cross-grains per stigma (Fig. 5), with only 24% of the stigmas carrying 20 or more pollen grains (Ish-Am, 1994). Therefore, we assume that the need for both high bee density and pollination rate for fertilization is a substantial feature of the avocado's reproductive system.

These conclusions may provide insight into situations of low yield caused by low pollination rates. Avocado flowers are of low attractiveness to honey bees, comparing to flowers of *Citrus* spp., wild mustard and some other cultivated, as well as wild species in Israel (Ish-Am & Eisikowitch, submitted for publication). The early-blooming avocado cultivars in Israel are highly exposed to this competition among the flowers, resulting in very low bee activity during most of their blooming period, which is not enough for fertilization and fruitlet set (Fig. 1). One may conclude that if competition among the bees would increase more honey bees would move to the avocados. This happened naturally with Israel's late-blooming cultivars, and may be artificially achieved by adding bee hives to the orchards during the early cultivars' blooming period (Vithanage, 1990). Honey bees do not distribute themselves equally throughout the avocado plot, and they usually prefer the perimeter trees over the inner-plot trees (Fig. 6). As a result, pollination rate and fruit set may be very low inside the plot, and much higher in the perimeter (Figs. 7,8). In this case, again, increased bee density found to force the bees to increase their activity on the inner-plot trees.

Therefore, we suggest using our quantitative correlations between bee density, pollination rate, PGPS number and fruit set for bee-monitoring during avocado bloom, and adding hives as needed. According to this work, some fruitlet set starts when bee density reaches 3 BPT, but 10-20 BPT are needed for efficient self-fertilization, 25 BPT or more are required for efficient cross-fertilization of the first two rows adjacent to the pollen-donor cultivar, and more than 55 BPT are needed to achieve this goal 4 rows away from the pollen donor.

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Fig. 1: Flower, Honey-Bee and Fruitlet Density in 'Hass', 1992 Seasonal Course

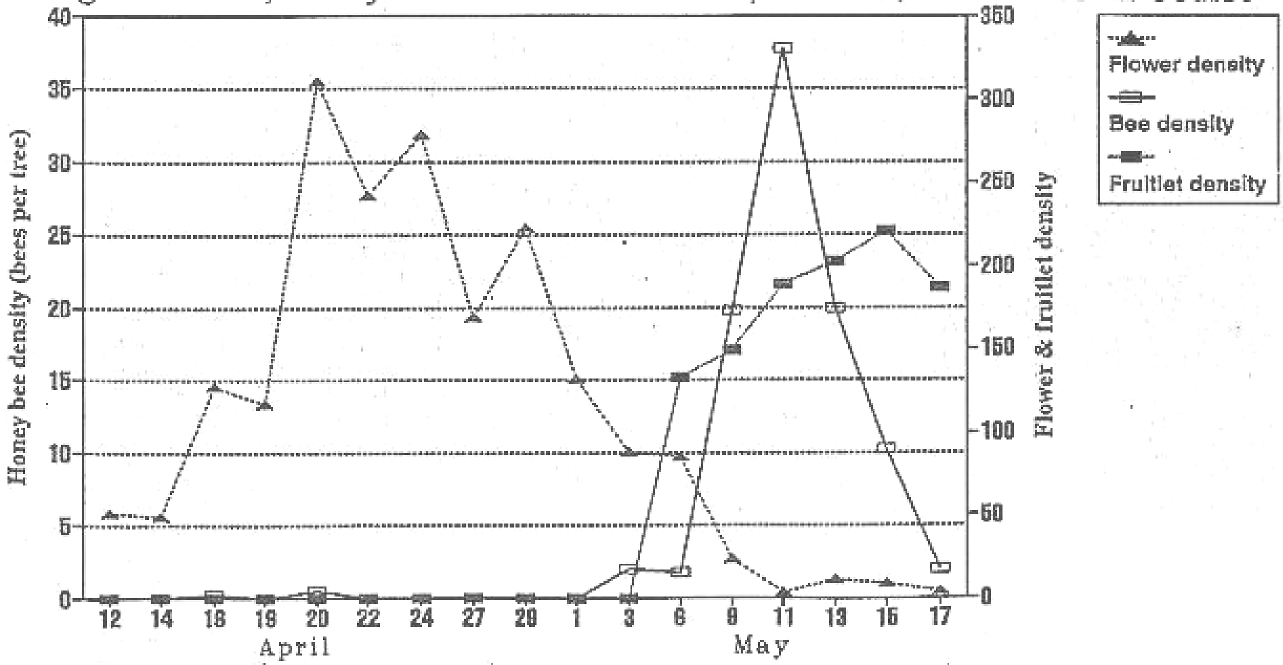

Fig.2: Pollination Rate vs. Bee Density

'Hass': self plus cross-pollination

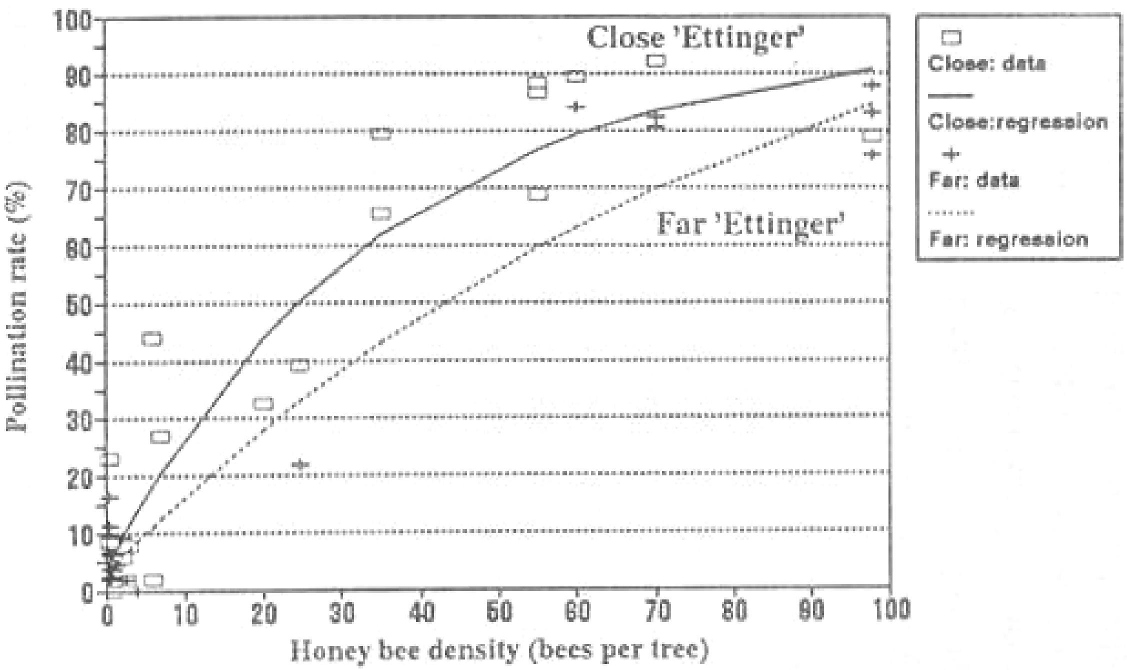

Fig.3: Pollination Rate vs. Bee Density

'Hass': cross-pollination

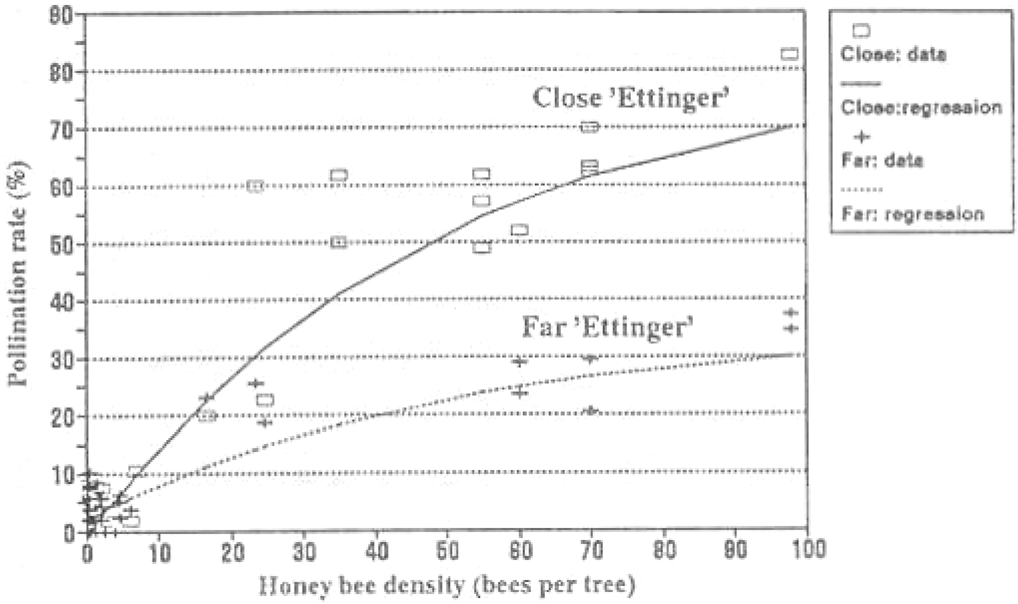

Fig. 4: Pollination Rate, 4-Season Mean

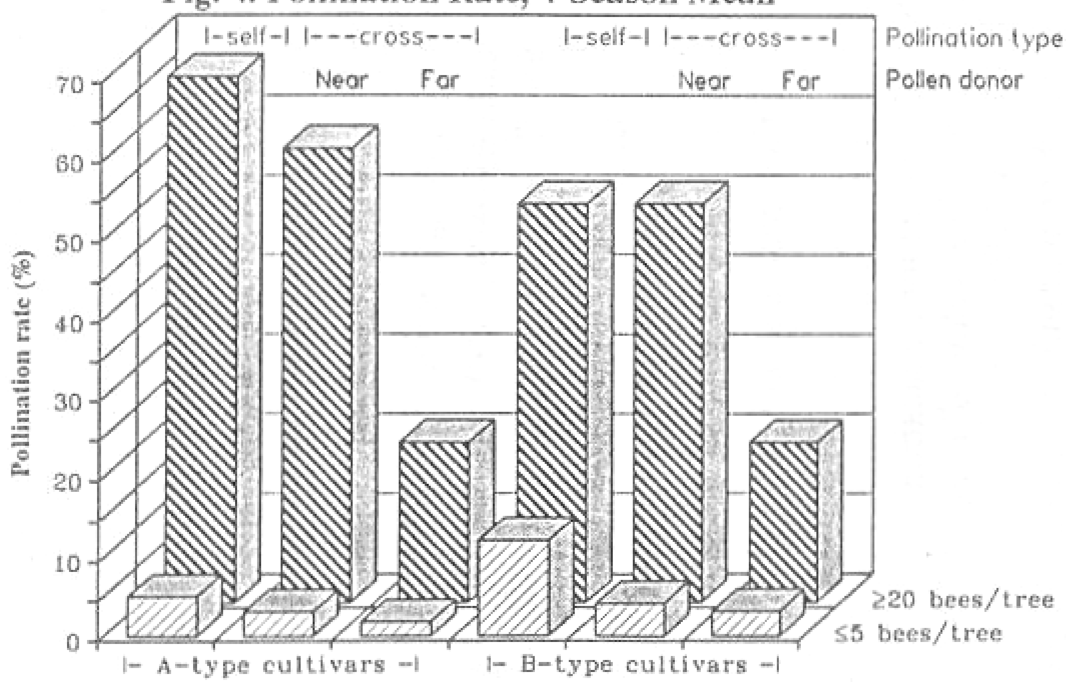

Fig. 5: Pollen Grains per Stigma

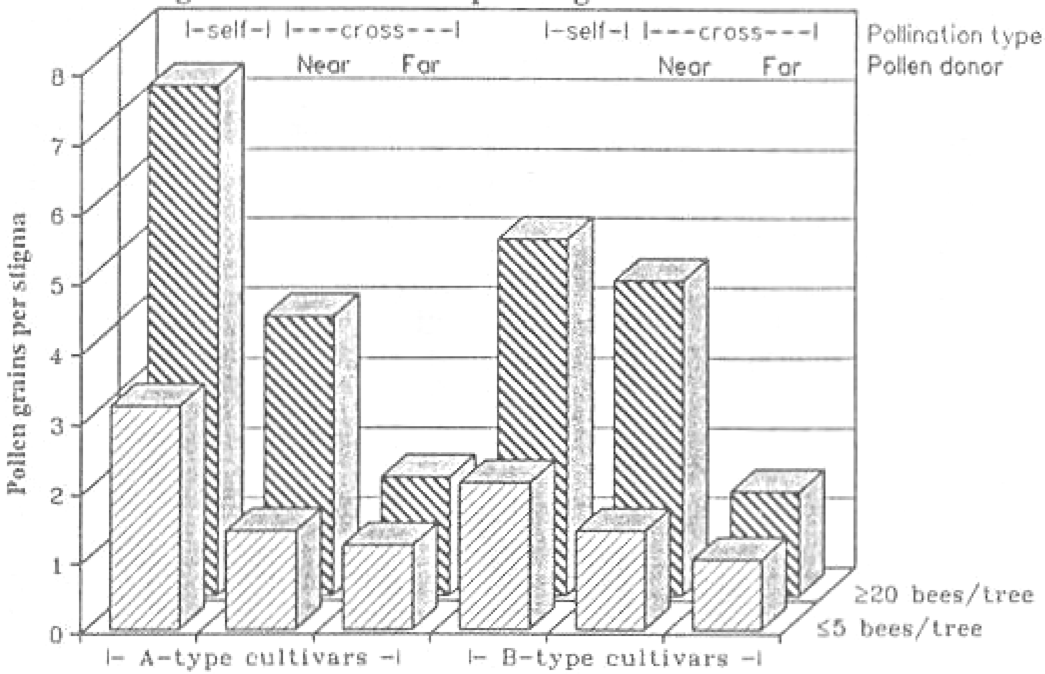

Fig. 6: Honey-Bee Distribution in 'Reed' Plot, Two Days in 1990

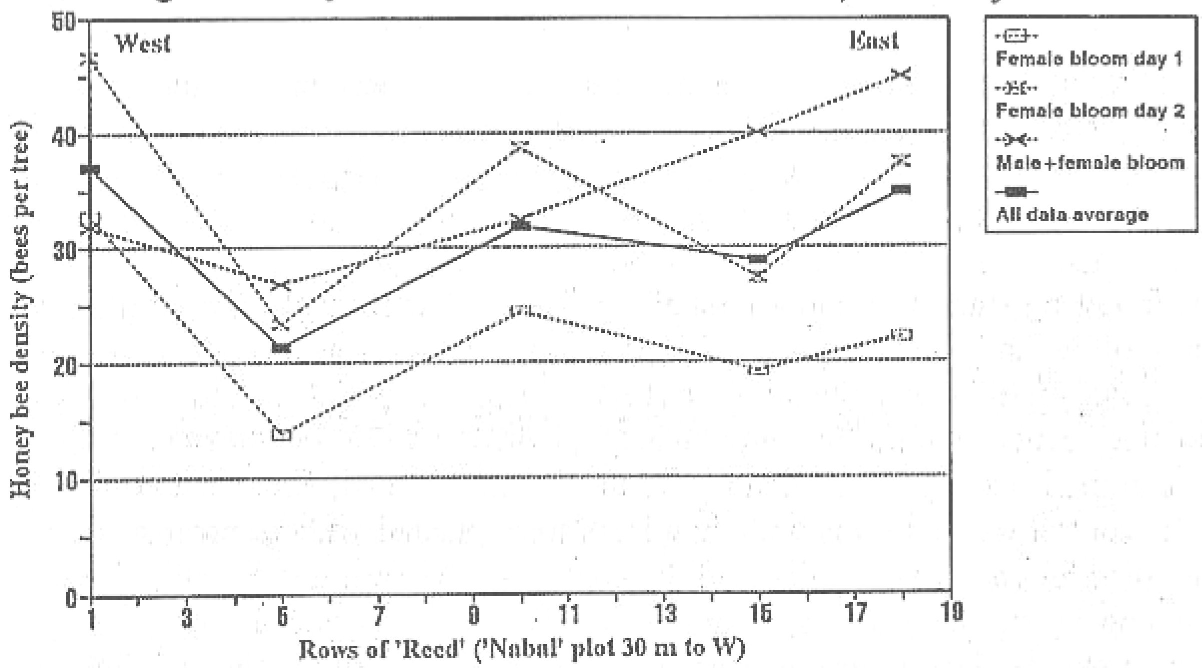

Fig. 7: Pollination Rate Gradient in 'Reed' Plot, Four Days in 1991

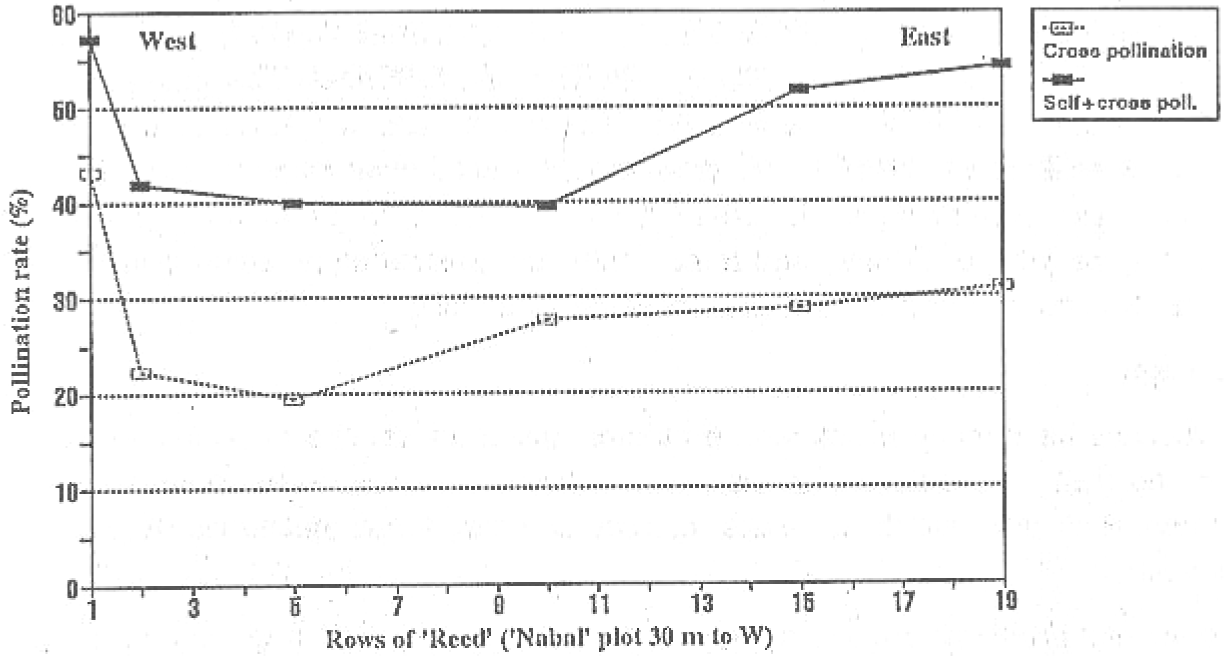

Fig. 8: Yield Spatial Distribution in 'Reed' Plot, Three Consecutive Years' Data