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The Agroecology of Corn Production in Tlaxcala, Mexico

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The primary components of Tlaxcalan corn agriculture are described, including cropping patterns employed, resource management strategies, and interactions of human and biological factors. Tlaxcalan farmers grow corn in an array of polyculture and agroforestry designs that result in a series of ecological processes important for insect pest and soil fertility management. Measurements derived from a few selected fields show that trees integrated into cropping systems modify the aerial and soil environment of associated understory corn plants, influencing their growth and yields. With decreasing distance from trees, surface concentrations of most soil nutrients increase. Certain tree species affect corn yields more than others. Arthropod abundance also varies depending on their degree of association with one or more of the vegetational components of the system. Densities of predators and the corn pest Macrodactylus *sp. depend greatly on the presence and phenology of adjacent alfalfa strips. Although the data were derived from nonreplicated fields, they nevertheless point out some important trends, information that can be used to design new crop associations that will achieve sustained soil fertility and low pest potentials.*

KEY WORDS: corn agroecosystem; agroecology; polycultures; agroforestry; traditional farming.

INTRODUCTION

Traditional farming systems in the Third World have emerged over centuries of cultural and biological evolution and represent accumulated ex-

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periences of interacting with the environment by farmers without access to external inputs, capital, or scientific knowledge (Chang, 1977; Wilken, 1977; Egger, 1981). Such experience has guided farmers in many areas to develop sustainable agroecosystems, managed with locally available resources and with human/animal energy (Harwood, 1979; Klee, 1980). These agroecosystems, based on the cultivation of a diversity of crops in time and space, have allowed traditional farmers to maximize harvest security with limited resources and space (Clawson, 1985).

As change occurs in the face of inevitable agricultural modernization, genetically variable indigeneous varieties of crops are being replaced by new high-yielding ones (Harlan, 1976), and knowledge of the traditional cropping patterns and management practices and the ecological rationale behind them are being gradually lost (Chambers, 1983). Modern agricultural development, characterized by broad-scale technological recommendations, has largely ignored the environmental, cultural, and socioeconomic heterogeneity typical of traditional agriculture (Conway, 1985). Large-scale promotion of uniform crop varieties, technologies, and farming systems, largely inaccessible to the great majority of peasants, has created an inevitable mismatching of agricultural development and the needs and potentials of local people (deJanvry, 1981).

A more appropriate agricultural strategy requires a holistic approach, sensitive to the complexities of agroecological and socioeconomic processes, which can lead to the design of farming systems and techniques tailored to the needs of specific peasant groups and regional agroecosystems (Altieri and Anderson, 1986). A challenge of this nature requires an understanding of the features of traditional agriculture such as the ability to bear risk, labor constraints, diet preferences, and the spatial and temporal dynamics of symbiotic crop mixtures.

Although assessments of traditional "know-how" and anthropological, geographical, and ethnobotanical studies of traditional farming patterns in the Third World are numerous (Bye, 1981; Denevan, Treacy, Alcorn, Padoch, Denslow, and Flores Paltan, 1984; Klee, 1980; Brokenshaw, Warren, and Werner, 1980; Posey, 1983; Vermeer, 1979; Weinstock, 1983; Alcorn, 1981, 1984; Brush, Carney, and Huaman, 1981; Alverson, 1984; Grossman, 1984; Gliessman, Garcia, and Amador, 1981; Marten, 1986). They have mainly focused on the patterns of behavior followed by an ethnographic unit in the realm of agricultural technology, which result in unique sets of land utilization in time and space, seasonal distribution of labor, nutrition, and other needs. Rarely have studies examined the ecological mechanisms that underlie the sustainability of these agroecosystems. Similarly, agronomic and economic evaluations of traditional agroecosystems are routinely conducted during Farming Systems Research (FSR) projects (Byerlee, Collinson, Perrin, Winkelman, and Biggs, 1980; Harwood, 1979; Shaner, Phillip, and Schenhl, 1982; Zandstra, Price, Litsinger, and Morris, 1981). Although FSR surveys analyze the natural and socioeconomic circumstances affecting small farms and attempt to involve the farmers themselves in all stages of the research and development process, their emphasis on higher yield inevitably still leads to the continual recommendation of high input technology (Oasa, 1985), with no apparent understanding of the ecological processes involved.

Although greatly modified, most traditional agroecosystems still utilize minimal inputs, lack continuous disturbances, and exhibit complex interactions among and between people, crops, soils, animals, etc., which makes them unique settings from which to extract ecological principles for the design of new, improved, and locally adaptable sustainable agroecosystems (Altieri, 1983). Therefore, it is crucial to ecologically analyze traditional farming systems, not only to evaluate their properties of stability, equitability, and sustainability, but also to determine which elements of resource use and conservation should be retained during the course of agricultural modernization.

With this in mind we studied the agriculture of the state of Tlaxcala, Mexico (Benitez, 1953; Wilken, 1977). Tlaxcalan farmers have continuously faced problems of low quality natural resources, low soil fertility, and extreme climatic limitations. They have managed to survive in this fragile environment through a process of ecological modification and adaptation based on diversified farming, genetic diversity maintenance, and unique land and water management practices.

As part of a long-term research project begun in 1982, ecology of corn-based traditional farming systems has been studied in order to derive agroecological principles that may serve to guide future agricultural development in the region. Corn production is the basis of Tlaxcalan agriculture, and corn fields are diversified at both the species and genetic level. Corn is grown mixed with annual and perennial plants in polycultural and/or agroforestry patterns, and also in genetically complex fields that maintain numerous genotypes over time and space. These systems provide a unique opportunity to examine the ecological consequences of crop diversity patterns on conservation of soil and water resources, pest regulation, stabilization of production, and on the long-term sustainability of the agroecosystem as a whole. We qualitatively describe here the general structure and management of traditional corn production systems. With data derived from a few selected fields, we also attempt to illustrate the ecological dynamics of the agroecosystems, with some quantitative descriptions of the influence of vegetational diversity on plant–soil relationships and on the population levels of insect pests and associated natural enemies. We focused on these processes because they seem to be important indicators of the dynamics of most mixed farming systems (Altieri, 1983, Altieri and Letourneau, 1982).

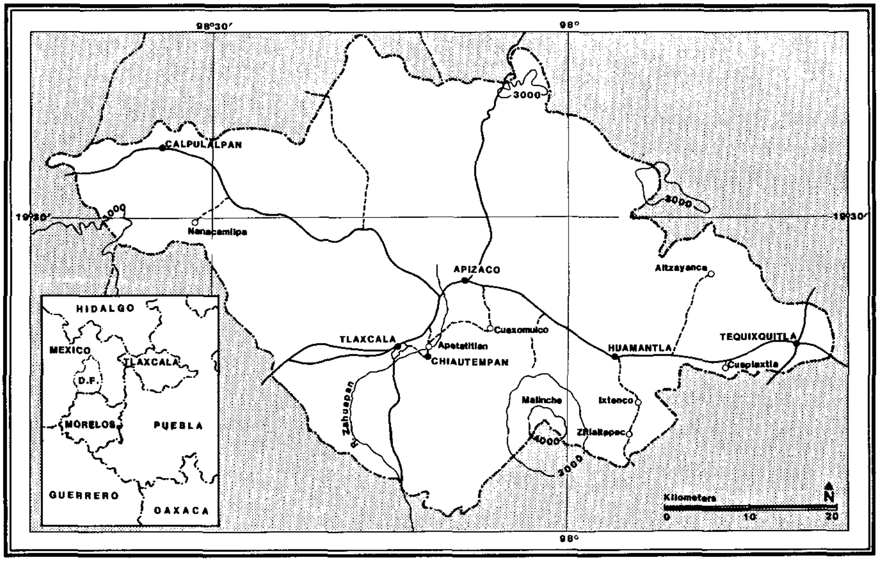

Fig. 1. A descriptive map of Tlaxcala, Mexico.

REGIONAL SETTING OF THE STUDY

Tlaxcala is located in east central Mexico in the highlands of the Neovolcanic axis on the Mesa Central (Fig. 1). The state, situated above 2300 m elevation, is bisected from the northwest to the southeast by a wide flat alluvial corridor bordered by low-lying hills and mesas. The climate of Tlaxcala is characteristically temperate (subhumid). Rainfall occurs from May–October, ranging from 500 mm per year east of Huamantla to 800–1000 mm in the southwest. Rainfall variations in the mid-summer months can lead to extended droughts. Average monthly temperatures fluctuate within a narrow range, with January being the coldest month (0–9°C) and April or May generally the warmest (19–27°C). Frosts are frequent and are particularly threatening from November–February. In about 40% of the state, it hails an average of 2–4 days per year (Anonymous, 1981).

Tlaxcalan soils are generally sandy and highly drained, though some soils are gravelly or rocky. Depth varies from 10 cm in the Lithosols of the west and north central regions to deep Fluvisols on the plains of Huamantla. Most soils are infertile due to lack of organic matter. Soil pH tends to be slightly acid (Anonymous, 1981). Much of the sloping land under agriculture is affected by erosion in different degrees. Tlaxcala has only two superficial waterways of importance: the Rio Zahuapan and Rio Atoyac. subterraneal water is the principal source of supply for all types of use.

More than 70% of the total land area of the state (nearly 2900 km^2) is dedicated to the production of corn, barley, wheat, beans, fava beans. potatoes, and some vegetables (Anonymous, 1984). Less than 4% is irrigated. Most of the land (71%) is government owned as part of the land reform program and farmed by *ejiditarios* (Anonymous, 1984). Average farm size in the state is 4.83 ha, where only a few families are able to produce sufficient harvests to both feed themselves and to sell in local markets for additional income. Most must look for off-farm work, many as day laborers (*jornaleros*) on other farms, or as workers in nearby cities such as Puebla or Mexico, D.F. during the off-season. Farm labor is generally supplied by all family members. Many farmers do exchange work with neighbors or other extended family, especially during peak demand periods such as harvesting. Rarely is labor hired except by some of the largest landowners.

METHODS

The information presented here was obtained through 3 years of field surveys, biological data collections, reviews of published materials, and interviews with farmers, agricultural technicians, and extensionists. Fifty farmers were interviewed throughout the state to gather information descriptive of farm designs, crop patterns, use of local resources, and farmers' practices, as well as to understand why, in light of their particular circumstances, farmers adopt such cropping systems and production methods. The interviews were also designed to assess the factors affecting farmers' decisions with respect to the use of crop technologies, and how they avoid risk and adapt to natural and socioeconomic constraints. Direct interviews and observations provided detailed information about crop management practices, i.e., land preparation, planting, weeding, pest control, fertilization, harvest, etc., their timing, and amount of inputs utilized in farm operations (Byerlee *et al.*, 1980).

Field surveys included the general description of the landscape, identification of existing crop patterns, description of cropping systems' determinants, and the actual and potential interactions between the various biological components in the various polycultures and agroforestry systems (Shaner *et al.*, 1982). Field measurements were conducted in a few selected fields to quantify the effects of trees on chemical and physical soild properties and corn yields, and to elucidate the population trends of pest insects and associated natural enemies, and the resulting degree of pest damage in corn systems grown under various levels of vegetational diversity.

Since all fields utilized were comprised of simple, nonreplicated experimental units, an inherent complication associated with research in farmers' fields, inferential statistics were not applied to the data. However, biological knowledge and intuition were used to appraise whether the observed differences in measured parameters between fields were due to the effects of differential diversification.

Tree Influences on Soil Properties and Corn Yields

In 1983, four rainfed cornfields in southeastern Tlaxcala with scattered capulin (*Prunus capuli*) and sabino (*Juniperus deppeana*) trees were selected for the study (Farrell, 1984).

Four similar-size (8–10 m) trees of each species were selected in each field. Five zones were chosen around each tree representing various areas of tree influence within which sampling was carried out. These included the canopy zone (C), morning shade zone (S-W), afternoon shade zone (S-E), root zone (R), and zone of no tree influence (NI; Zinke, 1962).

Surface soil samples to a depth of 15 cm were collected at 2, 6, 10, 14, 18, and 22 m from the base of each tree along four randomly chosen transects. Soil properties measured were: total nitrogen (by macropkjeldahl), water soluble phosphorus (determined colorimetrically), total carbon (by dry combustion), hydrogen ion activity (with a glass electrode using a saturated soil paste), and cation exchange capacity. Exchangeable potassium, calcium, and magnesium were displaced with ammonium acetate solution and estimated by atomic absorption spectrophotometry (Black, 1965). Soil moisture content was determined gravimetrically on samples brought to equilibrium on a semi-permeable ceramic plate maintained at a pressure differential of 1/3 and 15 bars.

Measurements of density, height, and grain yield of corn plants were taken within three, four, and five 4-m transects randomly placed along rows within the canopy, shade, root, and non-influence zones in mid-October after the maize had fully matured. Grain yield was estimated by determining the length and basal diameter of each ear along the transects using a ruler and calipers. A grain yield per ear index was obtained by multiplying length by diameter of ears. This method was extensively used during the Puebla Project to estimate yields of target maize fields (CIMMYT, 1974).

Three maize fields located 1.5–2 km east of Cuapiaxtla were chosen to study the potential effects that typical maguey (*Agave* sp.) border plantings have on adjacent maize crops. The fields were 150 m × 50 m and bordered on both sides by a row of 1.5–2 m high maguey plants running the length of the field. The outer maize rows were planted within a distance of 1.5–2 m from the border rows of maguey. After the maize had matured, plant density and yield were measured along five random 4-m transects in the outer two rows on both sides and center two rows of each field. In addition, growth and yield measurements were taken in various other tree-crop associations, including corn fields cleared within both a sabino and ailite (*Alnus firmifolia*) woodland and corn interplanted within apple and pear-apple orchards.

The Influence of Vegetational Diversity on Insect Populations

Soil dwelling and foliage insect communities were monitored during 1982 and 1983 (from May–August) in five corn fields of varying degrees of vegetational diversity: corn monoculture, corn strip-cropped with alfalfa, corn mixed with fava beans, corn intercropped with apple trees, and corn growing in an agroforestry system composed of sabino, alite, and capulin trees.

On a weekly basis, 20 corn plants were randomly selected in the center and border rows of each cornfield, and all arthropod species present on these plants and the level of pest damage were recorded. Soil arthropod populations were monitored by randomly placing five pitfall traps in the center of all fields. In the cornfields, adjacent to woodlands and alfalfa, five additional pitfall traps were randomly placed along the borders. The pitfalls were filled with a mixture of 250 ml water and 100 ml antifreeze, and replaced weekly. Traps were taken into the laboratory where arthropods were sorted and counted (Baars, 1979).

RESULTS AND DISCUSSION

The Corn Agroecosystems

The agricultural systems of Tlaxcala are closely related to the "Tequexquinahuac" system, which is based on the production of a variety of crops and animals assembled in several subsystems: (1) rainfed annual cropping systems (parcela de temporal), (2) kitchen garden (huerto familiar), (3) "agostadero," which includes fallow fields, secondary forests, and other areas for gathering, (4) forest plots in gullies and hillsides for firewood and charcoal production, (5) confined management of pigs, poultry, rabbits, etc., and (6) free-grazing management of horses, mules, cows, oxen, and goats. Our study focues on the dynamics of corn production in "parcelas de temporal," where corn is grown associated with a number of annual, semiperennial, and perennial plants in polycultural and/or agroforestry patterns (Fig. 2).

A common component of the borders of cornfields on hillsides is the maguey, a multipurpose plant of the central valley, sacred to the early Indi-

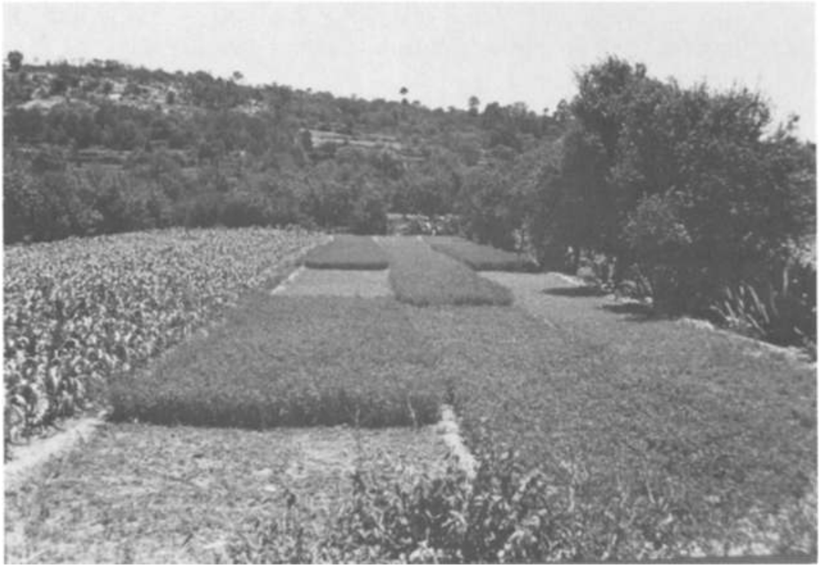

Fig. 2. A multiple-use agroecosystem, comprised by capulin (*Prunus capulli*), tejocote (*Crataegus mexicana*), pear-apple (*Pyrus communis*), and maguey (*Agave* spp.).

ans (Benitez, 1953). About 130,000 ha of agricultural land in the state have maguey planted in contour on sloping land or as part of a terracing system, a practice that can substantially limit soil erosion (Cruz, 1949; Donkin, 1979). Maguey is most valued for its role in the production of *pulque,* a traditional drink of the region.

Farmers also use maguey leaves as a rich organic amendment for the soil, to make a strong fiber for making ropes, lassos, and collars for mule teams, as a hot-burning, low-smoke fire source, and as forage for pigs. The strong spines have been used as needles, and the outer skin of the leaves can be peeled off and used in cooking. Magueys are also a source of the much coveted "gusano de maguey" (*Hypopta agavis* and *Aegiale hesperiaris*), worms considered to be a delicacy by many Mexicans; in 1983, the value of one kg of worms matched the price of 10 kg of beef.

Trees are also conspicuous components of the agricultural landscape. A number of different species, i.e., capulin (*Prunus* sp.), sabino (*Juniperus* spp.), tejocote (*Crataegus mexicana*), peach (*Prunus persica*), and tepozan (*Buddleja americana),* are integrated with corn in a variety of patterns resembling a veritable crop savannah (Fig. 3). These trees are not commonly planted by farmers but are maintained along field borders or left scattered within

Fig. 3. Corn planted within a woodland of sabino (*Juniperus deppeana*) and capulin (*Prunus capuli*), conforming a typical agroforestry pattern.

fields with corn planted right up to their base. Still higher tree densities can be found where narrow fields have been cleared and planted to crops within dense sabino and ailite woodlands. Trees and corn are also mixed in orchards, and in fruit-growing areas such as Cuaxomulco, rows of trees including apple, peach, plum, pear-apple, apricot, and walnut are commonly interplanted with corn and alfalfa.

Our interviews revealed that farmers appreciate the multiple uses of trees. They value the year-round vegetative cover provided by trees for erosion control, the addition or organic matter (leaf litter) from semi-deciduous trees, and the fruit of noncrop trees such as capulin, tejocote, and peach. Roasted seeds of capulin are a delicacy and are sold on many street corners in towns and cities for additional income. Trees are also a source of fuel wood and protective shade during the summer. In the case of orchards, farmers feel that by intercropping they utilize limited land and resources more efficiently. Wooded areas are also valuable sources of livestock food, especially the lower strata of grasses and herbs growing under trees bordering cornfields.

Traditional Corn Management Practices

Cropping Patterns

Our survey revealed that farmers choose their cropping patterns based on land resources available, the productive capacity of the land, traditional customs, cash constraints, family labor, and their perception of overall risks arising from natural and economic circumstances. In most areas, the major cause of crop failure is unpredictable rainfall; thus, farmers stagger planting and/or diversify cropping systems to reduce the effects of rainfall unreliability.

Corn intercropping systems are not commonly found in Tlaxcala as in other areas of Mexico. The traditional corn-bean-squash polyculture is confined to selected areas inhabited by indegenous populations, particularly in the Belen area and the drained-field zone of southwestern Tlaxcala where soil moisture is not so limiting (Wilken, 1969). More common, however, are mixtures of corn and frijol (*Phaseolus* spp.) or corn and fava beans (*Vicia fava*). The planting of corn with frijol is done in the traditional way of sowing both corn and bean seeds in the same hole; however, planting designs vary depending on the bean variety used. Usually, bush beans (*Frijol ayocote*) are planted at lower densities (about 8000 plants/ha), than most climbing bean varieties (mateado, venturero, guia larga), which are usually planted at very high densities (10–100,000 plants/ha). Fava beans are normally planted between mounds of corn within a given row. Both types of beans are important food sources and are also recognized for their soil-improving qualities ("buen rastrojo"). The corn–fava bean combination provides the additional benefit of risk aversion in areas to frost damage since fava beans are fairly tolerant of frost conditions.

The rotation of corn and alfalfa is very common in areas with available irrigation or with deep soils characterized by sufficiently high moisture-holding capacity. Alfalfa is grown as animal fodder and planted with corn in a strip-cropping arrangement, creating a mosaic pattern in the landscape that changes every year, as corn is grown where alfalfa grew the previous year and *vice versa* (see Fig. 2). Based on reliable agronomic data from similar areas, we estimated that, under Tlaxcala conditions, alfalfa could fix up to 150 kg/N ha, almost sufficient to meet most of the N requirement of a preceding corn crop (Sprague and Triplett, 1986). Other crops often grown in rotation with corn are wheat and barley, which are valued for their suppressive effect on certain weed species. There are numerous variations in rotation patterns, including corn-barley (or wheat)-corn, corn-fava bean (or frijol)-corn and corn-fava bean-barley-corn.

Soil Preparation

Farmers usually prepare the soil for planting around December. In sloping lands or very sandy soils susceptible to erosion, the soil is not worked after harvesting but rather just before planting. Thus, crop residue from the previous crop is left standing to protect the soil against early spring winds and rain.

Soil preparation generally involves breaking up the larger soil clods, the *barbecho,* and the mixing and leveling of the soil, the *rastreo*. There are variations in the practice depending on soil type and availability of equipment, but the end result of loosening and leveling the upper 20–30 cm of soil is the same. The equipment used includes discs, ploughs, harrows, or a combination of these. If a team of animals is used, a plough is generally used to loosen the soil while a railroad tie is often dragged for leveling.

Planting

The most commonly planted corn variety is the *criollo blanco* (white seeds), which matures in about 6–7 months and gives the highest yield depending on environmental conditions. Many farmers, however, prefer to mix several corn varieties in their fields, especially several types of early-maturing varieties (violentos) including *criollo amarillo* and *toluqueno* (yellow seeds), *criollo negro, morado, or azul* (blue-purple seeds), and another white-seeded variety, *monte alto de ocho carreras.* These mature within about 4–5 months after planting. The high genetic diversity resulting from such mixtures apparently provides some degree of risk aversion from diseases, pests, frosts, etc. Farmers normally obtain their seeds by selecting the best grains (xinastli) from the previous year's harvest, but when the harvest is poor, farmers buy seeds in the market or borrow from relatives and friends. A few farmers have recently switched to hybrid seeds, but most recognize the low ecological amplitude and the high input requirements of these varieties.

Considering the unpredictable nature of the weather in Tlaxcala, the decision of when to plant often represents a big gamble for the farmer. The object is to begin early enough to take advantage of a long growing season and to harvest before the early fall frosts. Thus, the average planting date usually occurs in April, although many farmers choose to plant in March. In particularly dry years, the first seeds may not be sown till June. Frost and rainfall risks may be avoided by planting later with an early maturing variety, although yields may be significantly lower. In years of late rains, farmers often choose to plant barley or wheat rather than corn. In the case of partial crop failure early in the season, most farmers will replant with the same type of seed or with early-maturing varieties in affected parts of the field.

Because the appropriate planting time is so dependent on the weather, farmers have developed unique and elaborate methods for predicting weather conditions passed from generation to generation. The *cabanuelas* are one of these predictive guides and apply to longer-term weather patterns. This method consists of the interpretation of weather conditions during the initial or final 12 days of a given year, including fractions of certain of these days. It is believed that the climatic conditions experienced on these days or factions thereof represent the conditions to be expected during their corresponding months of the upcoming year.

Farmers have also developed effective ways to predict short-term weather conditions. One of these is the observation of cow milk production, which according to farmers, changes with weather. The second involves the observation of maguey plants. Sometimes referred to as "vacas verdes" (green cows), they are said to produce more juice than normal with the coming of rain. When the quantity of juice is less than normal and the interior of the bowl takes on a white color, dry days may be expected.

Planting is most often carried out manually with a shovel, although more farmers are now using mechanical planting equipment. Furrows are made with a plow and seeds generally planted at the bottom of the furrow to a depth of 10–15 cm, depending on soil moisture. Many farmers affirm that the depth the shovel penetrates depends on the amount of moisture in the soil, suggesting that they use this method to indicate how deep to plant at that particular time. Seeds are usually planted at a greater depth under drier soil conditions, especially in sandy soils.

Spacing between plants within a given row is variable and depends on whether seeds are planted in clumps (*matas*) or evenly spaced, on the availability of water and nutrients, and, in some cases, whether the corn is grown for fodder or grain. *Matas* tend to be spaced about 80 cm apart with 2–4 seeds usually planted together. Plants sown individually are normally 50–60 cm apart. Corn planted for fodder is sown at much higher densities, with spacings of 25–30 cm within the row. Average distance between rows, depending on the size of the plow, ranges between 50–90 cm.

Cultivation and Management of Weeds

Three cultivation practices are carried out after initial planting: the *escarda,* the *labra,* and the *segunda.* The *escarda* is done when the young plants have reached a height of about 10–15 cm and transfers soil from the adjacent mound to the furrow, building up soil around the plants for support. The furrows also collect water in the area of root extension. The *labra* usually occurs when the plants have reached a height or about 25 cm. A slightly wider and deeper plow is used to build additional soil around the plants. The *segunda* is the last pass, when corn is about 100-cm tall, which deepens the furrow and builds up the mound higher and steeper to help guard against lodging.

The *segunda* is also the last cultural measure taken to suppress the growth of a variety of weeds that commonly invade cornfields, i.e., *Simsia foetida, Lopezia racemosa, Brassica campestris, Bidens* spp., *Cyperus* spp., *Chenopodium graveolens, Raphanus raphanistrum,* and *Lupinus elegans.* After this point, farmers recognize that these plants have little negative effect on corn growth (Moreno, Trujillo, and Ruiz, 1981).

Farmers do not refer to these plants as weeds (malezas) but rather as "hierbas," "arvenses," or "quelites" (wild plants); therefore, many of these plants are deliberately left in the fields as a second crop. Many of these quelites are important sources of minerals and vitamins such as calcium, thiamine, riboflavin, vitamin A, and vitamin C, thus improving the nutritional quality of the diet (Bye, 1981). In fact, there is evidence that Tlaxcalan farmers actually "sponser" wild plants in their fields through selective weeding (Williams, 1985). Many species of *Solanum, Jaltomata,* and *Physalis* are so adapted to the traditional patterns, perfectly mimicking the biological cycle of crops, to the point that their fruits mature when crops are ready for harvesting (Fig. 4). In a Tlaxcala barley field, Williams (1985) estimated a yield of 1325 kg of fruits from 4700 *Solanum mozinianum* plants/ha, with no apparent significant impact on barley production. In that area, fruit gathering afforded a meaningful input to agricultural subsistence, since the fruits of these "arvenses" are used for domestic consumption, restricted commercialization, and for ceremonial purposes (Wilkens, 1970). In the areas of Tlaxcala, Contla, and Apizaco, two species of *Amaranthus (A. Hypochondriacus,* and *A. cruentus)* are still grown associated or in rotation with corn, as farmers still recognize the ritual as well as nutritious (13–18% protein) importance of "alegria."

Chicle (*Asclepias* spp.) is traditionally used for making chewing gum and as a hemorrhoidal cure and can be commonly seen "sponsored" within many fields. Nopal (*Opuntia* spp.) is probably the most widely used of the "wild" plants, although it is planted as a crop in some areas. The "leaves" are peeled and cooked as a vegetable and the fruits (tuna) are eaten raw. They are also used as soil stabilizers and have been planted extensively on terrace risers east of Tlaxcala City. In certain areas such as Tequixquitla and Altamira, a variety of grass species are used for roofing material in homes and storage facilities. Table I lists several wild plants and their corresponding uses by Tlaxcalan farmers.

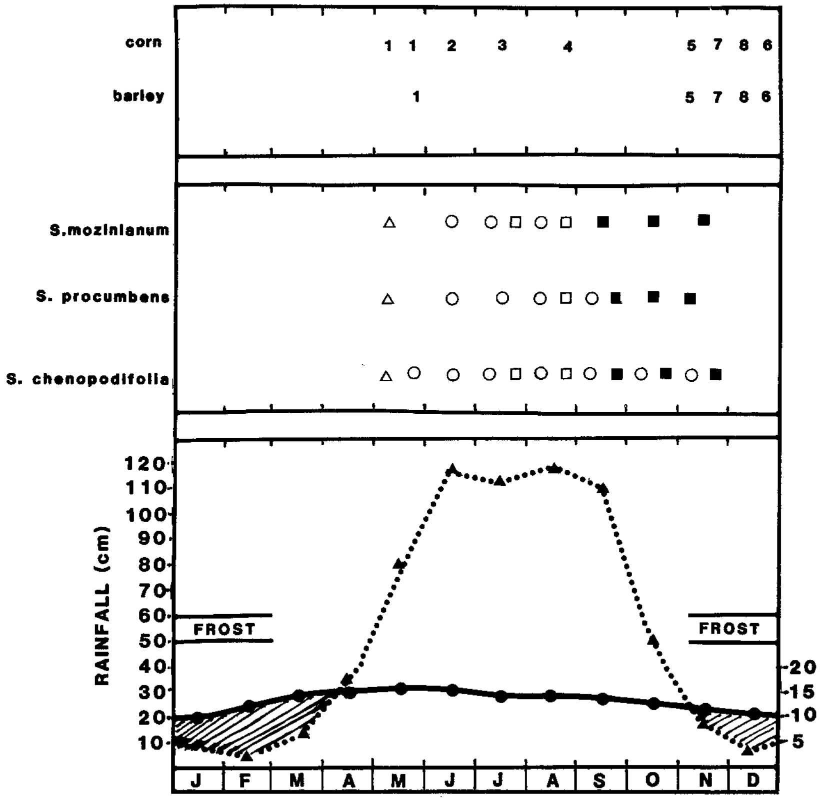

Fig. 4. Agricultural and phenological cycle of corn, barley, and wild Solanaceae (Solanum spp.) in Tlaxco, Tlaxcala (Williams, 1985). (1 = sowing, 2-4 = cultivation practices, 5 = corn piling, 6 = harvest, 7 = barbecho (fallow), 8 = mulching, Δ = spontaneous emergence, O = flowering, □ = fruiting, and ■ = fruit maturation).

Farmers derive other benefits from the presence of tolerable levels of wild plants in their fields. For example, frijolillo (*Lupinus* spp.) and colza (*Brassica campestris*) are at times intentionally left within corn fields, playing a beneficial role on the dynamics of the corn pest frailecillo (*Macrodactylus* sp). Our observations rvealed that frailecillo consistently fed more often on the flowers of colza and lupine than on corn flowers, indicating the potential importance of these plants as trap crops. Many plants are also collected after crop harvest, to be worked into the soil later during postseason cultivation, to enhance organic matter content in the fields.

Fertilization

The use of chemical fertilizers has increased over the last 15 years due to available credit. Common fertilizers used include superphosphate of cal-

Table I. Non-Cultivated (Wild) Plants Utilized by Farmers in Tlaxcala, Mexico

Scientific name	Common name	Uses
Amaranthus hypopondriacus[a]	Alegria	Ingredient for making candies
Amaranthus hybridus	Quelite	Forage
Argemone mexicana	Chicalote	Remedy for eye and skin infections
Aristida divaricata	Hierba (Pasto) de la virgen	medicinal
Artemisa absinthius	Ajenjo	Digestive; kills intestinal parasites
Bidens pilosa	Rosilla	Forage
Brassica campestris	Colza	Bird food, industrial oil source
Cedronella mexicana	Toronjil	Appetizer, digestive
Chenopodium ambrosioides	Epazote	Flavoring, remedy for intestinal parasites
Chenopodium graveolans	Epazote de zorillo	Intestinal parasites, diuretic
Cyperus sp.	Tule and Coquillo	Weaving of "petates" (bed mats) and baskets
Encelia mexicana	Acahual	Forage
Hedeoma piperita	Yerbabuena	Intestinal disorders and bronchitis, antispasmodic
Heterotheca inuloides	Arnica	Helps blood circulation, recovers muscles from contusive damages
Ipomoea stans	Cacaxtlapa	Relieves stomach and menstrual pains, sedant
Marrubium vulgare	Marrubia	Appetizer, remedy for diarrhea, bronchitis, and live inflamations
Matricaria parthenium	Manzanilla	Appetizer, antispasmodic
Opuntia spp.	Nopal	Edible fruit and leaves
Origanum vulgare	Oregano	Condiment, antiseptic
Ruta graveolens	Ruda	For hepatic and intestinal pains; used to control skin lice
Solanum mozinianum	Tlanochtle	Berries used for human consumption and ceremonial purposes
Thymus vulgaris	Tomillo	Cures gastroenteritis, antiseptic

[a]This plant is cultivated in some areas, although plantings rarely exceed 0.1 ha.

cium or ammonium, urea, and an 18-46-0 mixture. If affordable, farmers apply fertilizer twice during the season. The first application can be either at the time of planting or during the *escarda*. The second application is commonly done during the *segunda*. The fertilizer is distributed by land, with a given portion dropped either at the base of each plant or group of plants (mateado), or in strips along the furrow (en banda). Many farmers feel that chemical fertilizers are easy to use, and are effective even with little rainfall. However, others complain that fertilizers are costly and last for only 1 year, must be applied each year, and, in the long term, impoverish and weaken the soil because of the lack of organic matter import. In addition, many farmers indicate that excessive use of fertilizers "burn" the soil and create problems with salinization; however, we did not obtain scientific evidence to support these claims. Based on official data, it seems that farmers were better off

Table II. Production Costs and Yields of Corn under Different Technological Levels in Tlaxcala, Mexico[a]

	Cost (pesos/ha)	Yield (kg/ha)	Net gain (pesos/ha)
Improved seed, with fertilizer	3495	2534	960
Improved seed, without fertilizer	2074	1537	990
Criollo seed, with fertilizer	3130	1932	720
Criollo seed, without fertilizer	2045	1284	740

[a] Under rainfed ("temporal") conditions, average of 3-year data 1973–1976. Banrural (1976), Costos de producción de once cultivos básicos, Fideicomiso para la realización de Estudios de Desarrollo Agropecuario.

economically by not using synthetic fertilizers regardless of the type of corn variety used. As Table II suggests, although, in the short term, fertilizers increase yields, their use does not compensate for the higher costs of production that these inputs imply.

Low income farmers who cannot purchase commercial fertilizers sustain soil fertility by collecting nutrient materials from outside the farm, such as manure collected from pastures or enclosures in which animals are kept at night. This organic material is supplemented with leaves and other plant materials collected from nearby forests and fallow fields. Other farmers recycle nutrients among the various enterprises on the single farm, composting waste plant materials with household wastes and manure from livestock. Older leaves from the maguey plant are especially favored, and, in the primary pulque-producing areas, large quantities of leaves are collected in piles with other debris and soil and allowed to decompose before being used as a rich amendment. As the manure effectively provides nutrients for about 3–4 years, farmers have developed yearly rotations, applying available organic material to low-fertility areas of their fields. A familiar sight at the beginning of the growing season is mounds of manure evenly distributed over fields before being spread and incorporated into the soil (Fig. 5).

One method used to take advantage of soil enrichment by decomposing plant remains is the practice of rotating the placement of maguey borders. Once the maguey stop producing and begin dying back, they are removed and a new row planted where the center of the field used to be. The following year, corn is planted over the area of the previous maguey border, thus taking advantage of the organic matter accumulated over the years.

Another very old method of soil enrichment is the use of catchment ditches (cajetes) among field borders at the bottom of the slopes. These ditches collect runoff and debris, which is periodically returned to the field to replace lost nutrients and organic material.

The most valuable characteristics of organic manure recognized by farmers are its role in building up the soil, retaining soil moisture, and the fact

Fig. 5. Piles of manure (abono) ready to be spread over a field before corn planting in late March.

that its effectiveness lasts for about 3–5 years, all critical properties in sandy soils of low organic matter and low CEC. Farmers also indicate some problems with the use of manure, such as the production of "hierbas" the first year due to the number of weed seeds brought in with it and the favoring of gallina ciega (*Phyllophaga* spp.), a saprophagus larval pest that is harbored in organic waste.

Another strategy used by farmers to sustain soil fertility is to exploit the ability of the cropping system to reuse its own stored nutrients. Based on current information on nutrient dynamics in agroforestry systems (Nair, 1984), it is reasonable to expect that minerals lost by annual crops in Tlaxcala are rapidly taken up by perennial crop plants. In addition, the nutrient-robbing propensity of corn can apparently be counteracted by the enriching addition of organic matter to the soil by associated trees. Soil nitrogen is increased by incorporating legumes (fava beans or alfalfa) in the corn-cropping system.

Pest Control

The most important insect pest of corn is the scarab beetle *Macrodactylus* sp. or frailecillo, which feeds on newly formed female flowers, thus impeding grain formation. Armyworms (*Spodoptera* spp.), cutworms (*Prode-*

nia sp., *Agrotis* spp., and *Fenia* spp.), aphids (*Ropalosiphum* spp.), and gallina ciega sporadically cause damage.

Farmers believe that insect pest outbreaks are instrinsically related to climatic conditions. This is particularly true for frailecillo, armyworms, and red spider mites which tend to be more abundant during drier periods. Farmers also feel that the excessive use of chemical fertilizers and not preparing the soil in time leads to increased numbers of pests. Some farmers associate the phase of the moon at the time of planting with the occurrence of pests, while still others believe that the presence of pests is a consequence of their bad personal behavior, accepting them as a divine punishment.

Some explanations given decreases in pest numbers include climatic conditions such as low temperatures and strong and/or continuous rain, increasing plant maturity, the coming of a full moon, and certain religious days.

Despite credit support and technical assistance from agricultural extension, pesticide use in corn is still minimal, mostly limited to control severe outbreaks of frailecillo, armyworms, and rodents. Tlaxcalan farmers practice a number of cultural control methods, such as the manual collection of frailecillo from plants, and the direct application of lime onto frailecillo in the morning when dew is still present. Most farmers cultivate after the harvest or before planting to effectively destroy soil-borne insects. Other farmers use measures based on religious beliefs. For example, they collect a number of frailecillo and take them to the local where they are exorcized by one of the priests and later released back into the fields where they were collected.

In the valley areas, farmers have problems with mice and rats, whereas in the slopes of hill, they tend to have more problems with gophers and squirrels. Mechanical traps are often used to reduce rodent populations. Farmers also state that the planting of ayacote (*Phaseolus coccineus*) within fields is effective in preventing the establishment of gophers, apparently because these plants exude toxic substances from their roots. Many farmers recognize the importance of birds and snakes in the control of rodents. However, they do not seem to recognize the importance of insect predators and parasites in the maintenance of arthropod balance in their fields.

Harvesting

The most common harvesting method is the "amogotado," which involves cutting the corn plant at the base with a machete after the ears have matured. Plants are then collected and piled together in the form of small teepees (mogotes) and left to dry for 1–2 months, after which time the ears are picked and put in large burlap bags and the plant remains collected for forage. Some farmers, however, let the corn ears dry on the plant in the field and later pick them directly. This method is referred to as "dobla": the plant is broken toward the middle, doubled over, and left to dry.

Most farmers prefer the amogotado method, because by cutting and stacking the corn before it has dried completely, they are able to plow their fields sooner than they could otherwise. This enables them to incorporate the remaining noncrop plants into the soil when they are still green. Cutting the plants early also conserves the leaves, which otherwise might fall off when harvesting if the plants were dry. However, corn stacked in piles is most susceptible to disease after late rains as well as to damage by mice and rats.

Corn grain is usually stored still attached to the cob in specially built storage facilities (cuexcomates) or in one of the rooms of the house. To protect the grain against potential pest damage, farmers find that temperature and humidity are the two critical factors to control. In the cooler regions of higher elevations there are few problems with storage pests, but in warmer areas, some farmers must resort to chemical insecticides, e.g., Malathion, Lindane, etc., for control of weevils (Circulionidae) and Pyralid moths.

Ecological Interactions

The Effects of Individual Trees on Soil and Microclimatic Properties

In the soil study plots, a decreasing gradient in all soil properties measured was observed with increasing distance from the trees (Table III). Soil nitrogen, phosphorus, CEC, and calcium gradients were especially pronounced in the corn-capulin systems, suggesting that capulin had a greater degree of influence on soil properties than sabino. Available phosphorus increased 4- to 7-fold and nitrogen 1.5- to 3-fold under the trees (Fig. 6). Total carbon, calcium, magnesium fold, and CEC increased. Potassium levels decreased with distance from the trees, although its concentration was higher under sabino canopies. soil pH and percent moisture were also slightly greater under tree canopies. Both trees appeared to influence surface soil properties within a radius of 6–10 m from their base (Farrell, 1984).

The redistribution of nutrients with litterfall and the resulting accumulation of organic matter under the trees are probably the only significant factors determining the observed trends of soil chemical properties (Zinke, 1962). The higher concentration of carbon beneath capulin and sabino followed an expected trend due to the accumulation of litter by the trees, and a general lack of organic matter used in the management of these agricultural soils. The distribution of nitrogen under the trees also seemed correlated with car-

Table III. Surface Soil Properties in a Tlaxcalan Cornfield at Six Distances from the Base of Individual Capulin and Sabino Trees[a]

					Exchangeable					
Distance(m)	pH	Total*C*	Total *N*	Available *P*	CEC	Ca	Mg	*K*	%H_2O (1/3 bar)	%H_2O (15 bars)
Capulin										
2	6.6 ± .26[b]	1.34 ± .04	.091 ± .001	17.3 ± .58	7.0 ± .48	6.5 ± .05	1.29 ± .23	.58 ± .04	11.1 ± 1.0	5.9 ± .22
6	6.4 ± .28	.73 ± .23	.051 ± .012	6.6 ± 2.19	5.2 ± 1.26	3.9 ± .69	.69 ± .08	.26 ± .00	10.4 ± 1.3	4.4 ± .21
10	6.2 ± .18	.60 ± .20	.041 ± .009	3.4 ± .97	4.8 ± 1.00	3.0 ± .35	.52 ± .11	.19 ± .01	9.6 ± .75	3.9 ± .11
14	6.0 ± .00	.47 ± .12	.031 ± .005	2.3 ± 1.01	4.1 ± .85	2.3 ± .20	.40 ± .09	.17 ± .02	8.8 ± .14	3.6 ± .12
18	5.8 ± .05	.43 ± .11	.028 ± .003	2.0 ± 1.00	4.1 ± .71	2.1 ± .32	.34 ± .09	.15 ± .01	8.1 ± .71	3.4 ± .12
22	5.9 ± .09	.50 ± .12	.033 ± .005	2.2 ± .87	4.6 ± .60	2.6 ± .64	.34 ± .08	.18 ± .03	8.8 ± .62	3.7 ± .00
Sabino										
2	7.4 ± .01	.63 ± .10	.044 ± .008	2.5 ± 1.06	6.4 ± .69	6.6 ± .10	1.24 ± .15	.84 ± .13	9.2 ± .56	5.4 ± .52
6	6.9 ± .15	.51 ± .07	.038 ± .001	1.3 ± .18	6.0 ± .37	5.1 ± .49	.97 ± .01	.58 ± .22	8.4 ± .22	5.1 ± .25
10	6.5 ± .13	.36 ± .02	.030 ± .000	.6 ± .04	5.5 ± .69	4.1 ± .17	.85 ± .04	.48 ± .00	8.2 ± .14	5.0 ± .28
14	6.6 ± .05	.37 ± .06	.033 ± .001	1.4 ± .39	5.7 ± .03	4.2 ± .50	.97 ± .14	.47 ± .01	8.2 ± .08	5.2 ± .01
18	6.7 ± .38	.40 ± .01	.031 ± .001	2.2 ± .83	5.5 ± .08	4.5 ± .36	.98 ± .03	.56 ± .03	8.4 ± .39	5.1 ± .01
22	6.4 ± .21	.40 ± .02	.030 ± .001	1.5 ± .53	5.6 ± .27	4.3 ± .29	.89 ± .03	.48 ± .02	8.3 ± .18	5.1 ± .12

[a] See Farrell (1984).

[b] Mean values ± S.E.

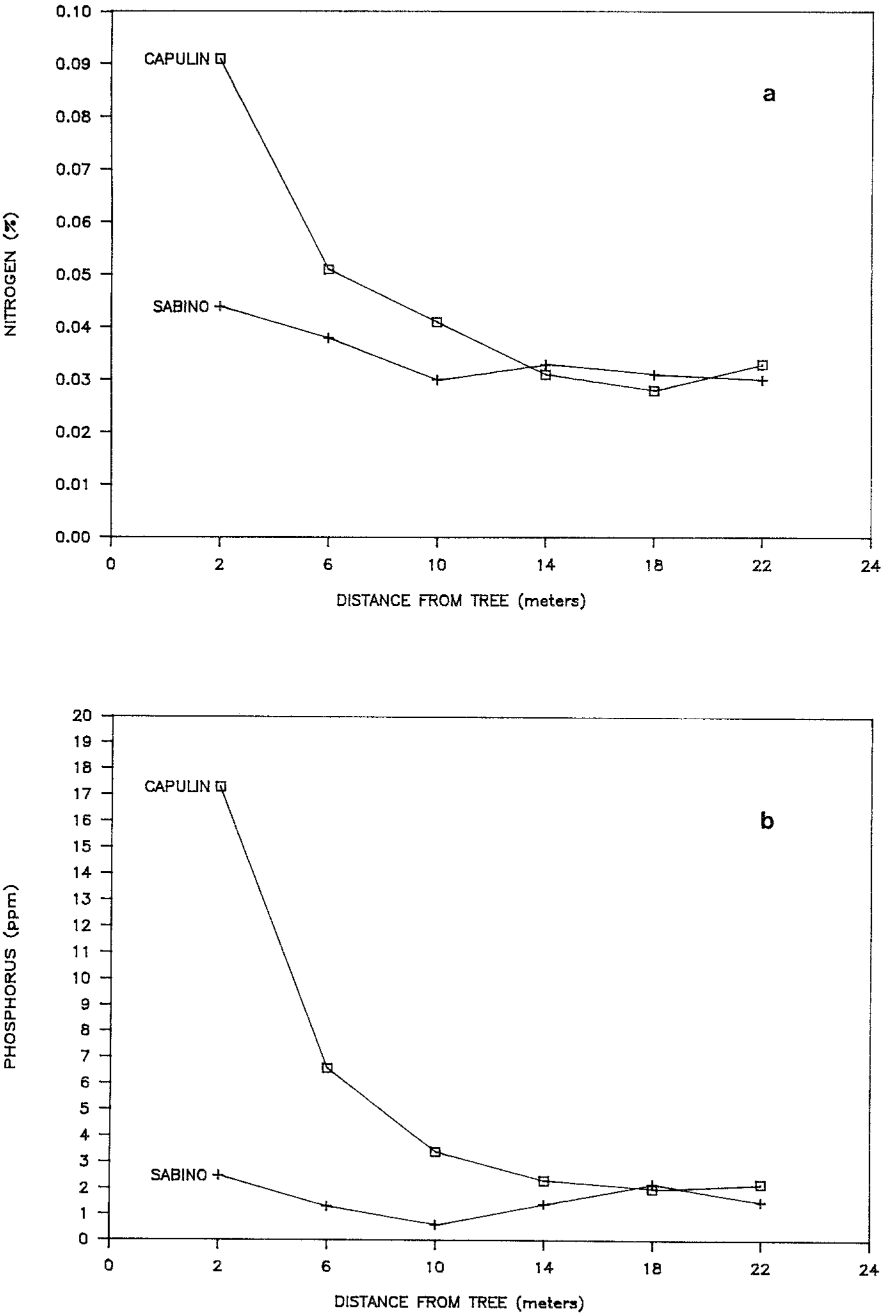

Fig. 6. Change in major surface soil nutrients in a corn-woodland agroforestry system, with increasing distance from individual capulin (*Prunus capuli*) and sabino (*Juniperus* spp.) trees: (a) nitrogen, and (b) phosphorus (Farrell, 1984).

bon accumulation. Accumulation of exchangeable cations also appear to be closely associated with organic matter.

Phosporus markedly accumulated beneath the capulin trees, corresponding with phosphorus amounts deposited with leaf litter. In addition, the higher pH found beneath the trees compared to in the open seemed to account for the increase in phosphorus availability in that area.

Soil moisture differences at the 0- to 15-cm depth were most pronounced around capulin where moisture was greatest under the tree canopy, somewhat less in the shade-west zone, and lowest in the remaining zones. No differences were observed between the shade-east, root, and non-influence zones. Around sabino trees, surface soil was wettest under the canopy, slightly drier in the two-shade and root zones and driest in the non-influence zone. In all zones except under the capulin canopy, soil at 15–30 cm was wetter than surface soils. No differences were observed between any of the zones at this depth, indicating that tree influences diminish with depth.

The increased capacity of the soils under capulin and sabino to retain water compared to soil in the open is due, in part, to the higher levels of organic matter beneath the trees. More important to the understory corn is the amount of water available for use (measurable difference in moisture between 1/3 and 15 bars), which was somewhat higher beneath the trees than away from them.

Corn Growth and Yield in Agroforestry systems

Corn yields varied considerably among the sampled agroforestry systems (Table IV); however, since the data proceed from nonreplicated farmers' fields, the effects of trees on corn yields cannot be statistically separated from other sources of variation, such as soil, microclimate, and management differences between agrofoestry systems, which can also determine significant effects on yields. Nevertheless, the data provide a tentative description of the yield potentials of each system. No significant differences ($p = .05$) were found in either plant height, density, or grain yield between corn growing along the edge (yield index = 729 ± 102) or in the center (734 ± 279) of our study fields bordered by rows of maguey. The characteristically wide border strips along which the maguey are planted (usually 4 m) ensure a 1.5- to 2-m distance between the last row of corn and the maguey border. Thus, although maguey plants have rather extensive superficial roots, they do not reach far enough into the field to have a substantial effect on corn production within the bordered fields.

Development and yields of early (March) and late (May) planted corn were measured in three zones in two sabino woodland fields. Zone 1 was located along the field borders, while zones 2 and 3 were progressively far-

Table IV. Average Yield, Height, and Density of Maize Growing in Association with Various Perennial Plants in Agroforestry Systems

System	Yield[a]	Height (cm)	Density (number of plants/ha)
Apple orchard	597	201	34,515
Pear-apple orchard	912	245	33,638
Sabino woodland			
Early-planted	1127	212	51,772
Late-planted	573	173	40,950
Ailite woodland	617	247	32,175
Maguey	734	162	45,922
NI (capulin)[b]	1005	192	57,623
NI (sabino)	1073	191	40,950

[a] Yield expressed as a relative index per 4-m transect (CIMMYT, 1974).

[b] Yields from the non-influence (NI) zone around capulin and sabino are included for comparison and are regarded as equivalent to monoculture yields.

ther from the trees into the center of the fields. In the early planted field, the rate of maize growth was staggered between the zones with maize in zone 3 maturing first, followed by zone 2 and zone 1. There were no differences in final grain yield between zones 2 and 3, while maize in zone 1 produced about 33% less (750 ± 95.1) and center (573 ± 90.9) zones in the late-planted fields. Throughout the season, corn growth was slowest along the eastern field borders. Corn along the western borders matured sooner than in the other sectors of the field. Grain yield was lower in the eastern border than in the other two zones. No differences in yield were found among corn plants grown next to a border of ailite trees (491 ± 88.3) and corn plants grown in the center rows (554 ± 116) of the same field. However, there were significant differences in plant height; maize along the center row away from the trees was 12% shorter than maize near the trees (237 cm).

Yield and height of corn plants growing near apple trees (516 ± 59.3) or 5 m away in the center (597 ± 191) of the interrow strips were similar. Yields of corn intercropped within pear-apple/peach orchards compared favorably to yields in other sampled agroforestry systems (Table IV).

Arthropod Dynamics in the Various Cropping Systems

Foliage Arthropods. Depending on the degree of vegetational diversity and the management intensity of the fields, populations of beneficial insects varied in species numbers and in relative abundance. Dominant predators included lady beetles (*Hippodamia convergens, H. Koebeli, Coccinella nugatoria,* and *Scymnus* sp.), malachiid beetle (*Collops* sp.), several species

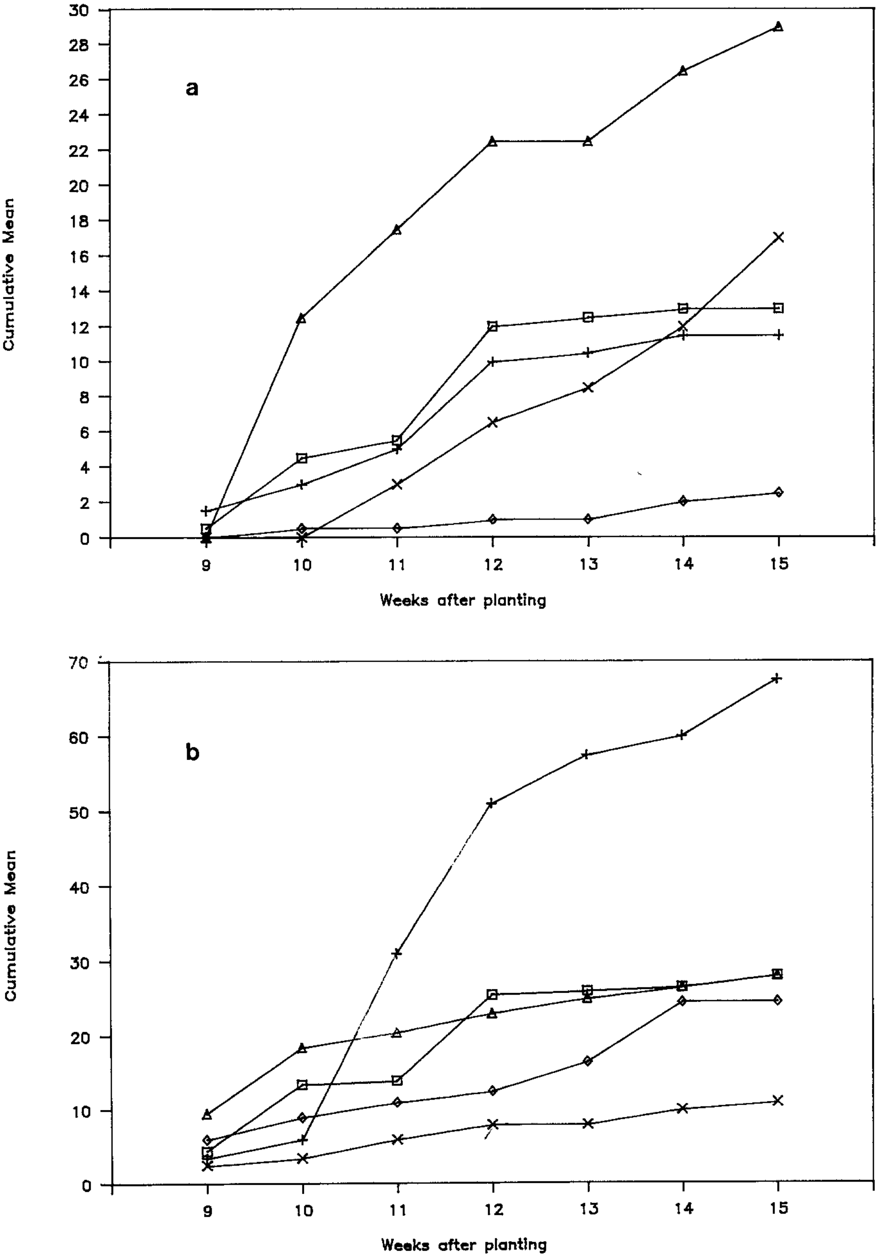

Fig. 7. Cumulative mean densities per 200 corn plants of: (a) the pestiferous scarab beetle *Macrodactylus* sp., and (b) the lady beetles *Hippodamia convergens,* and *Coccinella nugatoria,* in a range of corn-cropping systems. (□ = corn monoculture, + = corn-fava bean intercropping, △ = corn-alfalfa strip cropping, ◇ = agroforestry system of corn under a tree layer of sabino and ailite trees, and × = corn intercropped within an apple orchard).

of Carabidae, Staphylinidae, predaceous Hemiptera such as *Orious* sp., *Nabis* sp., predaceous Diptera of the families Syrphidae and Dolichopodidae, and the common earwig (*Doru* sp.). Spiders of the families Lycosidae, Argiopidae, Tethragnatidae, Salticidae, and Thomisidae were also commonly found on the plants.

The various vegetational arrangements under which corn was found affected the arthropod fauna in various ways. Some systems exhibited particularly high populations of corn-feeding insects. For example, in our sampled fields, the scarab pest, *Macrodactylus* sp., was predominantly more abundant in the corn-alfalfa strip-cropping system, whereas in the corn system growing adjacent to ailite woodlands it reached the lowest densities (Fig. 7).

The only system that exhibited high densities of several entomophagous insects was the corn-fava bean-squash polyculture. Populations of coccinellid beetles and of a crab spider species (Thomisidae) were higher in this polyculture system than in corresponding monocultures (Fig. 7b). The predator *Orious* sp. (Hemiptera: Anthocoridae) was noticeably more abundant in the corn-orchard and corn-alfalfa systems than in any other system.

The proximity of alfalfa strips to corn had a fundamental effect on the occurrence of all arthropods. As observed in Fig. 8, coccinellids

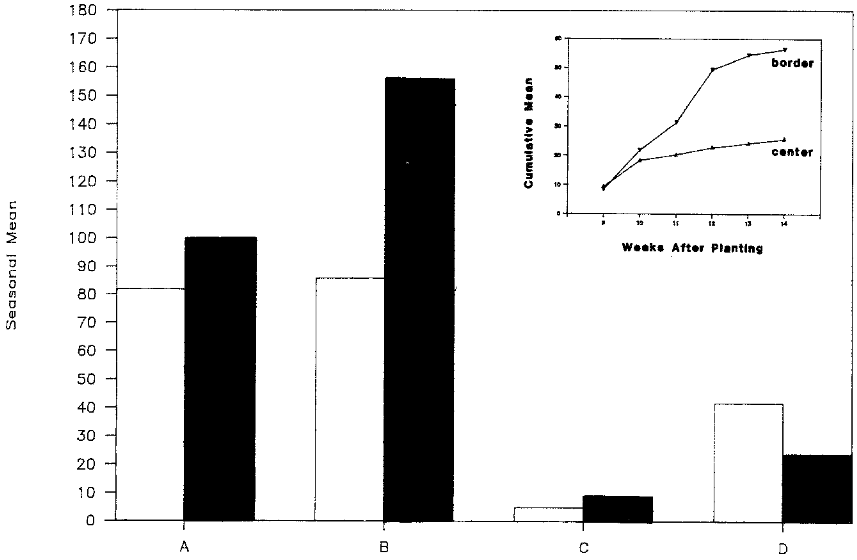

Fig. 8. Seasonal abundances of (a) predaceous: *Orius*, (b) Coccinellidae, (c), Collops malachiid beetles, and (d) the pest, *Macrodactylus* on corn plants located in rows immediately adjacent to alfalfa strips and in rows located in the center of the field away from the alfalfa. The line graph in the upper right corner illustrates the seasonal abundance patterns of Coccinellidae in the border and center rows of corn.

(*Collops* and *Orius*) were seasonally more abundant (about 30%) on corn plants located in the row adjacent to alfalfa than in the center of the field, away from the alfalfa strip. *Macrodactylus,* however, showed the opposite trend. In systems where alfalfa was periodically cut, we did not observe these abundance gradients. Apparently, cutting forces arthropods to disperse, and through redistribution they attain similar densities throughout the cornfield.

Soil-Dwelling Arthropods. Pitfall catches yielded significantly higher numbers of lycosid spiders in the corn-alfalfa system than in any of the other corn systems (Fig. 9a). Spider catches remained at similar low levels in all other systems, although at particular times spiders were caught more frequently in the corn-orchard system and in monocultures. Similarly, as in the case of foliage predators, substantially more lycosid spiders were caught in pitfalls placed in corn rows adjacent to alfalfa than in the center rows of the cornfield (Fig. 9b). Ground beetles reached highest densities in the corn-fava bean-squash polyculture, apparently encouraged by the shelter provided by the squash leaves.

DISCUSSION AND CONCLUSIONS

Many of the agricultural systems and practices currently used by Tlaxcalan farmers have evolved over many years of adapting to a fragile environment with soil, climatic, and biological limitations to food production (Williams, 1985). Other practices, however, have been more recently adopted as a result of increasing exposure to modern agricultural technologies. Thus small farmers in Tlaxcala are in a state of transition from the traditional to the modern. Our surveys indicate that the rationales behind traditional farming practices are often rooted in a sophisticated understanding of local environmental conditions and are closely associated with the persistence of a strong cultural tradition. Given the available resources and the production constraints, these systems and practices often represent extremely appropriate forms of land use (Toledo, Carablas, mapes, and Toledo, 1985).

Although the described systems may bear close resemblance to systems employed by other peasants in Mexico (Gliessman *et al.,* 1981; Wilken, 1970), they differ from some traditional models in a number of ways. Notably, corn is grown under a number of temporal (rotations) and/or spatial arrangements (intercropping, strip-cropping, and agroforestry) instead of in a cyclic polyculture or agroforestry pattern characteristically used by farmers in the lowland tropics (Beets, 1982). Tlaxcalan systems are genetically diverse, and this diversity results from interactions far more complex than the random planting of numerous corn varieties. Genetic diversity is also enhanced in the fields as a result of the protection and encourgement of "wild plants"

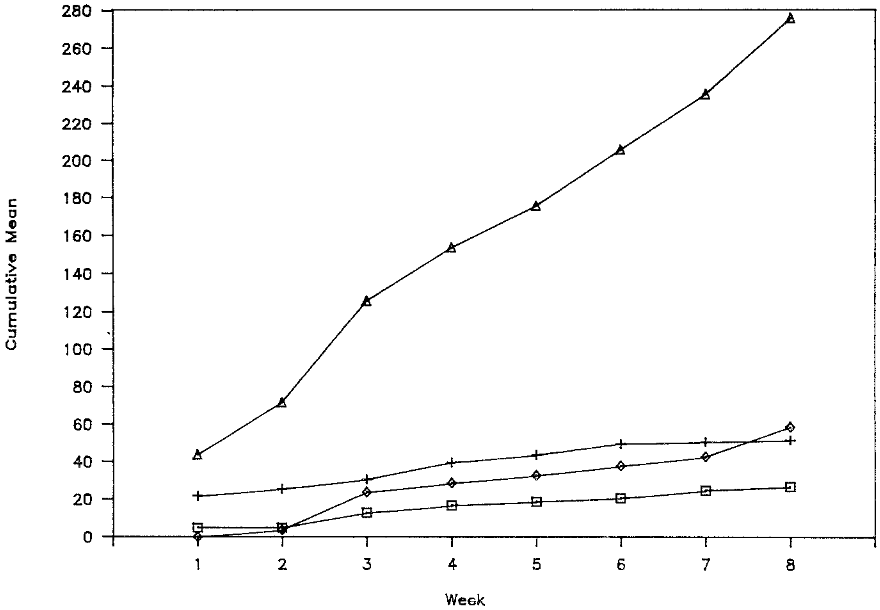

Fig. 9. (a) Numbers of lycosid spiders caught in pitfall traps placed in corn strip-cropped with alfalfa (△), intercropped with fava bean (+), intercropped with apples (◇), and grown in monoculture (□), and (b) numbers of lycosid spiders caught in pitfall traps placed in corn rows bordering alfalfa strips and in rows located in the center of the field.

that, in addition to firewood and medicines, provide dietary diversity. Thus, the systems serve as sources for local household needs and also provide cash returns from the sale of the various products.

The data presented above outline some of the interactions of human, management, and biological factors contributing to the ecological dynamics of corn-cropping systems in the area. Apparently, growing corn in a multiple array of vegetational designs is a strategy well adapted to the plethora of microenvironments to which corn production is subjected and an effective way to cope with seasonality and variability.

Although the farmers may not be aware of it, we found that the production of corn in polycultures and agroforestry patterns triggers a series of ecological interactions with important consequences for insect pest management and soil fertility relations. We recognize, however, that our data proceed from what may be considered "a handful of maize fields," and therefore we do not pretend to make broad generalizations about the ecological dynamics of corn agroecosystems. This would require more refined and well-controlled comparative experiments under a range of site-specific conditions. Our specific quantitative analyses were intended to illustrate some key biological interactions that result when Tlaxcalan farmers assemble their fields in various

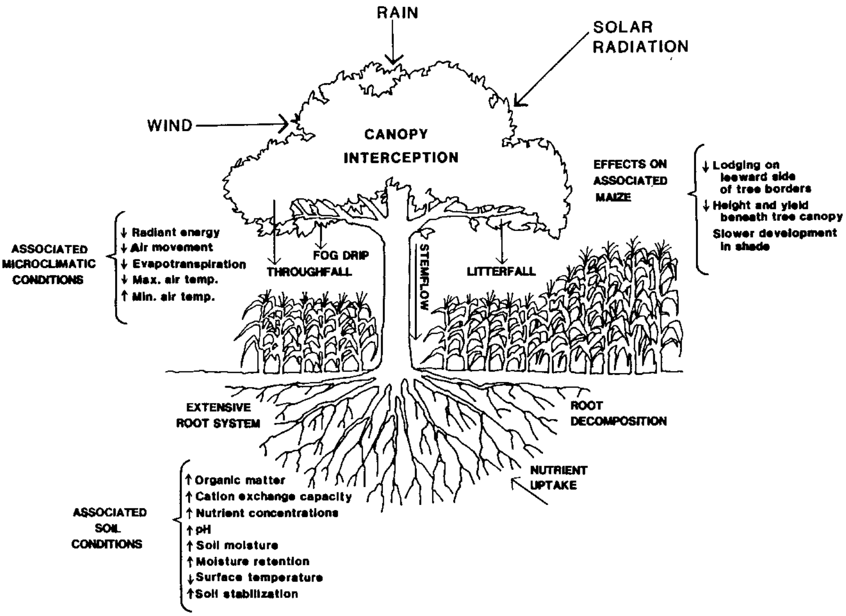

Fig. 10. A conceptual model of the potential influence of trees on the growing environment of corn in agroforestry systems of Tlaxcala (Farrell, 1984).

patterns. Our data suggest that, at least in our study fields, trees integrated into cropping systems modified the growing environment of associated understory corn plants, influencing their growth and yields. Figure 10 depicts various ways in which we assume selected trees modify soil and microclimatic factors. The greatest modification apparently results from the interception of solar radiation by tree canopies and deposition of leaf litter, but the above-ground tree structure also plays a significant role in intercepting, collecting, and redistributing precipitation, reducing wind velocities, and contributing chemical elements to throughfall precipitation. Below-ground, extensive root systems help to stabilize the soil, draw nutrients to be deposited later on the soil surface with litterfall, and contribute organic matter to the soil as a result of root decomposition.

With decreasing distance from trees, we observed an increase in soil organic matter, total nitrogen, available phosphorus, exchangeable potassium, calcium, and magnesium, cation exchange capacity, and water holding capacity. Soil moisture was also greater beneath the tree canopies. The reduced amount of solar radiation reaching the ground beneath the tree canopies resulted in lower evapotranspiration and a marked reduction in surface soil temperatures compared to the open cornfield. The trees also acted as a buffer against air temperature fluctuations and, as a result, lower maximum and higher minimum temperatures were found beneath the tree canopies than in the open (Farrell, 1984).

Certain tree species affected maize yields more than others. Such trees as apple, pear-apple, and peach, with smaller crowns and lower stature, appeared to have a minimal influence on yields; thus, substantial harvests were obtained from maize intercropped in fruit orchards. Germination was reduced near capulin and sabino trees in certain circumstances, and a reduction in yields was observed only directly beneach the canopies of these trees despite the fact that the soil near these trees was nutrient-rich. We feel that these differences may be due to sunlight and/or water differentials, an aspect that needs to be experimentally analyzed. Although corn monoculture systems in the region may exhibit significantly greater grain yields per hectare than most of the surveyed traditional agroforestry systems, when other considerations such as risk, multiple protective, and producive tree functions, and returns from the most limiting input, e.g., labor and capital, are examined, the yield superiority of the monoculture becomes less clear-cut and attractive.

Although these results describe tree influences on crop development for a single season, long-term effects are not indicated. Thus, in further evaluating the influence of trees on associated crops, the long-range effects, especially the trees' contribution to soil enhancement through organic matter input and their potential role in regulating faunal communities in these agroecosystems, should be considered. Such data can provide important information for determining which trees to encourage in fields, in what spatial designs, and for what purposes.

Our data on arthropod populations suggest that densities of the pest *Macrodactylus* and of foliage and soild predators fluctuated depending on the arrangement of crops in time and space, the composition and abundance of noncrop vegetation within and around fields, the surrounding environments, and the type and intensity of management.. Thus, *Macrodactylus* sp., predaceous beetles, lycosid spiders, and *Orius* sp. responded depending on their degree of association with one or more of the vegetational components in the systems. For example, the abundance of insect predators and spiders in corn depended greatly on the presence and phenology of adjacent alfalfa strips. A greater abundance of predators in corn rows adjacent to alfalfa strips corresponded with a lower incidence of *Macrodactylus* in those rows. Since alfalfa serves as a major source of natural enemies, correct designs of corn-alfalfa strip-cropping systems and proper timing of alfalfa cuttings could greatly increase the abundance and efficiency of beneficial arthropods in corn systems. Adoption of such designs would be confined, however, to areas with available irrigation, since alfalfa requires abundant water for growth. In addition, infestations of this pest on corn can be ameliorated by encouraging other host plants within or around the fields (*Brassica* spp., and *Lupinus* spp.) that serve as trap crosp, enticing *Macrodactylus* away from corn, as traditionally done by local farmers. Also the corn-fava bean-squash polyculture apparently exhibits inherent elements of crop protection as found by Letourneau (1983) in her studies in similar systems in Tabasco. We are currently conducting further research in Huamantla to determine optimal planting dates, planting density, and spatial designs of the component crops of this polyculture, for improved biological control of key pests (Altieri and Letourneau, 1982).

Since corn in Tlaxcala is managed over a range of energy inputs, levels of vegetational diversity and successional states, variations in arthropod dynamics are likely to occur; thus, their populations will be difficult to predict over broad areas. However, studies such as these will help us identify spatial and temporal conditions under which low pest potentials can be expected.

In summary, we feel that there are several stabilizing elements inherent to Tlaxcalan agriculture that should be preserved:

1. The farmers' tendency to manage polycultures and multiple purpose systems, both small- and relatively large-scale.
2. The rational utilization of hillsides and slopes through permanent terracing systems, especially managing *Agave* spp. borders.
3. The maintenance of genetically diverse fields apparently not only reduces the threat to crop loss, but also constitutes important *in situ* repositories of crop germplasm.
4. The myriad examples of resource management and appropriation systems to deal with site-specific environmental constraints, e.g., unique watering and drainage systems (Wilken, 1969), the "cajete system," and the large-scale canals bordering maize fields mimicking large "chinampas" found in the valleys near Nativitas (see Toledo *et al.*, 1985). So far, these local agricultural skills have been underutilized, but constitute potentially profitable resources for agricultural development.

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