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by

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ABSTRACT

This paper offers evidence that farmers' perceptions of soil quality ("folk" soil taxonomies) shape technology adoption. Econometric findings from Chiapas, Mexico indicate that the folk soil taxonomy reflects scientific properties of soils and significantly explains the partial adoption of high-yielding maize varieties on individual farms. Failure to account for land quality results in biased estimates of adoption equations and can encourage policy interventions that decrease, rather than increase, production efficiency.

Key words: Technology Adoption, Soil Quality, Variety Choice

"FOLK" SOIL TAXONOMY AND THE PARTIAL ADOPTION OF NEW SEED VARIETIES

Traditional agricultural systems in less-developed countries (LDCs) maintain not only the germplasm of native crop varieties (landraces) but also the human knowledge and behavioral practices that reflect a long co-evolution between crops and human populations. The germplasm of crop landraces provides the material from which high-yielding seed varieties (HYVs) have been developed by international and national agricultural research centers. Farmers' knowledge and behavioral practices, in turn, shape the manner and extent to which these new varieties are adopted and integrated back into the traditional farming system.

Although farmers in traditional agricultural systems frequently adopt new seed varieties and other modern inputs, many adopters also continue to cultivate traditional varieties. HYVs are introduced into agricultural systems where high levels of crop diversity exist and where different varieties are selected to fill specific ecological (e.g., land-quality) niches. Small farmers in the tropics are often confronted with complex and heterogeneous environments (Toledo *et al.*, 1985). A household may own or work several plots, usually scattered in different physiographic zones and comprised of different recognized soil qualities (Kirkby, 1973; DeWalt, 1979; Brush, 1980). Once farmers understand the principal characteristics of new HYVs, usually after a period of observation and experimentation, a "technology equilibrium" eventually is reached (Schultz, 1975). This equilibrium may entail the complete displacement of traditional varieties, but frequently it does not (e.g., see Brush, Taylor and Bellon, 1990). Instead, HYVs may simply be incorporated into one or more ecological niches on farms.

Efforts to explain partial adoption on farms have focused overwhelmingly on considerations of risk and farmer risk aversion (for example, see the detailed review by Feder, Just and Zilberman (1985)). However, when ecological factors like land quality are heterogeneous on farms, complete adoption is unlikely even within an expected profit (or expected household-farm income) maximization framework, unless the HYV outperforms traditional varieties in all production niches. Failure to account for partial adoption and for ecological diversity in adoption models, therefore, may produce results which are biased and which lead to erroneous policy prescriptions. For example, in a heterogeneous environment, suppose farmers have optimally matched different seed varieties, including a HYV, with land qualities on their farms. Then, a policy designed to encourage a more uniform cultivation of the HYV may result in less efficient cropping patterns.[1] An appropriate policy in this case might be to develop new technologies tailored to specific ecological niches (e.g., stressed environments) and to facilitate their adoption (e.g., through extension).

Regional data suggest that agroecological factors play an important role in the adoption of new technologies (Perrin and Winkelmann, 1976; Winkelmann, 1976). Some farm-level research (e.g., Richards, 1986; Collinson, 1975) also recognizes that farmers select and adapt varieties to specific ecological niches. Lipton and Longhurst

(1989) note that farmers may be reluctant to adopt HYVs in some niches because they absorb nutrients and deplete soils. In Mexico, Burke (1979) found that adopters had slightly less land per person but significantly higher land value (an indication of land quality) per person than non-adopters. However, econometric tests of how farmers' perceptions of land quality (the "folk" taxonomy) shape technology choice on individual farms are lacking.

The present study examines the effect of the folk soil taxonomy on maize variety selection in a maize cradle area, Chiapas in southern Mexico. Part I provides a theoretical rationale for partial adoption on individual farms in an expected farm profit-maximization model when farmers perceive land quality to be heterogeneous. In Part II, we construct a folk soil taxonomy and a land-quality ranking based on field data from Chiapas, and we present laboratory evidence that the folk taxonomy reflects scientific properties of soils. Our econometric findings, reported in Part III, support the hypothesis that the folk taxonomy shapes maize variety choice: farmers significantly match maize varieties with folk soil niches in a predictable way. Our findings also suggest that, controlling for land quality, farmers' ability to manage improved but management-intensive varieties and to finance modern farm inputs plays a role in shaping variety selection. We conclude with a discussion of the implications of our findings for agricultural research and development policy.

I. TECHNOLOGY ADOPTION AND LAND QUALITY

An expected-profit rationale for incomplete adoption on individual farms with heterogeneous land quality can be illustrated using a simple expected farm-profit maximization model. Consider a farm which controls I land types in the quantities $\bar{L}_i$, i=1,...,I. Suppose that each of these land types may be allocated in any proportion between two technologies, for example, between a traditional and a high yielding seed variety. Let L_{ij} denote land of quality i allocated to technology j and let π_{ij} denote expected per-hectare revenue, where j=1 for the HYV and j=0 for the traditional variety. The HYV has an expected per-hectare input cost, which for simplicity we assume is fixed for each land quality at c_i. The assumption of fixed input costs is consistent with the use of "packages" of inputs under modern technologies[2] . The subscript i permits these input packages to vary across soil qualities[3]. Input packages include costs of purchased inputs (seed, fertilizer, other chemical inputs). They also include other costs associated with cultivating HYVs, including the cost of capital and labor time to transport and apply inputs and to harvest outputs from different land-quality niches.

In addition to variable input costs, there may be a sunk cost k of adoption, regardless of how much land is allocated to the HYV once adoption occurs. These sunk costs include both capital and time investments to obtain information and access to new technologies, which may be a deterrent to adoption by small farmers in LDCs. Let r denote the cost of funds to finance sunk capital costs of adoption, or in the case of missing credit markets characteristic of small-scale farming in LDCs, the opportunity cost associated with farmers' self-financing of this cost. The annualized sunk capital cost of adoption then is rk.

The farmer's objective is to allocate (fixed) quantities of land $\bar{L}_i$ of qualities i = 1,...I, between the two production technologies in order to maximize expected profits Π. That is,

$$\text{(1a)} \quad \max_{\substack{\delta, L_{ij}, j=0,1; \\ i=1,\ldots,I}} \Pi = \sum_{i=1}^{I} [\pi_{i0}L_{i0} + (\pi_{i1} - c_i) L_{i1}] - \delta rk$$

where $\delta = 1$ if adoption takes place and 0 otherwise; subject to the land quality constraints[4]

$$\text{(1b)} \quad \sum_{j=0}^{1} L_{ij} \leq \bar{L}_i$$

for each land quality i.

Missing or imperfect markets, which are common in small-farm economies of LDCs, may impose additional constraints on adoption decisions. In the absence of smoothly functioning credit markets, farmers must self-finance the cost of adopting new technologies above and beyond any limited available credit. In the absence of perfect human capital markets, farmers must manage their own operations. Farmers' fixed time and financial and human capital endowments may represent a constraint on the adoption of more input and management-intensive HYVs whose adoption may entail a large sunk cost. This is especially the case early on in the adoption process (Lipton and Longhurst, 1989; Hewitt de Alcantára, 1978; Harriss, 1982; Byerlee and Harrington, 1982). These constraints are discussed in more detail in Part III.

Financial or managerial constraints are represented by (1c):

$$(1c) \quad \sum_{i=1}^{I} a_i L_{i1} + \delta k \leq \bar{K}$$

In the case of a financial constraint, k denotes the sunk capital cost of adoption, $a_i = c_i$ (the per-hectare cost of purchased input bundles), and $\bar{K}$ is the credit (or farmer's investment capital) available to finance these costs. In the case of a managerial constraint, a_i denotes the per-hectare input of management time required under the new technology, k denotes the sunk management time cost of adoption, and $\bar{K}$ is the farmer's total management time endowment.

To simplify exposition, assume that the land-quality constraints (1b) are binding.[5] Equations 1 (a-c) then constitute a mixed linear/integer programming problem which can be represented by the Lagrangian:

$$(2) \max_{\substack{\delta=0,1;L_{i1}, \\ i=1,\ldots,I}} \pounds = \sum_{i=1}^{I} \left[\pi_{i0} (\bar{L}_i - L_{i1}) + (\pi_{i1} - c_i) L_{i1}\right] - \delta rk + \lambda \left[\bar{K} - \sum_{i=1}^{I} a_i L_{i1} - \delta k\right]$$

Three interesting solutions to this problem are possible:

<u>Case 1: Homogeneous Land Quality, Perfect Capital Markets</u>

This is the traditional neoclassical model (with the exception of the fixed land constraints) in which $\pi_{ij} = \pi_j$ and $c_i = \bar{c}$ for all i, and the capital constraint is not binding, that is, $\lambda = 0$. This case leads to complete specialization on farms. The farmer adopts the new technology ($\delta^* = 1$) on all of the land ($L_1^* = \sum_{i=1}^{I} \bar{L}_i = \bar{L}$) if

$$(\pi_1 - c)\,\bar{L} - rk > \pi_0 \bar{L}.$$

Otherwise the farmer does not adopt at all ($\delta^* = 0$, $L_1^* = 0$), and assuming $\pi_0 > 0$, the farmer will specialize in the traditional technology ($L_0^* = \bar{L}$).

<u>Case 2: Heterogeneous Land Quality, Perfect Capital Markets</u>

When π_{ij} and c_i vary across land qualities, certain technologies may dominate other technologies in some, but not necessarily all, land-quality niches. With a nonbinding capital constraint, which implies $\lambda = 0$, this leads to specialization within quality niches but not necessarily to specialization on whole farms where land quality is heterogeneous. The farmer adopts the new technology ($\delta^* = 1$) if there is some positive level of $L_1^* = \sum_{i=1}^{I} L_{i1}^*$ at which

$$(3) \qquad \sum_{i=1}^{I} [\pi_{i0}(\bar{L}_i - L_{i1}^*) + (\pi_{i1} - c_i)\, L_{i1}^*] - rk > \sum_{i=1}^{I} \pi_{i0} \bar{L}_i$$

$\Sigma\ \pi_i L_i^{*})$

In other words, adoption occurs if the net return to utilizing the new technology over the traditional technology on at least some of the farmer's land exceeds the annualized fixed cost of adoption. Should adoption take place, the amount of land quality i placed in the new technology, L_{i1}^*, is:

$$L_{i1}^{*} = \begin{cases} \bar{L}_i \text{ if } \pi_{i1} - c_i > \pi_{i0} \\ 0 \text{ otherwise} \end{cases}$$

Each land quality is thus allocated entirely to the technology yielding the highest net return in that land-quality niche.

Case 3: Heterogeneous Land Quality, Imperfect Capital Markets

Given that inequality (3) holds, complete adoption in land-quality niches is ensured only if financial or human capital constraints are nonbinding. Otherwise (that is, if $\lambda > 0$), two cases are possible. If the sunk cost of adoption exceeds the capital constraint ($k > \bar{K}$), adoption will not be observed ($\delta^*=0$) even if the net returns to the new technology dominate those of the old in some or all of the quality niches. If $k < \bar{K}$, given (3), the farmer will adopt completely on lands with the highest net positive gain per hectare over the traditional technology ($\pi_{i1} - c_i - \pi_{i0}$) up to the point where the capital constraint becomes binding. The farmer will then shift into the traditional technology, which is not intensive in the constrained (capital) input.

Cases 1-3 yield straightforward testable implications. Consider a high-yielding, input-intensive seed variety engineered to outperform traditional varieties in the highest land-quality niche but not on lower quality lands. Other things being the same, if Case 1 holds (land quality is homogeneous), a marginal increase in land endowments on farms will have a positive effect on the area in the top-performing variety (either HYV or traditional) and no effect on the other variety. In case 2 (heterogeneous land quality), an increase in the highest land-quality endowment will be associated with an increase in the use of the HYV but will have no effect on the area in the traditional variety. The reverse will hold for an increase in lower quality land holdings. Finally, in Case 3, an increase in high-quality lands will result in an increased use of the HYV up to the point where the capital constraint is binding, and in an increase in traditional-variety plantings thereafter. In this case, variables reflecting looser capital constraints on individual farms (for example wealth) should be positively associated with adoption. By contrast, an increase in lower quality landholdings will have no effect on HYV plantings, as in Case 2.

II. EVIDENCE FROM CHIAPAS

Farm survey data from Chiapas, Mexico were used to test the relationship between farmers' knowledge with regard to maize varieties and soils and their technology adoption decisions.

Mexico is a primary center for maize diversity (Hernández X., 1973). From more than 40 maize races reported for México and northern Central America (Mesoamerica), 32 are found in the former (Bretting and Goodman, 1989; Wilkes, 1979). Native varieties are still widely grown (Mangelsdorf, 1974) and ethnobotanical reports suggest that up to 12 races are found at the farm or village level (e.g., Berlin *et al.*, 1974; Lauthlin, 1975). Associated with this cultivar diversity is an important knowledge base (Hernández X., 1985; Nigh, 1976). For example, Hernández X. (1985) reports that Indian farmers have an extensive knowledge of the climate, soils and biological nature of their maize populations. Important progress has been made toward understanding the agroecology of small farmers in México, especially in the areas of soil and water management (Kirkby, 1973; Gliessman, *et* *al.*, 1981; Wilken, 1987) and the intercropping of different species (Alcorn, 1984; Altieri and Trujillo, 1987). There has been little research, however, on the maintenance of intra-specific diversity in maize on farms (Brush *et al.*, 1988).

The state of Chiapas, in southern Mexico, is the third largest maize producer in the country (Coutiño-Estrada, *et al.*, 1986). Although high-yielding maize varieties are available and widely used, maize cultivation in this state is characterized by a large variety of maize types. It is also characterized by a complex "folk" soil taxonomy.

The existence of locally recognized "folk" soil taxonomies is well documented (Wilken, 1987; Williams, 1985; Williams and Ortíz-Solorio, 1981; Edwards, 1987; Carter, 1969; Ollier *et al.*, 1971). Soil taxonomies in Mesoamerica were described as early as the 16th Century (Sahagún, 1946; Williams, 1985). There are indications that soil knowledge and taxonomies are common among Indian and *mestizo* farmers in contemporary México (Wilken, 1987; Pérez-Pool, 1984; Quiroz, 1983; Luna, 1982; Williams and Ortíz-Solorio, 1981). Folk soil taxonomies are prime examples of indigenous technical knowledge that developed in the distant past and have persisted to the present (Tripp, 1989). Indeed, it has been proposed that these taxonomies can play a role in developing soil maps at low cost (Pájaro-Huertas and Ortíz-Solorio, 1987; Ortíz-Solorio *et al.*, 1988) and in conducting agronomic trials (Edwards, 1987).

Williams and Ortíz-Solorio (1981) write that: "Receptivity to agronomists' cropping recommendations may be influenced by folk perceptions of soil 'strength.'" In a study of a Mazahua community in

Mexico, Iwanska (1971) reported that farmers often referred to educated people from the outside (agronomists, engineers, professors) as *los que saben* (those who know) in contrast to themselves, *los que no saben* (those who don't know). However, "in the soil domain, the villagers claimed expert knowledge over that of the 'engineers'."

Several existing studies report physical and chemical analyses of soil samples taken from folk soil taxons (Williams and Ortíz, 1981; Wilken, 1987; Ollier, *et al.*, 1971; Edwards, 1987). However, there has been no formal attempt to test econometrically the relationship between folk soil taxonomies and seed-variety selection by individual farmers.

Fieldwork was conducted from June 1988 to February 1989 in a Chiapas *ejido* to examine farmers' perceptions of the characteristics of different maize varieties, farmers' folk soil taxonomies, and farmers' selection of maize varieties for soils in this taxonomy. The field site, Vicente Guerrero (hereafter referred to as "VG"), is a prosperous *ejido* of the lowlands, located 25 kilometers from the state capital of Tuxla. VG is a relatively progressive *ejido*. For example, parents are fined if they do not send their children to school, and the *ejido* assembly has banned the cutting of swidden plots in the old forest to preserve the watershed. New inputs and maize varieties have been used in the *ejido* for almost thirty years; however, farmers continue to plant several maize varieties and maintain swidden plots, as is characteristic of more traditional agricultural systems. The lowlands in which the *ejido* is located traditionally have been an important maize producing region, providing surplus for the national market. A CONASUPO grain-storage facility in VG purchases most of the local maize harvest. It reflects the presence of the Mexican state and its development efforts in this region. VG is the largest and most populated *ejido* in the *Municipio* (county) of Ocozocuautla. The *ejido* covers approximately 5,125 hectares and consists of 380 households with a total population of approximately 2,300. It is linked to both the state capital and the *Municipio* center by dirt roads.

A survey questionnaire was administered in person to a random sample of 96 VG farmers. The questionnaire solicited data on family demographics, landholdings, farmers' perceptions of soil types and maize variety characteristics, and areas planted in different maize varieties. In addition, soil samples from 104 randomly selected fields representing different soil categories in the local folk soil taxonomy were analyzed. Section II.1 summarizes farmers' perceptions of maize-variety characteristics, and Section II.2 presents the local folk soil taxonomy and the scientific properties of soils in this taxonomy. The folk taxonomy is the basis for our econometric test of the relationship between land quality and maize variety choice.

II.1. Maize Variety Characteristics

Farmers in VG reported planting fifteen maize varieties. Samples of each of these maize varieties were gathered and taken to the Colegio de Postgraduados in the state of Mexico for classification into races. Six distinct races were identified (Table 1): Olotillo, Tuxpeño, Argentino, Tepecintle, Zapalote Grande, and Nal-tel. Many varieties are a mixture of two or more of these races. The first five races were found planted in fields, while the last two were found in home gardens. Home garden varieties are the only ones used exclusively for subsistence. The three most important varieties in the *ejido* are Olotillo, a traditional variety; V-524, an improved, open-pollinated Tuxpeño variety; and Hibrido Amarillo, and "intermediate variety" that is an advanced generation of an earlier Argentino improved variety which has mixed with local landraces. Together, these three varieties comprise 82 percent of the total area dedicated to maize in the *ejido*. They are the focus of the empirical analysis that follows. These three varieties are referred to as TV ("Traditional Variety"), HYV ("Higher-Yielding Variety"), and IMV ("Intermediate Variety"), respectively, in the remainder of this paper.

The 93 farmers in the sample were administered an open-ended questionnaire to elicit their perceptions of the characteristics of the principal maize varieties they grow. Farmers were asked what varieties they had planted in the past, which varieties they currently planted, and what positive or negative characteristics they associated with each of these varieties. The farmers' answers reflect concerns about varietal response to ecological conditions (drought, wind, weeds, performance with intercropping), technological requirements (input intensity, timing of cultural practices), and yield and use (aptness for subsistence or for the market, storage properties, taste).

Table 2 summarizes farmers' answers to the variety-characteristics survey with regard to the three major maize varieties. Column A of the Table reports the share of farmers in the sample who referred to the corresponding trait in their responses. The numbers in this column reflect the importance farmers attach to the corresponding trait. For those who identified a specific trait as important, the share who associated that trait with each of the three principal maize varieties was calculated. These shares are reported in Panel B. For example, Row 1 of the Table reports that 64.5 percent of farmers in the sample identified a short growing cycle as a positive maize trait. Of these, 81 percent associated this trait with the HYV, 19 percent with the IMV, and none with the TV.

The most important maize variety traits (those identified by more than half of all farmers in the sample) include drought avoidance (as distinct from drought *resistance*),[6] resistance to lodging,[7] and yield.[8] Farmers consider the HYV to be superior to the TV with respect to all three of these traits. Not surprisingly, the IMV occupies an intermediate position on the performance spectrum between the two other varieties. The exception is yield by weight, for which a larger share of farmers attach a positive performance to the intermediate variety than to the HYV (58 and 42 percent, respectively).[9]

Despite these advantages, farmers perceive that HYVs have major disadvantages compared with traditional varieties in regard to time management and input intensity, and they have developed local descriptives to reflect this (Bellon, 1990). One third of all farmers identified sensitivity to timing of cultural practices as a negative varietal trait; of these, 90 percent characterized the HYV as *delicado* (sensitive). By contrast, 61 percent characterized the traditional Olotillo varieties as *aguantador* (resistant). Nearly one-fifth of all farmers consider high requirements of purchased inputs (e.g., fertilizer) to be a negative characteristic of the improved and intermediate varieties.

Classification of the HYV as *delicado* appears to extend to the soil domain. A controlled field experiment conducted by VG farmers during the study period found that the HYV failed to outperform the IMV on moderate-quality soils.

The Vicente Guerrero farm data reveal tremendous diversity in maize variety plantings within farms. Table 3 displays the shares of farmers who planted different maize variety combinations. The large share of traditional-variety cultivators who also planted more improved varieties is particularly striking. Thirty-five percent of all farmers planted TVs. Of these, 74 percent also planted the HYV, and 68 percent planted the IMV. Ninety-four percent of those who planted TVs also planted at least one of the other two varieties. Complete variety specialization is the exception, not the rule.

II.2. Soil Taxonomies

Folk soil taxonomies were elicited from the sample of 96 VG farmers. Each farmer was asked what types of soil he had and in what quantities, what characteristics he attributed to each soil type, and how to rank soils in terms of their quality for maize production. The VG soil taxonomy consists of five soil types. Ranked by farmers from best to worst for maize production, the "folk" soil taxons are: *Tierra Negra* (black earth), hereafter denoted "T1"; *Tierra Baya* (red-brown earth) and *Tierra Colorada* (red earth), "T2"; *Tierra Colorada-Arenosa* (red sandy earth), "T3"; and *Tierra Cascajosa* (stony or poor-quality earth), "T4". The basic soil taxonomy was shared by all farmers: all knew the soil category names. However, not all knew the specific properties of soils they had never cultivated.

Laboratory tests of soils in the folk taxonomy corroborate farmers' quality ranking of their soils.[10] An unbalanced one-way ANOVA was performed on soil properties measured in the laboratory. The farmers' soil taxons were used as the grouping variable.[11] Table 4 presents the results of the ANOVA for the four major folk soil categories and the major scientific properties that distinguish them. The soil properties include organic matter, pH, sand composition, and clay composition.[12] The table presents the means for each soil property and each folk-soil type. Farmers consider *Tierra Baya* and *Tierra Colorada* to be distinct but similar soil groups. Statistically, the properties of these two soils are not significantly different; the two soils therefore are combined into the single category T2. The p-values associated with an F-test of an unbalanced ANOVA for differences in means across folk categories appear in the right-hand column of the table. All are significant at well below the .01 level. T1, the highest-ranked soil, has a significantly higher organic matter content than the other soil classes. The high organic matter content of T1 is consistent with the view expressed by farmers in our survey that this type of soil yields well without fertilizer and releases nutrients slowly to the plant. The lower organic matter and larger sand content of T3 and T4 indicate a lower capacity to hold water and nutrients and support farmers' view that these soils are less productive. T4 has the lowest organic matter content of all soil types.

The pH levels of all soils except T4 are in the optimal range for maize production. The pH for T4, although outside the optimal range, is within the upper limit for maize production. This is consistent with the farmers' view that T4 is the poorest soil in the taxonomy, but it is also consistent with farmers' practice of cultivating this soil.

T1 has the highest clay content and the lowest sand content of all soil types. In their responses to our questionnaire, farmers characterized this soil as sticky, noting that in the flat it can become waterlogged in wet years but is drought-resistant in dry years. T2 has a slightly lower clay content than T1. Farmers claim that T2 soils hold moisture well but do not suffer from drainage problems. The last two soil types, especially T4, have a much higher content of sand and lower content of clay. Farmers claim that these soils have a low water-holding capacity and may suffer from drought in dry years.

III. ECONOMETRIC ANALYSIS OF MAIZE VARIETY SELECTION

Three-stage least squares estimation was used to test the hypothesis that the folk soil taxonomy significantly influences maize variety choice. This hypothesis corresponds to Cases 2 and 3 in the expected profit model of Part I, in which the (perceived) costs and returns to different technologies vary across land qualities. The null hypothesis corresponds to Case 1, in which costs and returns to specific technologies do not vary across soil types. If the soil taxonomy guides technology decisions, then, other things being equal, one would expect farmers to match the input-responsive but "delicate" (*delicado*) HYV with higher-quality soils that conserve moisture and retain nutrients for plant use. At the other extreme, one would expect the more resilient (*aguantador*), traditional varieties to be matched with lower-quality, stressed soil niches. The intermediate variety might occupy soil niches between these two extremes. In VG, rainfall and temperature are homogeneous throughout the *ejido*. These are no major altitudinal gradients. These conditions make it possible to isolate soil differences as the only major source of agroecological heterogeneity.

Two equation systems for the areas allocated to each of the three main seed varieties, one constrained and the other unconstrained, were estimated to test the hypothesis that farmers match maize varieties with soil qualities. The unconstrained model is of the form:

$$(4) \qquad L^*_{jn} = \alpha_j + \sum_{i=1}^{I} \beta_{ij} \bar{L}_{in} + \gamma_j \phi_n + \varepsilon_{jn}$$

for varieties j=1,...,J and (subjective) land qualities i=1,...,I where $\bar{L}_{in}$ denotes the endowment of land-quality i on farm n and ϕ_n (discussed below) is a vector of other exogenous variables that shape technology choice. The parameters β_{ij} measure the effect of land-quality endowment i on the area planted to variety j and γ_j is a vector of parameters measuring the effect of other exogenous variables on adoption decisions. If technology j has an absolute advantage on some land type k but not on some other land type k′ (for example, Case 2 in Part I), the effect of a marginal increase in farm size on the area in technology j will depend upon which land-quality niche is increased. That is, for $k \neq k'$,

$$\frac{\partial L^*_j}{\partial \bar{L}_k} \neq \frac{\partial L^*_j}{\partial \bar{L}_{k'}} .$$

The null hypothesis that land quality does not significantly shape maize variety selection (Case 1) is equivalent to the hypothesis that $\beta_{ij} = \beta_{i'j}$ for each pair of land qualities (i, i') and each technology j. In this case, no significant information is lost by replacing the I land quality endowment variables $\bar{L}_{in}$ on the right-hand side of equation system (4) by a single variable measuring total landholdings. The constrained model corresponding to this null hypothesis is given by equation system (5):

$$(5) \qquad L^*_{jn} = \alpha'_j + \beta_j \bar{L}_n + \gamma'_j \phi_n + \varepsilon'_{jn} \qquad\qquad j=1,\ldots,J$$

where $\bar{L}_n = \sum_{i=1}^{I} \bar{L}_{in}$.

The stochastic error terms ε_{jn} (in (4)) and ε'_{jn} (in (5)) are assumed to be independently and identically distributed as approximately normal $(0,\sigma_j^2)$ but with the possibility of cross-equation error correlations ($\sigma_{jj'} \neq 0$ for $j \neq j'$).

When variety selection is sensitive to land qualities, estimation of equations (5) will yield biased estimates of the effect of farm size on adoption. A Chow test can be employed to test the relationship between land quality and technology choice. This test entails estimating each of the equation systems (4) and (5) and then testing for the significance of separate land quality measures in explaining areas devoted to different seed varieties.

Estimation of (4) and (5) is complicated by the fact that positive values of L^*_{jn} are observed only if adoption takes place. That is, land areas in different technologies are censored at zero. The expected area devoted to technology j, $E(L^*_{jn})$, therefore is conditional upon $L^*_{jn} > 0$. That is,

$$(4') \quad E(L^*_{jn}) = \alpha_j + \sum_{i=1}^{I} \beta_{ij} \bar{L}_{in} + \gamma_j \phi_n + E(\varepsilon_{jn}/L^*_{jn} > 0)$$

$$(5') \quad E(L^*_{jn}) = \alpha'_j + \beta_j \bar{L}_n + \gamma'_j \phi_n + E(\varepsilon'_{jn}/L^*_{jn} > 0)$$

The conditional expectation of the error term cannot be assumed to be zero. Failure to correct for this censorship problem will produce estimates that are biased and inconsistent (Lee, 1978).

The two equation systems (4) and (5) were estimated using Amemiya's (1974) extension of Heckman's two-step estimator. Lee (1978) has shown that this method produces an estimator that is consistent and more efficient than other two-step estimators. Intuitively, the Amemiya estimator controls for the endogeneity of the discrete adoption decision while estimating the equations for land area in different technologies.

The variables in the vector ϕ_n capture the influences of farm structure and socioeconomic variables on planting decisions. These variables include the fragmentation of farm landholdings (F); farmers' age (A) and years of schooling (S); socioeconomic status (RI=rich, PO=poor; the default category is "medium"); off-farm income remittances (RMT); the number of adult male children in the farm household (CH); and farmers' off-farm income opportunities (OFF). These variables are summarized in Table 5.

When human capital and credit markets are imperfect, as is the case in small-scale agriculture throughout Mexico, farmers typically must supply their own inputs of human capital and must self-finance production. These market imperfections are likely to play a role in the adoption of HYVs, which farmers consider to be more intensive than traditional varieties both in purchased inputs and in management effort including the timely application of inputs. Farm configurations are likely to play an important role in farmers' ability to manage modern varieties. Management demands are greater on farms with fragmented land holdings: Given farm size and land qualities, farmers' human capital constraints are likely to be more binding when farmers must coordinate the timing of cultural practices across many small fields rather than on a single, larger field. Schooling, by contributing to farmers' human capital, may enhance farmers' ability to manage new seed varieties and coordinate farm production activities. Other things being the same, when credit markets are imperfect, wealthy farmers are better able to finance the costs of planting new seed varieties than are poor farmers. Income remittances from individuals outside the household may independently encourage a transition to commercial farming (Stark, 1978), which VG farmers associate with the adoption of improved seed varieties for market.

The availability of family labor may loosen financial constraints on farm production (i.e., by reducing the demand for hired labor). Family labor is likely to play a more important role in the production of traditional varieties, which lend themselves to stretching out labor demands over relatively long periods. By contrast, short timing windows and high labor demands on HYV production may necessitate the use of hired labor for HYVs to avoid crop losses (e.g., see Lipton and Longhurst, 1989).

Farmers' off-farm work opportunities may encourage adoption of HYVs by generating income that loosens financial constraints and by providing an income source that has a low correlation with farm production (Stark and Levhari). However, off-farm opportunities also raise the opportunity cost of cultivating time- and management-intensive crop varieties (Winklemann, 1976; Low, 1986).

III.1. Econometric Findings

The results of the censorship-corrected estimation of equation systems (4) and (5) appear in Table 6. Panel A of the Table presents the parameter estimates for equation system (5), which does not account for land quality effects. The estimates for equation system (4), which includes land quality effects, are presented in Panel B.

The combined area in the four land qualities has a significant, but varying, positive effect on plantings in all three varieties (Panel A). If we do not control for land quality, other things being the same, a one-hectare increase in farm size is associated with increases in HYV, IMV, and TV plantings of .22, .15 and .41, respectively. A positive association between farm size and HYV plantings is consistent with past empirical work on adoption (for example, see Feder, Just and Zilberman, 1985). Ruttan (1977) concludes that small farms tend to lag behind larger farms in adopting new technologies, although these lags tend to disappear in time. Theoretical work on adoption under uncertainty points to a positive association between farm size and the area in new technologies (Feder, 1980; Just and Zilberman, 1983), although not necessarily the share of land in these technologies (Just and Zilberman, 1983). The finding that *ceteris paribus*, marginal changes in farm size are also associated with an increase in areas planted in more traditional technologies is consistent both with a model of risk and with the model presented in Part I when land quality is not homogeneous.

The effect of farm size on the area planted in the three maize varieties varies significantly across land qualities, however (Panel B). A Chow test rejects the null hypothesis that the three land-quality effects are the same at well below the .01 significance level. The significant land-quality coefficients are reproduced in Table 7, which shows a clear relationship between land quality and variety selection. The econometric findings support the hypothesis that the folk soil taxonomy significantly shapes variety selection.

The highest quality land, T1, has a significant positive association with the area in improved and intermediate varieties. Other things being equal, a one-hectare increase in T1 results in a .26-hectare increase in the HYV and a .39-hectare increase in the IMV. By contrast, this land quality has no significant effect on the area in TVs.

As land quality decreases, farmers shift first towards intermediate varieties then to the robust, traditional varieties. The area in the poorest quality, T4, has a significant positive effect on plantings of the TV but no significant effect on plantings of the HYV or IMV. *Ceteris paribus,* a one-hectare increase in T4 is associated with a 1.06-hectare increase in TV plantings.[13] All land qualities superior to T4 have a significant positive effect on the area in IMVs. The IMV is the only variety that is significantly matched with the moderate-quality land, T3. No land quality except T4 has a significant effect on the area in TVs.

These findings suggest that traditional maize varieties are significantly favored over improved varieties in poorer-quality soils, and that both improved and intermediate varieties are favored on higher-quality lands where all varieties are likely to perform optimally, but where improved varieties are likely to have an absolute advantage over traditional ones.

The estimated parameters on the remaining variables in the Table conform to our expectation (Case 3 in Part I) that factors which enable farmers to overcome credit and human capital constraints are important in shaping planting decisions (Panel B). Fragmentation of land holdings is negatively associated with the area in improved, management-intensive varieties. Younger farmers allocate a significantly larger area to HYVs than do older farmers. Schooling, at least at the low levels observed in our sample, does not play a significant role in shaping variety choice. Other things being equal, rich farmers plant 2.5 more hectares in the HYV than do medium and poor farmers. This difference is equal to 28 percent of the average area in this variety for all farms in the sample. Farmers with off-farm income opportunities are significantly lower adopters of the HYV (–1.2 hectares) than are farmers who did not receive income from off-farm work during the year prior to the survey. The availability of male family labor appears to play a significant role in the cultivation of the traditional maize varieties: An additional adult male hand increases TV cultivation by 0.25 hectares. Family labor is not, however, significant in explaining plantings of the HYV. This is consistent with our expectation that farmers must rely on short-term, hired labor rather than on family labor for varieties whose cultivation is associated with short timing windows. By contrast, our empirical findings suggest that traditional varieties are associated with low-input, familial rather than commercial production.

The econometric results for the IMV are consistent with the perception that this variety occupies an intermediate position between HYVs and TVs. Older farmers and farmers with fragmented landholdings are not significantly low users of the IMV. However, there is some evidence that poor farmers plant less of this variety than do medium and rich farmers. Family labor is not significantly related to IMV plantings.

IV. CONCLUSIONS

The findings of this study provide theoretical and empirical evidence that farmers' perceptions of soil qualities on their farms (the "folk" soil taxonomy) significantly shape technology adoption. Our econometric analysis using farm data from Chiapas finds that the "folk" soil taxonomy reflects scientific soil properties and significantly explains the partial adoption of HYVs on individual farms. The findings also suggest that farmers' ability to overcome human capital and financial constraints plays a significant role in the adoption of improved varieties whose cultivation is input and management intensive. Three important lessons and directions for future research emerge from these findings:

First, a failure to account for partial (as opposed to dichotomous) technology adoption patterns is likely to result in unreliable and misleading findings and policy recommendations. In many cases, a substantial share of "non-adoption" (i.e., land area not in HYVs) occurs within, rather than among, farms. This argument is not new (e.g., see Feder, Just and Zilberman, 1985), but it is highlighted by the present research.

Second, where seed varieties are introduced into specific ecological (e.g., land-quality) niches, economic research, like agronomic research, needs to focus its attention on these niches. Farmers' perceptions may be useful in understanding environmental constraints on the adoption of new seed varieties. Agronomic research over the past three decades has focused primarily on developing input-responsive crop varieties to fill relatively high-quality and controlled environmental niches. Only recently has more research effort been directed explicitly at enhancing crop performance in stressed environments (poor soils, limited or uncertain water supplies, etc.). In light of the uneven performance of HYVs in different environmental contexts, it is surprising that econometric studies of adoption have made little progress in moving beyond the assumption of homogeneous land quality. In our field work, we found that soil taxonomies are relatively easy to learn, and data on soil quality easy to collect, with the assistance of farmers and field assistants. The benefits of incorporating this information into econometric analyses, we are convinced, greatly outweigh the incremental costs of data collection.

Third, one cost of assuming away ecological heterogeneity may be an undue emphasis on risk and risk aversion as an explanation for partial adoption on farms. We do not deny that these considerations play an important role in farmers' adoption decisions, and tests of the importance of risk aversion are beyond the scope of this study. However, our theoretical and empirical findings suggest that explanations for partial adoption that go beyond risk may be critical. Ecological diversity may easily result in *expected income* motives for partial adoption of new technologies. When ecological heterogeneity exists, models of technology adoption, with or without risk, that ignore this heterogeneity will yield biased and possibly misleading results. Moreover, policy interventions to encourage a more uniform adoption of existing technologies may decrease, rather than increase, production efficiency.

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NOTES

[1]There are exceptions, for example, when governments intervene to reduce institutional or informational constraints on adoption. A specific matching of seed varieties with land qualities that is optimal in one institutional setting may not be optimal in another.

[2] Our illustration is not altered substantively if we drop the simplifying assumption that input packages are fixed in proportion to land.

[3] For simplicity, we assume that the (smaller) input costs associated with traditional technologies in different land qualities are embedded in π_{i0}, so that π_{i0} represents net revenue per hectare under the traditional technology.

[4] The assumption of land-quality constraints on farms rules out land rental markets. For our empirical work this is not an unreasonable assumption (see part II, below). In contexts where active land rental markets exist, this model would have to be modified accordingly. A likely result of land rental markets would be a concentration of land quality on farms, and to the extent that technologies are matched with land qualities, a greater technological specialization on farms as well.

[5] If the land-quality constraints are not binding, they must be incorporated into the Lagrangian as inequality constraints (like 1(c)). Binding land-quality constraints are assured if the net revenue under the traditional technology is positive for all land qualities. This

appears to be a reasonable assumption in light of the results represented below.

[6]The length of the growth cycle determines the timing of flowering. In Chiapas, as in all Mexico, the middle of the rainy season normally is punctuated by a dry spell of uncertain length (*canicula*) (Mosino and Garcia, 1966). Farmers believe that a drought during the flowering period has a devastating impact on yield, a relationship that is well established in the scientific literature (Shaw, 1977). A short growing cycle increases the probability that flowering will occur before or shortly after the onset of the *canicula*. A short growth cycle is attributed to the HYV and to a lesser extent to the IMV. These perceptions are consistent with scientific literature on growth cycles of maize varieties (Ortega-Paczka, 1973; CAECECH, 1987).

Farmers generally consider the TV and IMV to be superior to the HYV with regard to drought *resistance* (that is, in the event plants are actually subjected to drought conditions). However, only 14% pointed to a lack of drought resistance as an important negative trait.

[7]Strong winds, common throughout the growing season, may knock down plants (a problem known as lodging), sharply reducing yields or destroying crops. There is strong consensus among farmers that the HYV is superior to other varieties with respect to lodging, because of its shorter stature and stronger stalk.

[8]The traditional varieties are considered to be inferior with respect to yield by weight. Harvest data for 1988 confirm the superiority of improved varieties over traditional varieties with

respect to yield (an average of 2 tons per hectare for the HYV versus 1 ton for the TV).

[9]This difference, as well as differences in yields between HYVs and TVs, may partly reflect differences in the quality of lands planted in different varieties and differences in management.

[10]Soil samples were drawn from a stratified random sample of 104 fields controlled by the farmers in the sample. The sample of fields was scattered throughout the *ejido* and was stratified by folk soil category. In each of the selected fields, three sites were randomly chosen and 700 g of soil were collected to a depth of 20 cm. The sample was taken to this depth because the farmers' soil taxonomy is concerned only with the arable portion of the soil and does not take into account the deeper soil profile. Farmers recognize the presence of rocks in the surface soil or immediately under, but not below the point to which the plow reaches. The soil analysis was carried out by the Colegio de Postgraduados in Mexico. A detailed analysis of the soil characteristics is available in Bellon (1990).

[11]Seven of the 104 fields were classified as transitional between two soil types and were dropped from the analysis.

[12] Several other soil characteristics (e.g., nitrogen content, cation exchange capacity) were also measured but are highly correlated with these four main characteristics; see Bellon (1990).

[13]A coefficient greater than one suggests substitution out of improved and intermediate varieties at low levels of soil quality.

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Table 1
Maize Races and Varieties in Vicente Guerrero

Race	Variety
Olotillo	Olotillo Amarillo Olotillo Blanco
Tuxpeño	V-524 Rocamex Canelo V-424
Argentino	Híbrido Amarillo
Zapalote Grande	Zapalote
Tepecintle	Negro
Tuxpeño/Olotillo	Jilguero Napalú
Olotillo/Tuxpeño	Olotillo Crema
Tuxpeño/Tepecintle	Crema
Zapalote Grande/Nal-tel	Chimbo Amarillo Chimbo Blanco

Table 2
Results of Open-ended Survey of Maize Variety Characteristics

Trait	A Percent Reporting As Positive (Negative) Trait	B Percentage of (A) Who Attribute This Trait To: HYV (V-524)	IMV (Hibrido Amarillo)	TV (Olotillo)
Drought Avoidance				
Short Growing Cycle	64.5	81.0	19.0	0.0
Long Growing Cycle	(22.5)	0.0	0	100.0
Wind				
Resistance to Lodging	54.0	81.1	18.9	0.0
Non-resistance to Lodging	(82.0)	0	15.4	84.6
Input Intensity	(18.0)	80.0	20.0	0.0
Sensitivity to Growing Conditions[a]				
Aguantador (resistant)	33.5	0.0	38.7	61.3
Delicado (non-resistant)	(33.5)	89.5	10.5	0.0
High Yield (by Weight)	60.0	42.0	58.0	0

N=93

[a]Includes sensitivity to environmental conditions and timing of cultural practices.

Source: Bellon (1990)

Table 3
Diversity of Maize Variety Plantings

	Share Who Also Planted...		
Of Farmers Who Planted...*	HYV	IMV	TV
HYV (.77)	1.00	0.64	0.34
IMV (.66)	0.75	1.00	0.37
TV (.35)	0.74	0.68	1.00

*Numbers in parentheses are shares of farmers who planted the corresponding variety.

Table 4
Selected Soil Chemical Properties by Farmer Soil Taxon

Property	Mean	T1 (Tierra Negra)	T2 (Tierra Baya-Colorada)	T3 (Tierra Colorada-Arenosa)	T4 (Tierra Cascajosa)	F-statistic*	p-value*
Organic Matter (%)	6.1	8.7	5.9	3.3	1.7	9.7	.0000
pH	6.6	6.7	6.4	6.1	7.3	8.1	.0001
Sand (%)	49.0	38.4	48.9	65.0	68.1	9.7	.0000
Clay (%)	28.0	36.2	26.2	22.9	14.0	6.7	.0004
No. of observations	97	33	44	10	10		

*F and p values associated with an Unbalanced Analysis of Variance on farmers' soil classes.

Table 5
Variables in Econometric Model

VARIABLE		Mean	Standard Deviation
Varieties (Endogenous)			
HYV	Area (hectares) planted in improved variety V-524	3.364	3.582
TV	Area planted in traditional (Olotillo) varieties	.987	1.910
IMV	Area planted in intermediate Hibrido Amarillo variety	3.044	3.418
Land Qualities (Exogenous)			
T1	Area in high quality Tierra Negra	4.313	3.135
T2	Area in intermediate-to-high quality Tierra Baya and Tierra Colorada	3.314	3.717
T3	Area in intermediate quality Tierra Colorada Amarilla	.812	1.488
T4	Area in lower quality Tierra Cascajosa	.619	1.233
T	Total land area	9.058	4.644
Other Exogenous Variables (ϕ)			
F	= Index of fragmentation (ratio of number of plots to farm area)	.527	.253
A	= Farmer's age	41.760	11.308
S	= Farmer's completed years of schooling	2.240	1.758
RI	= 1 if rich, 0 otherwise	.219	.416
PO	= 1 if rich, 0 otherwise	.354	.481
MED	= Default wealth category	.427	.497
RMT	= 1 if farmer received income remittances from outside the village, 0 otherwise	.125	.332
CH	= Number of adult children on the farm	1.865	1.593
OFF	= 1 if farmer had off-farm income in year prior to 1988, 0 otherwise	.646	.481

Sample Size = 96

Table 6. Censorship-Corrected 3-Stage Least Squares Estimates

Variable	A: Estimated Coefficient	A: T-Ratio 85DF	B: Estimated Coefficient	B: T-Ratio 82DF
HYV:				
T	0.217	2.515		
T1			0.260	2.127
T2			0.254	2.599
T3			0.303	1.533
T4			-0.155	-0.658
F	-3.387	-2.606	-3.001	-2.194
A	-0.073	-2.645	-0.075	-2.633
S	-0.116	-0.704	-0.099	-0.570
RI	2.386	3.254	2.533	3.401
PO	0.477	0.768	0.371	0.579
RMT	1.397	1.704	1.257	1.493
CH	-0.250	-1.289	-0.217	-1.091
OFF	-1.195	-2.036	-1.196	-2.011
IMRHYV*	2.312	5.892	2.286	5.747
CONSTANT	6.846	3.925	6.531	3.525
TV:				
T	0.154	3.337		
T1			0.047	1.020
T2			0.058	1.580
T3			-0.004	-0.060
T4			1.063	11.899
F	1.782	2.563	0.791	1.529
A	-0.012	-0.820	-0.008	-0.726
S	-0.032	-0.365	-0.086	-1.311
RI	-0.114	-0.291	-0.478	-1.695
PO	0.093	0.281	0.343	1.416
RMT	-0.776	-1.770	-0.407	-1.278
CH	0.324	3.115	0.249	3.307
OFF	0.010	0.034	0.022	0.099
IMRTV*	1.303	6.987	1.134	8.286
CONSTANT	-1.296	-1.390	-0.405	-0.577
IMV:				
T	0.406	5.170		
T1			0.394	3.474
T2			0.397	4.376
T3			0.576	3.139
T4			0.319	1.456
F	2.014	1.705	1.926	1.516
A	0.044	1.749	0.037	1.409
S	0.226	1.519	0.188	1.165
RI	-0.654	-0.983	-0.634	-0.917
PO	-1.198	-2.123	-1.264	-2.127
RMT	-0.169	-0.227	-0.113	-0.145
CH	-0.195	-1.106	-0.166	-0.897
OFF	0.265	0.498	0.299	0.541
IMRIMV*	2.207	7.457	2.171	7.105
CONSTANT	-3.244	-2.047	-2.918	-1.696
Sample Size	96		96	
Log Likelihood	-580.48		-546.22	
Chi-Square (df)**	253.48 (30)		321.98 (39)	

*IMRHYV, IMRTV and IMRIMV are inverse-Mills ratios corresponding to the adoption of HYVs, TVs, and IMVs, respectively.

**Corresponds to a test of the null hypothesis that all slopes in the equation system are zero.

Table 7
Marginal Effects of Land Qualities on Maize Plantings

Soil Quality	Variety		
	HYV	IMV	TV
T1	0.260*	0.394**	
T2	0.254**	0.397**	
T3		0.576**	
T4			1.063**

*(**)Significant at below the .10 (.05) level for a 2-tailed test.