Local Seed Markets and the Determinants of Crop Variety Diversity in Marginal Environments: The Case of Millet in Semi-Arid India

Latha Nagarajan
Consultant, International Food Policy Research Institute
Melinda Smale
International Food Policy Research Institute and
International Plant Genetic Resources Institute
Paul Glewwe
University of Minnesota, USA

Contact Author:

Latha Nagarajan
Room 5012-C, IFPRI
2033 K Street, N.W.
Washington, DC 20006

Phone: 202 862-5626
Fax: 202 467-4439
Email: l.nagarajan@cgiar.org

Selected Paper prepared for presentation at the American Agricultural Economics Association Annual Meeting, Providence, Rhode Island, July 24-27, 2005

Selected Paper

American Agricultural Economics Association Annual Meeting
Providence, Rhode Island, July 24-27, 2005

Local Seed Markets and the Determinants of Crop Variety Diversity in Marginal Environments: The Case of Millet in Semi-Arid India

Latha Nagarajan, Melinda Smale, and Paul Glewwe

ABSTRACT

The purpose of the research paper is to characterize biological diversity related to millets in the semi-arid regions of India at various spatial scales of analysis (e.g., farm household versus community levels) and place that evidence in a broader seed systems (includes both formal and informal) context. An important finding of this research is that producer access to millet genetic resources is affected by the extent to which seed is traded via formal markets or through other social institutions, along with farm and household characteristics. Findings also underscore the need for an enhanced theoretical understanding of local seed markets in analyzing crop variety choices and the diversity of materials grown in less favored environments.

The authors gratefully acknowledge helpful comments from Phil Pardey on the earlier version of this paper. The views expressed herein are those of the authors and not necessarily those of International Food Policy Research Institute and University of Minnesota.

Local Seed Markets and the Determinants of Crop Variety Diversity in Marginal Environments: The Case of Millet in Semi-Arid India

Latha Nagarajan, Melinda Smale, and Paul Glewwe

Millet crops are mainly grown for food and feed purposes in the arid and semi-arid regions of Africa and Asia. An option for farmers operating in harsh environments where other crops do poorly, millet crops are grown with as little as 400-500 mm of rainfall per year, without application of fertilizers or other inputs. Smallholder millet producers in the semi-arid regions of southern India make their economic decisions in an environment characterized by recurrent droughts. With limited alternatives for earning cash income and no crop insurance, these farmers depend largely on their own production for food, feed and fodder needs. They grow five different millet crops (sorghum, pearl millet, finger millet, little millet, and foxtail millet), in diverse combinations.

Several studies have employed farmer decision-making models and econometric analysis to identify the determinants of diversity in crops and varieties grown, including modern varieties, in marginal environments of developing or transitional economies (Brush, Taylor, and Bellon 1992; Meng 1997; Van Dusen, 2000; Smale, Aguirre and Bellon, 2001; Benin et al. 2004; Birol 2004; Gauchan 2004). Findings establish that economic criteria are as critical as plant population genetics and agro-ecological factors in influencing whether farmers will choose to continue cultivating diverse crop variety combinations. A few studies have tested hypotheses about the linkages of spatial diversity in crop varieties with productivity and vulnerability, particularly in modern farming systems (Widawsky and Rozelle 1998; Hartell et al. 1998; DiFalco 2002; Meng et al. 2003). Although population genetics suggests that the structure of genetic diversity may be better measured at the level of the village or community than the individual household level, little research attention has focused on the relationship between the two. Furthermore, the critical role of local seed markets has been investigated only anecdotally, perhaps because the features of village seed markets in subsistence-oriented production are not well understood.

Understanding systems for developing, distributing, and (re-)using planting material is crucial for maintaining crop biodiversity in locations where it is believed to be of social significance. Though the physical unit of seed that reproduces a crop is a private good, the diversity of the genetic resources embodied in it has public good attributes (Morris, Rusike and Smale 1998). Farmer and community access to the genetic resources embodied in seed is affected by the extent to which it is traded via formal markets or through other social institutions, as well as by related legal and institutional frameworks, including various national and international regulatory and intellectual property arrangements. Seed systems convey incentives for farmers to choose one crop variety over another, or to grow one set of crops and varieties rather than another.

The seed system consists of all the channels through which farmers acquire genetic materials—both outside of, and in interaction with, the commercial seed industry. Markets are a component of seed systems, transmitting value through consumers' willingness to pay, including both consumers of planting material (farmers) and consumers of products (which in semi-subsistence agriculture, also include farmers). Though economists have studied formal seed systems in developing countries (Morris 1998) there has been comparatively little economic analysis of less formal, often localized seed systems (Tripp 2000). Moreover, the crop diversity dimension of either formal or informal seed systems has received limited attention.

This study contributes to this literature in two ways. First, it identifies and compares the factors that influence both the decision of individual farmers to grow more millet crop varieties, including both modern and local varieties, and the spatial diversity of these varieties at the level of "village community" (*panchayat*). A new econometric application is developed to reflect a unique farming system in which multiple types of millet crops are grown in complex cropping and variety combinations. Hypotheses are tested at both the household and community level of analysis, to investigate the importance of geographical scale in analyzing patterns of crop variety diversity. Second, based on an integrated definition of a local seed system that includes formal (modern variety) and informal (farmer variety) channels, market and non-market transactions, local seed system characteristics are measured and their effects on farm-level and village-level diversity tested. The empirical analysis is motivated conceptually by the theory of the farm household, treating crop and variety diversity as a consequence of optimal production and consumption choices.

Conceptual Model

Our conceptual approach to analyze on-farm diversity and seed markets is based two bodies of literature: 1) the theory of the farm household model developed by Singh, Squire, and Strauss (1986), de Janvry, Fafchamps, and Sadoulet (1991) and Taylor and Adelman (2003) and 2) a large body of empirical literature on partial adoption of agricultural innovations, including varieties of seed, summarized in Feder et al. (1985) and Feder and Umali (1993). Van Dusen (2000) developed an estimable version of a farm household model applied to study crop diversity among and within species on farms in the *milpa* (maize, bean, and squash) system of Mexico. Other, related, applied econometrics studies of variety diversity on household farms include Brush, Taylor, and Bellon (1992), Meng (1997), Smale, Aguirre and Bellon (2001), Birol (2004) and Gauchan (2004).

At the core of household model is the issue of separability—that is, whether the household's production, consumption and labor decisions are simultaneously or jointly determined (non-separable) or the decisions are recursive (separable). In the separable case, the household is a perfect neo-classical household, and farm decisions regarding inputs and outputs are taken first and the net income derived can be used to solve the consumption decisions. Especially, but not only, in developing economies and marginal production environments, market failures exist. Market failures result in nontradable outputs or factors of production (Sadoulet, de Janvry and Benjamin 1996). Realistically, households often face mixed markets, where both tradables as well as nontradables exist (Taylor and Adelman 2003). The sources of non-separability include both aspects related to production decisions and those related to consumption.

In semi- arid regions of India, millet crops are produced mainly for consumption as food or fodder on the farm. They are cultivated mostly in marginal (dry) lands with inconsistent weather conditions. Markets for millet grains, especially for the farmers' varieties or varieties of finger millet, foxtail millet, or small millet, are 'shallow', and in many instances, absent[1]. Markets for the grain of improved or modern varieties are also

[1] When the harvest is good and households could have marketed surplus, the market price falls because all other households also have plentiful harvests and decision price of the household then falls within the price band. Conversely, if there is a drought and household supply falls, so does the supply of all households, and the sharp rise in price may force them to remain self-sufficient (de Janvry et.al 1997). Shallow markets

limited, or 'thin'[2]. The millet crops sold in markets obtain low (procurement) prices compared to the millets purchased for consumption at the retail level[3], creating a wide band between sales and consumer prices. For instance, the price range in case of sorghum varies between Rs.100 to 150 per 100 kg of grains sold and bought in the market. Although it may not be profitable to grow millets for off-farm sale, a household might opt to grow certain variety for food or fodder consumption because of taste or food preferences that are not easily substituted through market purchases.

Adding to this, farm households in these areas normally do not make their transaction decisions based on market prices because they have limited access to markets. Rural road networks are poor in most of the millet growing communities, augmenting transactions costs. In particular, poor rural roads restrict the ability of farmers to travel from their own community to another community to transact in local seed or grain markets. Hence, the farm households who grow millet crops remain self-sufficient, consuming what they produce.

Following Singh, Squire and Strauss (1986) and Van Dusen (2000) the farm household maximizes utility over bundle of consumption items generated by the set of (millet) crops and the varieties they grow,

---

imply a high negative covariation between household supply and effective prices (Sadoulet and Janvry 1995).

[2] A thin market may be defined as a market in which the structure of the market inhibits or prevents prices across space, time, and form from attaining the relationships characteristic of a perfect market. The structural causes of thinness includes low trade volumes, few buyers or sellers, scarcity of market information, barriers to entry, certain forms of government market intervention (Hayenga 1979).

[3] The procurement prices are fixed and announced by the government for the whole country at the beginning of the season and they are always lower than the market prices. In the case of millet crops, private retailers use this price for procurement at the farm gate.

$$U = U(X_i, X_{nt}, X_m, X_l; \Omega_{HH}) \tag{1}$$

where arguments are vectors of millet consumption goods produced by the household X_i, the consumption of products derived from farmers' cultivars of millet crops, for which markets are missing and denoted as *'non-tradables'* X_{nt}; the consumption of market purchased commodities X_m; and total leisure time designated as X_l. Household utility depends on the preferences of its members, which are shaped by household characteristics denoted by the vector Ω_{HH}, such as age, education, and wealth. Choices among consumption goods are limited by the full income *(Y)* of the household which is composed of the total time endowment of the household (T) that is allocated either to farm production (H) or leisure (L), and the households income ($\overline{Y}$), which is exogenous to the season's crop and varietal choices and includes stocks carried over, remittances, pensions and other income transfers from the previous season. Thus the household maximizes utility subject to a full income (Y) constraint.

The utility function is also assumed to be well behaved, quasi-concave with positive partial derivatives. Household profits must equal the value of sales of farm output less the values of household labor, H, used in the production of farm output, and the cost of variable inputs used C, required for production of outputs, Q. (All households surveyed utilized family labor for millet cultivation purposes rather than hiring from outside.)

$$Y = P_i(Q_i - X_i) - P_c C + \overline{Y} - P_m X_m - wH \tag{2}$$

$$F(Q, C, H; \Omega_{farm}) \tag{3}$$

The household production technology, represented by $F(.)$, combines farm inputs *H a*nd *C* with the physical characteristics of the farm Ω_{farm} to produce outputs, Q. The household faces a time constraint and cannot allocate more time to millet cultivation, H, off-farm employment, *L* leisure, than the total time available to the household.

$$(H + L) = T \tag{4}$$

The household is constrained by 'thin' or non-existent markets for some of the outputs it produces, such as the grain of local varieties of sorghum or pearl millet, finger millet, foxtail millet or little millets. When markets are imperfect or missing, household demand (2) for the product is equated with supply (3):

$$Q_{nt} = X_{nt}(\Omega_M) \tag{5}$$

Q_{nt} and X_{nt} represent vectors of the quantity demanded and supplied of no-tradable millet crops, and Ω_M is a vector of exogenous characteristics related to the availability of off-farm employment opportunities and access to markets. The equality condition implicitly defines the shadow price for such goods, inducing the household to equate supply and demand. In the non-separable case, the shadow price is a function of household preferences as well as market prices. The household maximizes its utility (equation (1)) subject to its cash income, production technology, time endowment, and equality of production and consumption for non-tradable portion of millets (equations (2), (3) and (4) and (5)), and to fixed, exogenous prices.

Assuming interior solutions exist, the optimal set of output and consumption levels and endogenous prices for the traditional and minor millets are given by the solutions of the first order conditions. The shadow price for millet cultivars with missing markets is affected by household and market characteristics, and becomes the price that is used in making household production and consumption decisions (Van Dusen 2000).

$$\rho_{nt} = \rho^{*}(P_i, P_m, P_c, w; \Omega_{HH}, \Omega_{farm}, \Omega_M) \qquad (6)$$

Hence in the event of non-separability, the level of crop and variety diversity maintained on farms is derived from the household's demand for consumption goods produced on the farm. As in Van Dusen (2000), the range of crops and varieties grown on the farm, or the diversity of the genetic resources they embody, are a consequence of optimal choices over the levels of goods to produce and consume.

$$MD = MD[Q_{nt}^{*}(Y, P_i, P_m, P_c, w; \Omega_{HH}, \Omega_{farm}, \Omega_M)] \qquad (7)$$

Equation (7) is estimated at two levels, or scales, of analysis: 1) household, and 2) community.

Econometric model

In both the household-level and community-level regressions, diversity indices are expressed as a function of vectors of farm household characteristics, farm physical features that vary among farms and districts, and market characteristics, including seed system factors. The reduced form equations estimated econometrically take the general form shown in equation (7). The definitions of the dependent variable, its form and range, have implications for the econometric technique applied. Dependent variables are defined next, followed by a summary of the regression method, the data, and independent variables.

Dependent variables

There are many ways to measure millet diversity at households and communities, none of which is inherently superior (Meng et al. 1998; Brock and Xepapadeas 2003). Both dependent variables used here are indices of richness. Richness is an intuitive concept drawn from the ecological literature about species diversity (Magurran, 1988), and it is has a straightforward interpretation in an econometric equation. The summary of dependent variable used in econometric analysis is given in Table 1.

The dependent variable in the household-level analysis is the count of individual millet crop varieties grown. A simple count does not control for the scale of measurement, however. In modeling an ecosystem or higher geographical scale of analysis than the single farm, spatial indices of diversity adapted from ecological literature are more appropriate. The Margalef richness index is a count of millet crop varieties grown in the community, normalized by the scale of the millet area. The Margalef index has a lower limit of zero if only one variety is grown. The Margalef richness index is constructed as (Magurran 1988):

$MD = (S-1) / LN(A)$ where $MD \geq 0$

MD = Millet diversity

A_i = Total area planted to millet crop varieties

S = Total number of millet crop varieties

Ordered Probit Analysis[4] *(Household Level)*

Poisson regression models are often used for count data that take non-negative integer values and where the outcome is zero for at least some members of the population (Woodridge 2002). Count data can alternatively be modeled using discrete choice methods surveyed in Maddala (1983). If most observed counts take values 0, 1, or 2, with few counts excess of 2, a standard discrete model such as a multinomial logit model could be used. Application of multinomial logit for count data may not be suitable if the outcome is naturally ordered. If there is order in occurrence of events, an ordered probit or logit is preferable.

Ordered discrete-choice models treat the data as generated by a continuous unobserved latent variable, which on crossing a threshold leads to an increase of one in the observed number of events. In theory, one should use an ordered model for data for which the data generating process is thought to be a continuous latent variable.

The process by which counts are assumed to arise decides the regression framework. One alternative that has been used in similar contexts is Poisson regression (Van Dusen 2000; Benin et al. 2004). The Poisson and negative binomial models treat discrete data as the result of an underlying point process, resulting from direct observation, considered to be stationary and homogeneous. By contrast, the ordered discrete-choice model treats the data generating process as a continuous one. That is, the count arises from the categorization of a latent continuous variable which on crossing a threshold leads to an increase of one in the observed events (Cameron and Trivedi 1998).

[4] Adapted from Prof. Glewwe's Lecture notes (APEC 8212 Econometric Analysis) and Greene (2000) pp. 875-878.

Ordered probit forms are often applied to a context where an agent such as an individual, household or decision maker chooses among a discrete set of alternatives (similar to random-utility models). The values or categories of such discrete variables can be naturally ordered such that larger values correspond to “higher” outcomes. We consider that this formulation generalizes the probit model of variety choice from a single to multiple decisions, also corresponding closely to a popular formulation in the variety choice literature, a Heckman-type decision to participate and conditional on that participation, a choice of area allocation.

In this application, higher numbers denote a higher level of richness in millet crop varieties grown at the household level, and the maximum number is five. STATA 8.1 software version was used to estimate the parameter β and the thresholds μ in the ordered probit model.

$$Y_n^* = x_n' \beta + \varepsilon_n$$

where Y^*_n = latent and continuous measure of millet richness faced by the household ‘n’ during the rainy season

x_n = a vector of explanatory variables describing household, farm, market and seed system characteristics

β= a vector of parameters to be estimated, and

ε_n = a random error term (follows normal distribution).

Thus the observed choice, Yn, is determined from the model as follows:

$Y_n = 0$ if $Y_n^* \le \mu_0$, (zero varieties grown)
$Y_n = 1$ if $\mu_0 \le Y_n^* \le \mu_1$, (only one variety grown)
……..
$Y_n = 5$ if $\mu_{5-1} \le Y_n^*$ (five varieties grown)

The parameter μ represents thresholds or cut off points to be estimated along with the parameter β. The probability that individual 'n' chooses alternative 'j' is easily derived as follows:

$$Prob(Y = 0) = \Phi(-\beta' x),$$
$$Prob(Y = 1) = (\mu_1 - \beta' x) - \Phi(-\beta' x),$$
$$\dots\dots\dots\dots$$
$$Prob(Y = 5) = 1 - \Phi(\mu_{5-1} - \beta' x)$$

$\Phi(.)$ is the cumulative standard normal distribution. The sign of the estimated parameters β can be directly interpreted because of the increasing nature of the ordered classes: a positive β indicates higher millet richness as the value of the associated variables increases, while negative signs suggest the converse. The ordered probit model can be estimated using maximum likelihood (ML). The log likelihood function is numerically maximized subject to $\mu_0 < \mu_1 < ... < \mu_{J-1}$. The maximum likelihood estimators β and μ are consistent and asymptotically efficient and accordingly, it is assumed that the error term also follows a normal distribution.

OLS Analysis (Community Level)

By construction, the Margalef index has a limit value at zero. As its expected value is not a linear function, using the OLS method would, in principle, yield biased estimates of β s in equation. Censored dependent variable or Tobit models are widely used to account for the qualitative difference between limit observations and nonlimit (continuous) observations. Nonetheless, at the community level, no zeros were observed, since this would imply that only one millet variety is grown. We estimated the community level regression with OLS, which is preferred for other statistical properties.

Data

The model is applied to data collected from personal interviews with farm households, seed experts, traders, dealers and seed company representatives during the period of October 2002 to May 2003, covering the rainy and post-rainy seasons. A self-weighting sample of 432 households was selected in 60 communities in 6 districts of Andhra Pradesh and Karnataka states. States and districts were purposively selected based on agroecological similarity and evidence of millet diversity. Details are provided in Nagarajan (2004) and Nagarajan and Smale (2005).

Varieties were identified by comparing names, descriptors, and seed samples with the results of previous genetic analyses. All crops and varieties are units that are identified by farmers and millet scientists as genetically and phenotypically distinct. Representative seed samples were then collected from a matured crop stand or threshing floor, seed storage structures, or seed stocks of farmers, and compared with descriptors used by the ICRISAT gene bank experts or seed companies, or those found in research reports (Prasada Rao, 1980; Gopal Reddy 1993, 1996).

Data are analyzed for the major rainy season. Survey findings confirm that there is a greater richness of millet crop varieties in this season relative to the post-rainy season, when farmers plant opportunistically, depending on moisture and local seed supplies. Farmers surveyed grew 18 different millet crop combinations and a total of 53 distinct modern and local varieties in the rainy season. A maximum of five varieties of millet crops were planted per household during this season, with an average of 7 per community. During the rainy season, households cultivated between one to five millet varieties. Nearly 30 percent planted only one millet variety. About half (46 percent) grew two varieties; 16 percent cultivated three, and around 8 percent of farmers planted four or more varieties.

Independent variables

The summary statistics of the dependent and independent variables are reported in Table 1. Definitions of independent variables, hypothesized effects are shown in Table 2. The comparative statics of the non-separable model are ambiguous, and dependent variables are metrics over optimal choices. Thus, hypotheses are based on findings reported in related literature rather than theory (Benin et al. 2004; Brush, Taylor and Bellon 1992; Meng 1997; Taylor 2004; Smale, Bellon and Aguirre 2000; Van Dusen 2000; Birol 2004, Gauchan 2004).

Household characteristics are averaged at the community level, including education, the gender composition of the household, wealth, and income. Education can enhance access to seed and related information, contributing to a wider array of crops and varieties, or may be associated with specialization in one crop or variety. Gender composition of the labor stock may affect millet diversity in the form of variety choices either indirectly, through wealth effects and access to inputs, or directly, through variety preferences, or both. In this farming system, livestock ownership measures both the demand for fodder and wealth. Low income families are hypothesized to prefer more crops and varieties, as a risk coping mechanism.

Farm characteristics are the total rainfed cultivated area, number of millet plots and the share of millet area under different soil types. Households depending more on rainfed lands are expected to rely more on the diversity of their millet crops. As the number of millet plots cultivated increases, farmers can accommodate more varieties of crops on different types of land. Millet crops are allocated depending on the fertility nature and the irrigation availability or moisture retention capacity of the soil. In the surveyed regions the millet crops are grown widely in less fertile black and red laterite soils. Fertile red loamy soils were found in very few communities. Pearl millet is cultivated widely in red loamy and laterite soils, while sorghum and minor millets are cultivated mainly in black and laterite soils.

Market characteristics included the length of the paved road in the village community, representing physical infrastructure, and levels of off-farm employment, reflecting labor market development. Poor market infrastructure is thought to induce dependence on a range of crops and varieties to meet household consumption needs; active labor markets may either draw labor out of complex crop production, or enable seed purchases.

Seed system parameters have not previously been tested in the related literature. This study tests the relationship of the distance to seed sources, seed replacement rate (historical), quantity of seeds traded (three year average), and seed-to-grain price ratios on millet diversity levels for the households and communities surveyed. No direction of effect of these variables is hypothesized a priori. However, each seed system variable used in the analysis has an economic interpretation or is used by the seed industry in analyzing the seed demand. District level fixed effects (dummy variables) control for the unmeasured attributes of the administrative region in which these communities are located (i.e., six districts across two states).

Results

Household level

Results of the ordered probit regressions explaining the richness of millet varieties grown per farm household are shown in Table 3. While household, farm, and market effects were all jointly significant, tests of individual hypotheses are most robust for the market characteristics, including the seed system factors previously omitted in similar analyses. Taken together, the effects of market characteristics are or greatest magnitude and statistical significance.

More educated decision makers maintained higher levels of millet richness on their farms, suggesting that access to information and ability to assimilate it is related to willingness and capacity to diversify millet production. Households with more livestock units also had more diversity, perhaps reflecting the importance of millet as fodder apart from food in these dry regions.

Farmers operating a larger share of red laterite soils maintained higher levels of diversity, perhaps reflecting the use of farmers' varieties on these poorer soils. In general, millet crops are more tolerant of abiotic stress than other crops. Consistent with other literature and the hypothesis of non-separability, farm households located in communities with lower road density relied on a richer set of millet varieties to meet their consumption needs. The extent of off-farm employment in the community is associated with greater richness at the household level, perhaps because it provides access to other materials grown or supplied elsewhere. The effect of exogenous income received at the household level is of no statistical significance, however.

The results also indicated that farmers who procured seed from distant sources also maintained higher levels of millet richness. There are two explanations for this finding. First, distance is associated with procurement of improved open-pollinated varieties and hybrids of sorghum and pearl millet. These millet types are available only through formal channels which are most often found in district head quarters, far away from villages. Second, consistent with the non-separability hypothesis, distance from such sources means that farmers must rely more frequently on their own seed, which typically constitute a range of local farmers' varieties. High rates of seed replacement in communities over time imply higher levels of richness on individual farms.

Farmers located in the districts of Bellary district maintained higher levels of millet diversity in their farms relative to the farms in Dharwad district, the omitted district. In this district, farmers often combined the production of sorghum and pearl millet (major millets) with cultivation of finger, foxtail or little millet (termed minor) during the rainy season.

Community level

The results of the OLS analysis to determine the factors influencing millet biodiversity at the community level are reported in Table 4. Higher income farm communities in the semi-arid regions of Andhra Pradesh and Karnataka maintained greater richness of millet varieties across their farms, perhaps because of greater access to materials and capacity to grow them. More livestock ownership in these communities appears to be associated with less richness in millet varieties, suggesting specialization in certain varieties to satisfy specific needs such as food and fodder.

Among the market characteristics, village communities with developed physical (road) infrastructure facilities maintained lower levels of millet diversity, as hypothesized. The availability of off-farm employment in the village communities increased the diversity of millet varieties. Probably off-farm income can release the cash income constraint faced by some farmers, enabling them to shift their focus from growing varieties for sale to growing the varieties they may prefer to consume. The distance traveled varies with crop improvement status – in general farmers traveled longer distances to procure hybrids and other improved varieties especially during the major crop season – namely rainy season. Higher seed-to-grain price ratios also enhanced millet richness among communities probably due to the presence and frequent use of modern varieties in these communities. The presence of formal seed transactions through dealers also improved the millet variety diversity among the communities surveyed, providing farmers with a range of varieties over time. District level effects were significant, but had negative influence on overall variety richness for almost all the farm communities located in these districts relative to the omitted communities in Dharwad district.

Joint tests of hypotheses suggest that at the community level, farm level characteristics were not statistically significant. As in the household level regressions, market characteristics, and in particular seed system factors, are of greatest statistical significance.

Conclusions

The purpose of the research paper was to characterize biological diversity related to millets in the semi-arid regions of India at various spatial scales of analysis (e.g., farm household versus community levels) and place that evidence in a broader seed systems (includes both formal and informal) context. Two methodological issues motivated this aspect of the research. Most applied economics studies of the incentives for maintaining biological diversity in situ have used household as the unit of observation. However, in many cases, the smallest social unit for conservation programs is more likely to be a community. The household analysis involved a point-in-time analysis of the extent and determinants of millet diversity using farms as the unit of analysis. Whereas here we take a more aggregate perspective on biodiversity measured at the community level. While the factors investigated at the households in part account for within-farm patterns of varietal choice, these same factors, may operate among farms in ways that generate a different pattern of millet diversity at the spatial scale of a community.

Farmer and community access to the genetic resources embodied in seed is affected by the extent to which seed is traded on markets or through other institutional mechanisms, as well as by related legal frameworks, national and international agreements. Markets are a component of seed systems, transmitting value through consumers' willingness to pay, including both consumers of seed (farmers) and consumers of products. These seed systems and the population genetics of crop varieties are often better modeled at a higher level of aggregation than the household. Hence this research is an initial exploration into the relationship between seed systems and other development-related factors and the levels of crop biological diversity at two different spatial scales namely households and communities.

A farm household model framework was employed to analyze the millet crop and variety choices of households in a semi-arid, subsistence environment. This model provided the conceptual basis for the reduced-form, econometric estimation of millet crop and variety diversity both at the household and community level. The econometric analyses were aimed at identifying and quantifying the extent to which the physical and household attributes of farms interact with seed market-related factors that affect farmer choices concerning millet diversity on farms.

Ordered Probit and OLS regressions were used to determine the total millet richness (using varietal counts and area shares) among households and village communities. Seed system characteristics were found to be important determinants of both household and community-level millet biodiversity, in addition to the farm, household, and market factors identified in the previous literature studies. We also recorded a modest rate of varietal turnover and varietal diversity for millets grown in the rainy season (albeit still a marginal agricultural environment by any measure). Notably, the season most intensively using commercially bred varieties is the one with the more diverse varietal use.

An important finding of this research is that producer access to millet genetic resources is affected by the extent to which seed is traded via formal markets or through other social institutions, along with farm and household characteristics. By judicious introduction of improved varieties that complement farmers' cultivars by providing a needed trait, it may be feasible to enhance farmer income while maintaining the extent of millet biodiversity that is useful for the resilience of the farming system in these marginal environments. Another important concept that emerges from this research is the degree of market imperfections and its measurement at different spatial scales. In the marketing literature, the concept and indicators of thinness have been widely researched. Whereas in farm household and community level analysis still there is need for a more precise definition and an empirical estimation of the same. For e.g. in the case of household analysis the markets which are 'shallow' for millets are viewed as 'thin' at the level of community analysis.

Findings from this research also underscore the importance of an enhanced theoretical understanding of local seed markets in analyzing crop variety choices and the diversity of materials grown in less favored environments. A more fully developed conceptual framework for analyzing the role of seed markets and related interventions in managing local crop biodiversity is envisaged as the future extension of this research.

References

Benin, S, B., M. Smale, Gebremedhin, J. Pender, and Ehui, S. The economic determinants of cereal crop diversity on farms in the Ethiopian highlands. *Agricultural Economics, Volume 31, Issues 2-3, December 2004, Pages 197-208.*

Birol, E. 2004. Valuing agricultural biodiversity on home gardens in Hungary: An application of stated and revealed preference methods, PhD Thesis, University College London, University of London, UK.

Brock A.W. and A. Xepapadeas. 2003. Valuing Biodiversity from an Economic Perspective: A Unified Economic, Ecological, and Genetic Approach. *The American Economic Review* Vol. 93, No. 5, December 2003.

Brush, S.B., Taylor, J.E. and Bellon, M.R. 1992. Biological diversity and technology adoption in Andean potato agriculture. *Journal of Development Economics* 38: 365-387.

Cameron, A. C., and P.K.Trivedi. 1998. Regression analysis of count data. Cambridge, UK: Cambridge University Press.

de Janvry, Alain, Gustavo Gordillo de Anda, and Elisabeth Sadoulet. 1997. Mexico's Second Agrarian Reform: Household and Community Responses. Center for U.S.-Mexico Studies, University of California, San Diego, La Jolla.

de Janvry, A., Fafchamps, M., and Sadoulet, E. 1991. Peasant household behavior with missing markets: Some paradoxes explained. *Economic Journal* 101: 1400-1417.

Di Falco S. 2003. Crop Genetic Diversity, Agro ecosystem Production and the Stability of Farm Income. Ph.D. dissertation, Environment Department University of York, UK.

Feder, G. and D.L.Umali. 1993. The Adoption of Agricultural Innovations- a Review. *Technological Forecasting and Social Change* 43, no.3-4: 215-239.

Feder, Gershon, Richard E.Just, and David Zilberman. 1985. Adoption of Agricultural Innovations in Developing Countries: A Survey. *Economic Development and Cultural Change* 33, no.2: 255-298

Gauchan, D. 2004. Conserving Crop Genetic Resources On-Farm : The Case of Rice in Nepal. PhD dissertation, University of Birmingham.

Glewwe, P. 2004. Lecture notes of the course on Econometric Analysis – II (ApEc 8212), Department of Applied and Agricultural Economics, University of Minnesota, USA.

Gopal Reddy, V., and V.D.Sharma.1996.Rabi Sorghum Germplasm Collection in Maharastra and Adjoining Areas of Karnataka. Genetic Resources Progress Report-85. A Joint Collection Mission by ICRISAT Asia Center and NBPGR (ICAR). January-February 1996, ICRISAT, India.

Gopal Reddy, V., P.N.Mathur, K.E.Prasada Rao and M.H.Mengesha. 1993. Rabi Sorghum Germplasm Collection in Northern Karnataka and Adjoining Areas of Andhra Pradesh. Genetic Resources Report - 74, ICRISAT, India.

Greene, W.H., 2000.Econometric Analysis. New Jersey, USA: Prentice-Hall, Inc.

Hartell J, M. Smale, P.W. Heisey and B. Senauer.1998.The contribution of genetic resources and diversity to wheat productivity in the Punjab of Pakistan, in M. Smale eds., *Farmers, Gene Banks, and Crop Breeding*,Boston: Kluwer.

Hayenga, M.L. 1979. Pricing Problems in the Food Industry (With Emphasis on Thin Markets). N. Cent.-117 Monograph No. 7, 1979.

Maddala, G.S. 1983. Limited dependent and qualitative variables in econometrics. New York, USA: Cambridge University Press.

Magurran, A., 1988. Ecological diversity and its measurement. Princeton, NJ, USA: Princeton University Press.

Meng, E. C. H. 1997. Land allocation decisions and *in situ* conservation of crop genetic resources: The case of wheat landraces in Turkey. Ph.D. dissertation, Davis, California, USA: University of California.

Meng, E. C. H., M. Smale, S. D. Rozelle, R. Hu, and J. Huang. 2003. Wheat genetic diversity in China: measurement and cost. In S. D. Rozelle, and D. A. Sumner (ed.) *Agricultural trade and policy in China: issues, analysis and implications*, 251-267. Burlington ,Vermont, USA: Ashgate.

Meng, E.C.H, Taylor, J.E., and Brush, S.B. 1998. Implications for the conservation of wheat landraces in Turkey from a household model of varietal choice. In M. Smale (ed.), *Farmers, Gene Banks and Crop Breeding: Economic Analyses of Diversity in Wheat, Maize, and Rice*, pp. 127-143, Kluwer Academic Press and CIMMYT, Dordrecht and Mexico, D.F.

Morris, M.L., Rusike, J., and Smale, M. 1998. *Maize seed industries: A conceptual framework.* In M. Morris (ed.), *Maize Seed Industries in Developing Countries*, Lynne Rienner and CIMMYT, Boulder and Mexico, D.F.

Morris, M.L.,1998. 'Thailand' in M. Morris (Ed) *Maize Seed Industries in Developing Countries.*Boulder, CO: Lynne Rienner and CIMMYT, Boulder and Mexico, D.F.

Nagarajan, L. 2004. Managing Millet Diversity: Farmers' choices, seed systems and genetic resource policy in India. PhD dissertation, Department of Applied and Agricultural Economics, University of Minnesota, St.Paul, USA. December 2004.

Nagarajan, L. and M.Smale. 2005. Local Seed Systems and Village-Level Determinants of Millet Crop Diversity in Marginal Environments of India . Joint Publication of

IFPRI/ICRISAT/FAO Forthcoming Discussion Paper at EPT Division, IFPRI, Washington, D.C.

Prasada Rao, K.E., and V.Gopal Reddy. 1980. Kharif Sorghum Germplasm Collection in Karnataka and Adjoining Areas. Genetic Resources Progress Report 29. ICRISAT, India.

de Janvry, Alain, Elisabeth Sadoulet, and Benjamin Davis. "Ejido Sector Reforms: From Land Reform to Rural Development". In Laura Randall, ed., *Reforming Mexico's Agrarian Reform*, Armonk, New York: M.E. Sharpe, 1996.

Singh, I., L. Squire, and J. Strauss (ed.). 1986. *Agricultural Household Models: Extensions, Applications, and Policy*. The World Bank and Johns Hopkins University Press, Washington, D.C., and Baltimore.

Smale, M., Bellon, M.R. and Aguirre Gómez, J.A. (2001) Maize diversity, variety attributes, and farmers' choices in Southeastern Guanajuato, Mexico. *Economic Development and Cultural Change* 1, 201-225.

Taylor, E. and I. Adelman. 2003. Agricultural Household Models: Genesis, Evolution and Extensions. *Review of the Economics of the Household*. Vol 1, No. 1 (2003).

Tripp, R. 2000. Seed Provision and Agricultural Development: The Institutions of Rural Change. Overseas Development Institute, London, James Currey, Oxford, and Heinemann, Portsmouth (N.H).

Van Dusen, E. 2000. In Situ Conservation of Crop Genetic Resources in Mexican Milpa Systems. PhD Thesis. University of California, Davis, USA.

Widawsky, D., and S. Rozelle. Varietal Diversity and Yield Variability in Chinese Rice Production, in M. Smale ed., *Farmers, Gene Banks, and Crop Breeding*, Kluwer, Boston, 1998 pp.159-187

Wooldridge, J.M. 2002. Econometric Analysis of cross section and panel data. Cambridge, MA,USA: Massachusetts Institute of Technology.

Table 1 *Summary statistics of dependent and independent variables*

Variables	Mean	StdDev	Min	Max
Dependent variable				
Varietal counts - Households	1.94	1.04	0	5
Margalef Index - Community	2.78	0.90	1.3	5.2
Independent variables				
Proportion of adult males in the family	45.9	15.4	25.0	100.0
Years of schooling of production decision maker (No.)	3.7	3.5	0.0	12.0
Expenditure of the family (Rs.)	2361	1188	755	5715
Livestock units (No.)	6.0	3.6	0.0	21.7
Rain fed area owned by the households (Ha)	5.0	5.9	0.0	40.0
Share of the red soil	0.3	0.1	0.0	0.7
Share of the black soil	0.4	0.2	0.1	0.9
Share of red laterite soil	0.2	0.1	0.0	0.7
Number of millet plots	3.0	1.6	0.0	7.0
Length of paved road in the village communities(Kms)	3.0	0.9	1.2	5.2
Months off-farm employment per household	1.7	2.0	0.0	7.7
Distance to nearest seed sources (Kms)	7.2	2.8	0.0	17.3
Seed replacement rate	5.1	2.4	0.0	10.6
Seed-to-grain price ratio	4.1	3.0	0.0	17.2
Quantity of seed traded through dealers	206.3	455.7	0.0	1600.0

Source: Field survey conducted in 2002-2003 (Nagarajan 2004). n=a total of 432 households.

Table 2 *Definition of explanatory variables and hypothesis*

Variable name	**Definition**	**Sign**
Household characteristics		
Gender composition of farm labor	Ratio of total adult men to total adults engaged in farming	**(+,-)**
Education	Years of school attended by production decision maker (years)	**(+,-)**
Income	Annual cash expenditures (Rs.) per household in year preceding survey	**(-)**
Livestock owned	Number of bullocks, buffaloes and cows owned in 2002	**(+,-)**
Farm characteristics		
Rainfed area	Total rain fed area (in ha.)	**(+,-)**
Millet plots	Number of millet plots cultivated per household	**(+,-)**
Area share	Proportion of area under red and red laterite soils for each millet crop	
Market and seed system characteristics[a]		
Road density	Km of structured (all weather) road per community (Kms)	**(-)**
Off-farm employment	Months worked off-farm by all adults (aged more than 15)	**(+,-)**
Distance to seed source	Kms from the farm gate to nearest source of millet varieties	**(+)**
Seed replacement rate	Number of times the seed of a variety planted in the survey season has been replaced since first sowing, averaged over all millet varieties	**(+,-)**
Seed-to-grain price ratio	Ratio of seed price to grain price for crop variety	**(+,-)**
Quantity of seed traded	3-year average kg of millet seeds sold by dealers or traded in shandies (2000-2002)	**(+,-)**
District fixed effects[b]		
Location in Bijapur District	Dummy variable =1 if community located in Bijapur, else 0	**(+,-)**
Location in Bellary District	Dummy variable =1 if community located in Bellary , else 0	**(+,-)**
Location in Chitradurga District	Dummy variable =1 if community located in Chitradurga else 0	**(+,-)**
Location in Belgaum District	Dummy variable =1 if community located in Belgaum, else 0	**(+,-)**
Location in Mahabubnagar District	Dummy variable =1 if community located in Mahabubnagar, else 0	**(+,-)**

Note: [a] Market and seed system characteristics are measured at the level of communities.
[b]In the regression analysis, district level fixed effects were analyzed with respect to the omitted communities in the Dharwad district.

Table 3 *Determinants of household level richness in millet varieties*

	Coefficient	**Z-Value**	**P>Z**
Household characteristics			
Gender composition of farm labor (%)	0.0010	0.29	
Education of household head (Years)	-0.0396	-2.53	**
Income (Rs.)	0.0001	0.93	
Livestock units owned (No.)	0.0384	2.11	*
Farm Characteristics			
Rainfed area (ha)	0.0071	0.67	
Millet plots (No.)	-0.5484	-0.86	
Area share in red soil type	0.2754	0.52	
Area share in laterite soil type	0.4286	10.58	***
Market and seed system characteristics			
Road density (Kms)	-0.2304	-2.43	**
Off-farm employment (months)	0.1198	3.29	***
Distance to seed source (Kms)	0.0884	2.93	**
Seed replacement rate	0.0980	3.23	***
Seed-to-grain price ratio	-0.0206	-0.87	
Quantity of seed traded through dealers (kg.)	0.0001	0.60	
Location Characteristics			
Location in Bijapur district	-0.3105	-0.67	
Location in Bellary district	1.1917	3.65	***
Location in Chitradurga district	0.1302	0.36	
Location in Belgaum district	0.4354	1.21	
Location in Mahabubnagar district	-0.2097	-0.55	
Equation statistics			
Number of observations	396		
LR Chi^2 (18)	243.1		
Prob > Chi^2	0.0000		
Pseudo R^2	0.197		
Log Likelihood ratio	-495.5808		
Coefficient of threshold variable 1	0.4227		
Coefficient of threshold variable 2	1.6162		
Coefficient of threshold variable 3	3.1976		
Coefficient of threshold variable 4	4.2555		
Coefficient of threshold variable 5	5.4362		
Joint tests of hypothesis (Likelihood ratio tests)		***LR***	***P>Chi²***
Household effects	λ (4,.05)	12.74	*
Farm effects	λ (4,.05)	120.42	***
Market effects	λ (5,.05)	44.91	***
Seed system effects alone	λ (3,.05)	25.16	***
District fixed effects [a]	λ (5,.05)	44.05	***

Note: (*) denotes 10 percent, (**) 5 percent and (***) 1 percent significant levels.

[a] The omitted district is Dharwad.

Table 4 *Determinants of community-level richness in millet varieties*

	Coefficient	T -Value	P > T
Household characteristics[a]			
Gender composition of farm labor (%)	-0.0090	-0.48	
Education (%)	0.0129	1.09	
Income (Rs.)	0.0006	2.15	**
Livestock units owned (No.)	-0.1474	-1.63	*
Farm Characteristics			
Rainfed area (ha)	-0.0020	-0.04	
Millet plots (No.)	0.7154	0.59	
Area share in red soil type	-1.1307	-1.11	
Area share in laterite soil type	-0.1011	-0.69	
Market and seed system characteristics			
Road density (Kms)	-0.3332	-2.02	**
Off-farm employment (months)	0.1936	1.79	*
Distance to seed source (Kms)	0.1227	2.22	***
Seed replacement rate	-0.0458	-0.76	
Seed-to-grain price ratio	0.1200	2.55	***
Seed traded through dealers (Kg)	0.0004	1.53	*
Location Characteristics			
Location in Bijapur district	-5.1589	-3.78	***
Location in Bellary district	-2.4318	-3.01	***
Location in Chitradurga district	-2.9799	-3.31	***
Location in Belgaum district	-3.3688	-3.72	***
Location in Mahabubnagar district	-3.1973	-2.59	***
Equation statistics			
Number of observations	58		
F(19,38)	3.03		
Prob > F	0.0018		
R Squared	0.6027		
Adj. R squared	0.404		
Root MSE	0.69104		
Joint tests of hypothesis (Likelihood ratio tests)		***LR***	***P>Chi***^{2}
Household effects	λ (4,.05)	13.80	**
Farm effects	λ (4,.05)	5.28	
Market effects	λ (5,.05)	19.97	***
Seed system effects alone	λ (3,.05)	14.70	**
District fixed effects [a]	λ (5,.05)	24.26	***

Note: n=58 communities/ OLS regressions. Marginal effects are partial derivatives of expected value, computed at the means of variables. (*) denotes 10, (**) 5, and (***) 1 percent significant levels. The omitted district here refers to Dharwad. [a] The household characteristics were calculated across households in the community. For e.g. Education refers to the proportion of adult literates across the households in the community.