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Local Seed Systems and Village-Level Determinants of Millet Crop Diversity in Marginal Environments of India

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ABSTRACT

In the subsistence-oriented, semi-arid production systems of Andhra Pradesh and Karnataka, India, the environment is marginal for crop growth and often there is no substitute for millet crops. Across communities, farmers grow thirteen different combinations of pearl millet, sorghum, finger millet, little millet, and foxtail millet varieties, but individual farmers grow an average of only two to three millet varieties per season. The notion of the seed system includes all channels through which farmers acquire genetic materials, outside or in interaction with the commercial seed industry. Data are compiled through household surveys and interviews with traders and dealers in village and district markets. Based on the concept of the seed lot, several characteristics of local seed markets are defined and measured by millet crop, including seed transfer rates for farmer-to-farmer transactions and seed replacement ratios. Most seed transactions appear to be based on money. Seed supply channels differ by improvement status of the genetic material. Econometric results indicate the significance of the seed replacement ratios and seed volumes traded in determining the levels of crop biodiversity managed by communities, in addition to the household, farm and other market-related factors identified by previous studies. These are interpreted as indicators of market strength.

Keywords: seed systems, millet diversity, variety change, seed users

GLOSSARY OF TERMS

ancestral variety	farmer variety for which farming communities or individual farmers have saved seed for generations
farmer variety	variety bred/selected by farmers
formal seed supply channel	a channel that transmits planting material developed by professional plant breeders
FV	farmer variety
HYB	hybrid
improved variety	variety improved by professional plant breeders
informal seed supply channel	a channel that transmits planting material developed by farmers or previously developed, saved, and transferred by farmers. Typically, although not always, involves non-market transactions. One counterexample is a *shandy.*
IOPV	improved open-pollinated variety
IPLS	improved pureline selection, from a farmer variety
Kharif	the cool, rainy season, (mid-July to the end of October)
market seed transaction	a seed transaction that occurs in a marketplace, generally between anonymous actors
mixed variety	a variety for which seed lots of improved varieties and farmer varieties have been mixed
non-market seed transaction	a seed transaction that occurs outside a marketplace, generally a mode of transaction that involves less anonymity
Panchayat	literally, a "village community," or cluster of villages; an administrative designation
Rabi	the post-rainy season (December to March).
seed lot	physical unit of seed the farmer uses to reproduce a variety
seed replacement rate	no. of times a farmer has replaced the seed of the same named variety divided by the number of years the farmer has grown the variety
seed transaction locus	distance to seed transactions
seed transaction mode	social relationship and means of exchange of those involved in seed transaction of exchange
seed transfer rate	no. of times a farmer has transferred the seed of a given variety of a crop to another farmer divided by the number of years the farmer has grown the variety
seed-to-grain price ratio	ratio of seed price to grain price for crop variety
shandy	a weekly local market
variety age	no. of years farmer has grown the same named variety

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Local Seed Systems and Village-Level Determinants of Millet Crop Diversity in Marginal Environments of India

Latha Nagarajan[1] and Melinda Smale[2]

1. INTRODUCTION

SEED SYSTEM DEFINITION AND IMPORTANCE

Typically, the notion of a seed system in economics has been limited to the "formal" seed industry for developing, multiplying, and distributing finished varieties as certified seed, which can be publicly and privately-funded, and organized in different ways. For example, maize seed industries are thought to develop along a path from pre-industrial organization to the maturity stage, characterized by entirely commercial organization with plant variety protection, patents, and various financing arrangements (Morris et al. 1998). The notion of an "informal" seed system is documented extensively by other anthropologists, ethnobotanists and geographers. Most often, the informal system is treated separately by economists as vestigial or marginal to the process of economic development (Zimmerer 2003; Thiele 1999; Sperling, Loevinsohn, 1993; Almekinders, Louwaars and de Bruijn 1994).

A well-functioning seed system is defined as one that uses the appropriate combination of formal and informal supply channels, market and non-market transactions to stimulate and meet efficiently the evolving demand of farmers for quality seeds (Maredia et al. 1999). In some cases, the planting material of varieties demanded has

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been saved and selected for many generations on local farms (farmer varieties, ancestral varieties). In others, farmers procure planting material on local markets or from other farmers that was initially developed far away by professional plant breeders (such as hybrids and improved open-pollinated varieties). Farmer seed selection may include mass selection practices or farmer breeding. Farmers in marginal environment often save and replant hybrid seed and the seed of other commercial varieties.

Markets are a component of planting material[3] systems, transmitting value through consumers' willingness to pay. Farmers consume planting material as production inputs and in semi-subsistence agriculture, they also consume the harvest. When product markets are incomplete, the demand for planting material is derived from the agricultural household's demand for both consumption attributes and agronomic traits that suit the technology and physical features of the farm (Edmeades et al. 2004). In semi-subsistence agriculture, purchases of improved seed may be periodic, and most of the seed is reproduced from the harvests of the previous seasons or the stocks maintained by community members, who may or may not trade seed with other communities, according to local norms.

Understanding systems for planting material is crucial for managing crop biodiversity on farm in locations where it is believed to be of both private value to farmers and social significance for future crop improvement and the resilience of the farming system. Though the physical unit of seed that reproduces a crop is a private good, the diversity of the genetic resources embodied in it is a public good (Morris et al. 1998; Heisey et al. 1997; Smale 2005). Seed systems convey incentives for farmers to grow one crop variety rather than another, or to grow a number of crops and varieties

[3] Planting material is seed, in a broad sense.

rather than one. Farmer and community access to the genetic resources embodied in seed is affected by the extent to which it is traded on markets or through other social institutions, as well as by related norms and legal frameworks, national and international agreements.

This study relates village seed systems to biological diversity of millet crops grown by farmers in the semi-arid lands of Andhra Pradesh and Karnataka, India. "Crop biodiversity" refers to both genotypic and phenotypic variation, as recognized by either farmers or professional plant breeders. The research presented here is part of a larger project whose purpose is to provide practical information to those involved in millet breeding programs or who formulate seed policies. To design local seed market interventions in less favored environments, such as targeted plant breeding or seed system relief, understanding the structural features of both formal and informal systems for seed of varying crop reproductive systems and improvement status is fundamental (Sperling et al. 2005).

This paper is one in a set of three[4]. The second paper compares farm-level and village determinants of millet biodiversity. The third paper explores the formal seed industry and genetic resources policy environment, building on the baseline data presented in the first two papers. Given the difficulty in anchoring the concepts to existing theoretical and conceptual frameworks for seed systems, the research is still at an exploratory stage. Terminology, some of which has been developed or adapted specifically for use in seed system analysis, is defined in the glossary.

[4] The other Discussion Papers are L. Nagarajan, M. Smale and P. Glewwe, "Local seed systems and Farm-level Determinants of Millet Crop Diversity in Marginal Environments of India," and L. Nagarajan and P. Pardey and M.Smale,"Local Seed Systems in Marginal Environments of India: Industry and Policy Perspectives."

MILLET CROPS AS A CASE STUDY

In the semi-arid and arid lands of India, farmers depend on millet crops (including sorghum, pearl millet, finger millet, foxtail and little millet). India is a major world producer of millet crops, ranking first in terms of pearl millet production and second in terms of world sorghum production after the United States. Millet crops constitute 15 percent of the total cereal grain production in India, although their relative importance differs markedly by state. An estimated 95 percent of the millet produced in India comes from rainfed or dry land production systems (AGROSTAT 2002-03). Poor households in these areas consume most of this production as food, feed, or fodder, or market their surplus locally.

In more favored growing environments of India (such as the states of Punjab, Maharastra, Haryana), where farmers have access to irrigation and rising incomes are changing food consumption patterns, the area sown to sorghum and other millet crops is gradually giving way to rice, wheat, maize and other specialty crops (Seetharam, Riley, and Harinarayana 1989). Nonetheless, farmer demand for a range of millet crop varieties is unlikely to diminish soon in the arid and semi-arid regions (including the states of Karnataka, Andhra Pradesh, Rajasthan and Gujarat) because there are currently few substitute crops in these harsh growing environments. Seed supply channels and the extent of crop improvement differ markedly among millet crops.

Evenson and Gollin (2003) maintain that crop improvements have been less pronounced for millet crops than for rice and wheat in India, in part because of research investments and lesser economic importance of some millet crops, and in part because of the environments where they are grown. There has been some progress in terms of yield and area expansion, especially under pearl millet and sorghum. In 2002 about 60 percent

of the area under pearl millet hybrids and nearly 40 percent of the area under sorghum hybrids was planted to germplasm developed by the International Crops Research Institute for Semi-arid Tropics (ICRISAT) [5] materials (Bantilan and Deb 2002). More than 50 private companies market approximately 75 hybrids of pearl millet, and nearly 11 companies market 20 hybrids of sorghum, many based on seed and pollen parents from ICRISAT. Some research effort by professional plant breeders is evident for finger millet, in the form of pure-line selections from farmer's varieties. By contrast, farmers' varieties of foxtail and little millet appear to be largely managed as a pool, with few distinguishing characteristics (grain color and texture).

The next section summarizes the research design for this study. Section III presents a characterization of the village seed system for millet crops in the study sites, beginning with the taxonomy of millet crops and varieties grown by farmers. Concepts and definitions are proposed. In Section IV, variation among villages in the biological diversity of millet crops is explained with an econometric model, drawing hypotheses from the related literature, and incorporating parameters developed in Section III. Implications are drawn in the concluding section.

2. METHODS

RESEARCH DESIGN

Economic analyses of incentives for biodiversity conservation on farms have been based largely on models of decision-making by agricultural households, applied with

[5] ICRISAT (International Crops Research Institute for Semi-Arid Tropics) is one of the international agricultural research centers, established in the year 1972 at Hyderabad, India to focus research on the arid and semi-arid regions of the world. The mandate crops of ICRISAT consist of sorghum, pearl millet, finger millet, groundnut and pulse crops.

econometrics to household survey data (Brush, Taylor, and Bellon, 1992; Van Dusen and Taylor, forthcoming**;** Meng 1997; Smale, Bellon and Aguirre 2001; studies compiled in Smale 2005). Market studies are often compiled from secondary data. Neither household surveys nor secondary data are sufficient for analyzing seed systems as we have defined them, for several reasons (see Van Dusen 2003).

On one hand, the data collected from farm households reveals how individual farmers exchange seed and products but lead to few conclusions about supply channels and the role of other institutions that affect exchange. On the other, secondary data typically are not disaggregated by variety, and even when they are, names are likely to be inconclusive regarding farmer-managed units of biological diversity. The timing of seed exchange is particularly seasonal for farmers' varieties (just before planting), and may also occur in limited geographical areas (a few farmers; a few villages). Often there is no recognition of volumes traded because they are so minimal. In some cases, planting material and product are also indistinguishable—particularly after poor harvests, when farmers may purchase seed from food grain if they are unable to find quality seed through other sources. Finally, those who participate in informal systems, even in local markets, may not generally describe themselves as "traders" by occupation, or may not engage in trading full-time. The nature of the transaction may include barter or exchange without cash.

To address these limitations, this research combined: 1) a sample survey of households based on a structured questionnaire; 2) key informant surveys with farmer seed experts, seed dealers/distributors and grain traders based on a semi-structured questionnaire; 3) checklist interviews conducted with traders in weekly, village markets

("shandy"); 4) and interviews with representatives of private seed companies. Survey data was collected between October of 2002 and June of 2003, spanning the cool, rainy season (*Kharif*, lasting mid-July to the end of October) and the post-rainy season (*Rabi*, from December to March).

The domain was purposively selected to represent major areas of production for a number of millet crops in a semi-arid environment, including some improved varieties as well as a range of farmers' varieties. Within the states of Andhra Pradesh and Karnataka, historical data on millet acreage and production, supported by expert consultation and documentation[6], enabled the selection of 6 districts: Mahabubnagar (Andhra Pradesh), Bijapur, Bellary, Chitradurga, Belgaum, Dharwad (Karnataka). Within the 6 districts, 17 (out of 61) *Taluks* (the next lower administrative unit) were selected based on the same criteria. Within *taluks,* millet-growing *panchayats* were ordered on a distance gradient from the major market center (from a minimum of 1 km to 42 km), and 60 were selected (out of 223) based on the same criteria and representing each point in the gradient. A *panchayat* (literally, a village community) represents a set of contiguous villages. *Taluks* and *panchayats* were grouped to form roughly equal population sizes to ensure similar probabilities of selection for sample households.

From a list compiled and reviewed with *panchayat* officials, all millet-growing villages (75 out of 345 villages) were selected. All households in villages were listed with the assistance of Assistant Agricultural Officers from the *panchayat* and each was assigned a consecutive number. Households were selected using a random number table

[6] Personal communication with Dr. A. Seetharam, All India Co-ordinated research on Small Millets, UAS Bangalore; Dr. K.N.Roy and Mr.Gopal Reddy, Scientists, ICRISAT and Prof. Naik, Millet Breeder, UAS Dharwad; Rabi Sorghum Germplasm Collection in Northern Karnataka and Adjoining areas of Andhra Pradesh, Genetic Resources Progress Report -74 &85, ICRISAT; Rainy Sorghum Germplasm Collections in Karnataka and Adjoining Areas, Genetic Resources Progress Report -29, ICRISAT

with a constant sampling fraction of 9 – 10 per cent, ranging from 1 to 11 households per village. The self-weighting sample consists of 432 households, with an overall sampling fraction of 0.75 percent. Of the 432 households surveyed, one fourth (108) of the sample was drawn from one district in the state of Andhra Pradesh and the remaining households were selected from five districts in the state of Karnataka.

A set of structured survey instruments were developed and pre-tested, including: a) general household information about size and composition, income sources, assets, and expenditures b) area and plot characteristics for millet crops grown in each season; c) general information on crops grown and for variety-specific data for millet crops, including subjective yield estimates, assessments of other attributes, and seed management practices. Seed management questions elicited information to quantify the direction, frequency and nature of farmer transactions in formal and informal channels.

The seed system instruments recorded the volumes, prices and frequencies of seed and grain transactions from the community to the industry level for dealers, local market (shandy) traders, and farmer seed experts. Local seed experts were identified from each of the 60 *panchayats* included in the domain through key informants. A semi-structured questionnaire elicited information about the nature of their involvement in seed channels during good and bad cropping seasons, why they are considered to be experts, and their social and economic characteristics.

Seed distributors and dealers are located either in the district headquarters or in the commercial towns, and are the major source of information about the seed of modern varieties. The seed distributors are often few, specializing in varieties from specific firms, serving as a conduit between the firms and the input dealers and facilitate the marketing

of seeds through a vast network of dealers in the district level. Twenty-nine dealers, representing 10-12 percent of all millet seed dealers in each of the 6 district headquarters, were selected at random to represent 8 to 10 percent of traders who sold commercial varieties of millets along with other crop seeds. The dealers at the district level normally handled more than 1 mt of millet seeds, depending on their area of operation and the existing demand different millet varieties. Only in Bijapur district of Karnataka state was the demand for pearl millet substantial, although all the dealers sampled also sold other kinds of millet crops such as sorghum and improved pure line selections of finger millet.

Shandies are weekly markets in cater specifically to local seed demand in. Shandies operate weekly at various places, typically with a group of 5-6 villages, covering the radius of 10 to 15 Kms. For logistical reasons, it was not possible to cover all shandies simultaneously and a total of 25 were selected arbitrarily. Seed flows are thin in shandies and often those who engage in transactions do not differentiate between seed and food grain, or between seed types. Participants were interviewed in groups, and asked to estimate the frequency of transactions and seed volumes, prices and the quality of material transacted.

Both farmer and scientist taxonomies were employed to assess the extent of biological diversity in millet crops. Farmers were asked to identify each variety grown by name for each millet crop and then describe its distinguishing characteristics (grain color, shape and size; plant height; maturity and shape of spikelets). 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)[7].

The resulting taxonomy of distinct varieties, and their improvement status, served as the basis of the seed system parameters and diversity indices analyzed in this paper. Units of observation and analysis include: seed lots; varieties; household farms; dealers; local traders; farmer seed suppliers; villages; and village communities (*panchayats*).

3. LOCAL SEED SYSTEM CHARACTERISTICS

SEED USERS

The characteristics of farm households who use millet seed are shown in Appendix Table 1. In this dry environment, on average, nearly 75 percent of the total cultivable area owned per household is rainfed, which explains the preference for more drought tolerant crops in the states selected for study. Millet crops represent about half of the area they cultivate, and on the remaining lands, households grow peanut (25 percent), cotton and maize (10-12 percent), followed by other legume crops and rice. An average of 32 percent of millet area is irrigated per farm in Andhra Pradesh, as compared to 15 percent per farm in Karnataka.

Household incomes are much higher in Andhra Pradesh than in Karnataka, as measured by average annual cash expenditures (Rs. 3400 vs. Rs. 2012). The average value of livestock assets owned by households in Karnataka is almost half that of Andhra Pradesh, where farming communities belong to a nomadic tribal community (*Banjara*) whose major occupation is livestock production. Demographic characteristics such as the

[7] Personal consultation with Professor A.Seetharaman, Professor (Emeritus), ICAR Center for Small Millets, University of Agricultural Sciences, Bangalore, January 2003.

proportion of adults in the household who are men, and years of schooling of the household head, do not differ significantly among the two states. From the sample, it is evident that the average number of months of off-farm employment per household is much higher in the village communities of Andhra Pradesh (2.9 months) than in Karnataka (1.2 months). Mahabubnagar district of Andhra Pradesh borders the state of Maharastra (where Mumbai is located), providing ample opportunities for off-farm employment (both skilled and un-skilled). Villages are more widely dispersed within *panchayats* in Andhra Pradesh, where average density of paved (all-weather) roads is 3.3 km per *panchayat*, as compared to 2.2 km in Karnataka.

CROP BIODIVERSITY ON FARMS

Millets refers to a group of annual grasses mainly found in the arid and semi-arid regions of the world. Millets belong to five genera: Pennisettum, Eleucine, Setaria, Panicum and Paspalum. Sorghum is not classified under millets by genus but belongs to the same family classification as that of other millet crops (Monocotyledonae and the sub- family of Poaceae), and is often referred to India as "great millet." These grasses produce small seeded grains and are often cultivated as cereals.

Finger millet is grown widely in the southern part of Karnataka and in Tamil Nadu. Nearly two-thirds of the national output is produced in this region. Grown as an irrigated crop during the dry season in south India, finger millet is also inter-sown between rows of maize and other crops. Foxtail millet requires good soil, but grows in dry weather. Although not extensively grown, foxtail millet is of significance in certain sections of the lower Deccan plains and the highlands of Andhra Pradesh, Karnataka and Tamil Nadu. Local knowledge is that food prepared from foxtail millet is considered to

be good for pregnant women and invalids. Little millet is grown mostly in southern India, in parts of Andhra Pradesh and Karnataka, apart from the central and hilly tracts of the north India. Grown mainly as a rainfed crop, on poor, infertile soils, little millet is often used as dry fodder for ruminants and the grains fed to poultry.

In this paper, the terms "millets" and "millet crops" refer to sorghum, pearl millet, finger millet, foxtail millet and little millet. "Major" and "minor" refer to the extent of research investment and commercial importance of the crop in terms of area, production, and consumption. Minor millets are often termed "coarse grains," and pertain here to finger millet, foxtail millet, and little millet.

A total of 53 distinct varieties of millet crops were grown in the rainy season and 24 were grown the post-rainy season, with 63 overall since some varieties (14) were grown in both seasons. By far the highest counts (richness) were found in sorghum followed by finger and pearl millet. Appendix Tables 2 and 3 report counts by crop and improvement status and list the names of all distinct varieties grown, by season.

Diversity in crop and variety combinations is distributed spatially across households rather than per household, with eighteen crop combinations among farmers surveyed but an average of only two to threevarieties of millet crops per household, and seven millet crop varieties per *panchayat*. During the rainy season in the survey period, 36 farmers planted no millet crops because of the drought conditions. The monsoons began late in the third successive drought year experienced by farmers in the survey area. The extent to which the most recent, more prolonged drought influenced the patterns of variety cultivation observed during the survey was not possible to ascertain. Forty-two percent grew one millet crop only (sorghum, pearl, finger, or little millet), and of that

group, farmers growing only sorghum were the most common. Only 5 percent grew major millets only (pearl millet and sorghum), and the remaining forty-five percent grew some combination of major and minor millets (Appendix Table 4).

SEED REPLACEMENT AND VARIETY CHANGE

To analyze seed utilization, we use the "seed lot" as the unit of observation. A seed lot is the physical unit of seed the farmer uses to reproduce a variety each season (Louette 1994). A farmer might grow a variety for many years, but each season, a new seed lot is planted. Seed lots of either improved or farmers' varieties are often mixed or replaced, partially or completely, after seed of the variety is initially acquired (Aguirre Gómez, 1999). The age of varieties on farms measures the speed of variety change (Brennan and Byerlee 1991; Heisey and Brennan 1991). These definitions pertain regardless of improvement status. Hybrids and improved varieties dominated the seed lots of pearl millet and sorghum planted in the rainy season. Seed lots for finger millet included improved selections from farmers' varieties. Only farmers' varieties of little and foxtail millet were planted. In the post-rainy season, farmers' varieties of sorghum were far more frequently planted than were improved types. One reason why is that the formal plant breeding system has focused on the main rainy season, because of the more reliable commercial demand in that season.

Farmers were asked to classify their varieties according to whether they considered them to be improved, ancestral, or mixed. A sizeable percentage of farmers classified their pearl millet or sorghum hybrids as ancestral or mixed (24 and 36, respectively), suggesting that they are saving seed and replanting it. Farmers may deliberately mix the seed or the materials may become genetically mixed through pollen

flows among varieties that are planted contiguously, as has been reported for pearl millet in Rajasthan (vom Brocke 2001). In the rainy seasons, only 7 percent of the seed lots of IOPV pearl millet, as compared to 63 percent of those of IOPV sorghum, were classified as ancestral or mixed. Farmers might recycle (save and replant) improved varieties of sorghum more because their yield advantages are more easily maintained over the years, or because the pearl millet IOPVs are more recent releases. Some respondents also described farmers' varieties of finger millet as improved, perhaps because they consider those released by the State Department of Agriculture (pure line selections from farmers' cultivars) as their own (Appendix Table 5).

The frequency with which seed is replenished by farmers from external sources is known as the seed replacement rate. Used by commercial seed organizations to forecast the demand for their varieties, the seed replacement rate is defined here as the number of times a farmer has replaced the seed of a *given* variety of a crop grown in the study season *since* first growing that variety. A higher seed replacement rate is thought to be desirable for improved seed. Seed replacement for the same variety protects against genetic deterioration; replacing seed for the purposes of changing varieties can enhance yield potential (Heisey and Brennan 1991). Heisey and Brennan (1991) developed a model to analyze farmers' demand for replacement seed. In their simulations, they found that a wide range of seed replacement times were consistent with economically optimal behavior. Moreover, base yields and the seed-to-grain price ratio had almost no impact on optimal replacement time; though increasing the rate of yield improvement reduces the time to replacement.

Seed replacement buffers pest and disease problems through maintaining genetic resistance or the diversity in sources of resistance over time (Apple 1977). In landrace systems for cross-pollinating crops, some genetic studies indicate that mixture and replacement serves the purpose of protecting the genetic viability of the seed (Berthaud et al. 2002). In a number of empirical studies, farmers have reported the need to replace their "tired" variety or "renew" seed (Almekinders, Louwaars and de Bruijn 1994; Louette and Smale 2000; Sperling et al. 1996; Li and Wu 1996).

Whether or not higher seed replacement rates in landrace systems are desirable, however, depends on the context. High seed replacement rates within the informal sector could reflect "distress" sales and purchases of seed with poor quality. Farmers with failed harvests, who were not able to save much seed, might end up purchasing lower quality seed. In local markets, anecdotal evidence from this research suggests that farmers sometimes sell small quantities of seed of unknown identity in order to purchase other consumption items. Unknown variety identity means that quality is also unknown.

During the rainy season, the 432 farmers surveyed planted 5 types of millet and a total of 165 seed lots of pearl millet, 381 of sorghum, 192 of finger millet, 77 of little millet and 25 of foxtail millet. Farmers' varieties have clearly been grown for longer than any improved types (25-32 years). Little millet varieties are the oldest, though farmers also appear to have grown their local sorghum varieties for a long time. The average age of sorghum or pearl millet hybrids is 5-7 years, similar to that of improved selections of finger millet. This is a relatively higher rate of variety change than is observable with improved, open-pollinated sorghum varieties, which have a mean age of 10 years (Table 1).

Table 1--Seed replacement, transfer rates and age of varieties grown in the rainy and post-rainy season, by millet crop

	Pearl millet				Sorghum				Finger millet			Little millet	Foxtail millet
	Total	Hybrid	IOPV	FV	Total	Hybrid	IOPV	FV	Total	IPLS	FV	FV	FV
A. Number of seed lots –Rainy season	165	95	46	24	381	201	38	142	192	131	59	77	25
Years of growing the same named variety	7.6	4.5	4.7	25.3	15.6	6.8	10.4	29.6	12.5	6.9	24.8	32.7	29.1
Number of seed replacements per variety	3.9	4.2	4.3	1.9	2.3	3	1.4	1.6	2	2	2	2	2.1
Number of seed transfers per variety	2	0	0	2	1.5	1.1	1.8	1.7	1	1	1	2.7	3.7
Seed replacement rate	0.8	0.9	0.9	0.1	0.4	0.6	0.2	0.1	0.3	0.3	0.1	0.02	0.1
Seed transfer rate	0.01	0	0	0.1	0.1	0.04	0.1	0.1	0.1	0.1	0.1	0.04	0.1
B. Number of seed lots –Post-rainy season[a]					318	41	14	263	36	13	23		
Years of growing the same named variety					24.5*	10.8	7.6	27.6	11.7	20.9*	6.5*		
Number of seed replacements per variety					2.7	3.1	4.6*	2.6*	2.9*	2.9*	3*		
Number of seed transfers per variety					3	2.6	1.2	3.2	1.6	2	1.3		
Seed replacement rate					0.2	0.3	0.8*	0.4*	0.4*	0.5*	0.2*		
Seed transfer rate					0.2	0.3	0.1	0.2	0.2	0.2	0.1		

Source: Calculated from the field surveys conducted during October 2002-June 2003. (*) indicates statistically significant differences between seasons at 0.05 level.
Note: Definitions in glossary.

The frequency of seed replacements for varieties grown during the rainy season is lower for farmers' varieties relative to modern varieties of either pearl millet or sorghum, though it is the same (only twice on average since the original seed for the variety was obtained) across the minor millets (finger, minor, and foxtail). The frequency of seed replacements is higher for hybrids of pearl millet than sorghum, perhaps because a broader range of these hybrids is available to farmers. By contrast, the number of seed transfers from farmer to farmer is greater for little and foxtail millets than for major millets, and for farmers' varieties of major millets as compared to improved types.

In general, mean seed replacement rates demonstrate the expected positive relationship to improvement status. The rates at which farmers replace seed for farmer varieties are much lower than for improved types, and are higher for hybrids than improved open-pollinated varieties, and higher for heavily out crossing crops like pearl millet. Seed replacement rates are highest for pearl millet hybrids and improved open-pollinated varieties (these are replaced nearly annually), considerably higher for these than for sorghum hybrids, and higher for sorghum hybrids relative to improved selections of finger millet. Seed replacement rates are extremely low for farmer varieties. In the case of finger millet, most of the improved varieties available are publicly bred and the replacement rates are not as high as for sorghum and pearl millet. They are higher, however, than for other minor millets, since the government subsidizes and supplies seed of finger millet through assistance. Farmers reported that they replace the seed of their farmers' varieties more often during drought years (which occurs once in 5-7 years in the semi-arid regions), when local seed supplies dwindle. Seed is then procured from other farmers, shandies or public assistance.

Farmers transfer seed to other farmers less frequently than they replace it. That is, when controlling for the number of years the variety is actually grown, it is more common for farmers to demand replacement seed from any source (farmers, traders, dealers) than for them to supply it to other farmers—farmer suppliers are few relative to those who demand seed. Only for little millet and foxtail millet does this not appear to be the case, since seed for these crops is not supplied through formal channels at all.

During the post-rainy season only sorghum and finger millet are grown, and farmers planted a total of 318 seed lots of sorghum and only 36 of finger millet, though farmers' varieties of both crops dominated. Little formal research has been devoted to sorghum varieties suited to post-rainy production, and the farmer variety *Maldandi* and its derivatives are the most popular post-rainy sorghum varieties among the farmers. A comparison of the seasonal patterns reveals that the sorghum varieties grown during post-rainy season are much older (25 as compared to 16 years) because they are composed of a higher proportion of farmers' varieties. Compared to the rainy season, average seed replacement rates are four times higher for the IOPV and FV sorghum varieties, and twice as high for IPLS and FV varieties of finger millet grown in post-rainy seasons (also in Table 1).

SEED TRANSACTIONS

Distances to seed sources, in either formal or informal channels, are positively related to the improvement status of the seed, and are higher for major than for the minor millets. The higher the improvement status (generally this also implies higher seed production costs), the longer the distance traveled to procure it. Distances are similar for original and replacement sources—meaning that farmers tend to return to the original

source of seed for a named variety in order to replace it. Transfers from one farmer to the next are more localized and proximate. No pattern can be discerned in the quantities of seed exchanged. One reason may be the difficulty farmers have in recalling amounts involved in specific transactions, so that the figures are not accurate. If they are accurate, one explanation could be that in marginal environments, where germination rates can be low, farmers need only to ensure some extra seed on hand, though of an indefinite quantity. Quantities reported are not directly comparable across millet crops, because the seeding rates, seed sizes and weights differs (sorghum seed is large, pearl millet is relatively small, and the seed of finger, foxtail and little millets is even smaller). Since differences in distances and quantities did not vary meaningfully between seasons, they are reported for all seed transactions in Table 2.

Table 2--Distances to seed source, quantity transferred and seed-to-grain price ratios for varieties grown in rainy and post-rainy seasons, by millet crop

	Pearl millet				Sorghum				Finger millet			Little millet	Foxtail millet
Characteristics	Total	Hybrid	IOPV	FV	Total	Hybrid	IOPV	FV	Total	IPLS	FV	FV	FV
Total number of seed lots	165	95	46	24	699	242	52	405	228	141	82	77	25
Distance to original source (km)	11.2	9.3	18.1	5.1	7.25	7.65	7.7	3.7	7.1	7.7	5.8	3.6	3.8
Distance to replacement (km)	11.2	11.3	14.2	4.9	8.1	10.4	9.2	6.4	8.7	9.4	8.4	5.3	5.9
Distance to transfer (km)	4	0	0	0	4.4	4.4	4.3	4.4	3.5	4.8	2.9	4.9	1.2
Quantity purchased (kg)	8.6	9.2	8.1	6.7	7.6	8.8	8.8	6.3	8.3	9.2	8.1	5.7	4.8
Quantity replaced (kg)	9.5	9.4	10.9	7.1	9.6	10.5	8.7	8.3	9.4	9.3	9.2	8.8	8.1
Quantity supplied (kg)	5	0	0	0	7.5	5.9	6.4	8.3	4.9	5.3	5.1	6.7	7.4
Seed-to-grain price ratio	12.5	19.1	4.1	2.2	2.4	3.1	3.3	1.1	1.4	1.7	0.9	1.2	1.1

Source: Calculated from the field surveys conducted during October 2002-June 2003. See glossary for definition of terms.

Note: The data refers to the mean value for seed lots of varieties grown by farm households in the surveyed region.

Seed-to-grain price ratios denote two aspects of seed systems, given a uniform grain price: 1) the extent to which a crop variety is improved, as reflected in the costs of seed production; and 2) the costs of transacting in the seed market. The ratio is calculated here with average prices recorded at different nodes of market transaction, depending on the seed supply channel. Typically both seed and grain prices were lower by 15 to 30 percent in shandy transactions, as compared to dealer shops, reflecting quality differentials. Comparing among the millet crops, pearl millet, the most highly bred, also had the highest seed-to-grain price ratio (12.5). The lowest ratio was recorded in foxtail millet (1.1), the least bred. Comparing among improved types, pearl millet, the most heavily out-crossing crop, has higher seed-to-grain price ratios (hybrids 19.1; IOPVs 4.1) than sorghum (hybrids 3.1; IOPV 3.3). Improved varieties of finger millet, which are only selections, have seed-to-grain price ratios that are somewhat higher than farmers' varieties. Minor millets and farmers' varieties exhibit low seed-to-grain ratios because the distinction between seed and grain is negligible.

For the purposes of comparison, evidence reported by Heisey et al. (1998) for maize, another heavily out-crossing crop, suggests that widespread adoption of hybrids by small-scale farmers in developing countries is associated with a seed-to-grain price ratio of 10 or below during the initial phase of seed industry development. Seed-to-grain price ratios rise sharply during the maturity phase of the seed industry, often stabilizing in the range of 25:1 to 30:1 (Heisey et al. 1998). In countries like China, Pray et al. (1998) argue that the price controls imposed by the government kept the seed-to-grain price ratio unreasonably low compared to other Asian countries at that time, bringing about widespread adoption of hybrid maize but discouraging investment in agricultural research

(Rozelle, Pray, and Huang 1997). Morris (1998) found that seed prices in Thailand, as in Europe and North America, increased with yield potential, leading to single-cross hybrids with a seed-to-grain price ratio of 27-30 compared to open pollinated varieties of 4-5.

What do seed-to-grain ratios tell us about adoption? Byerlee, Morris, and Lopez-Pereira (1993) calculated a set of break-even yield gain curves to show the expected profitability of adopting hybrid maize. These curves depict the set of minimum percentage yield increases, across different yield levels, that a hybrid must generate to compensate farmers for the higher seed cost and increased risk. They found that at a low seed-to-grain ratio of 5:1, the yield advantage of the hybrid need not be large for adoption to be attractive; as the ratio increases, however, the associated yield advantages of adoption of hybrids must be large for adoption to occur, especially if the existing yield levels were low. In our case, subjective yield distributions elicited from farmers reveal an expected yield gain of around 50.7 percent for the most popular existing hybrid under better growing conditions in Bijapur district of Karnataka state,[8] with a seed-to-grain price ratio at the farm-gate is quite high (19:1). Although yield advantages appear to be great, price ratios are fairly high, and perhaps as a consequence, adoption rates of pearl millet hybrids are low (20 percent) among farmers surveyed.

Seed transactions are heavily monetized, regardless of mode of transaction. Historical transactions for seed lots planted in the main rainy season reveal that though family and friends are important sources of original seed and replacement seed as well as recipients of transfers, the frequency of market exchanges in all three categories is substantial. Transactions with family and friends, referred to as "gifts," typically involve

[8] Calculated with triangular yield distributions elicited from farmers, by variety (Hardaker, Huirne and Anderson 1997).

"token money." Farmers acquired the original seed for varieties grown during the rainy season primarily through markets, though less so, as expected, for farmers' varieties as compared to improved varieties. Even so, 33 percent of farmers' varieties of pearl millet, 52 percent of farmers' varieties of sorghum, 31 percent of farmers' varieties of finger millet, 61 percent of farmers' varieties of little millet, and 48 percent of those of foxtail millet were originally obtained through purchases. Seed replacement transactions for these varieties also occurred primarily as monetary exchanges, typically through dealers for improved varieties and hybrids and through village traders for farmers' varieties. Farmers also supplied their own seed to others for "token money." Some original and replacement seed was provided through the government as aid. From time to time, the Department of Agriculture purchases seed from farmers, particularly for popular varieties such as *Maldandi,* and especially during drought cycles. Farmers supply seed at a nominal rate (government purchase rates are always less than the market rates) (Appendix Table 6).

During the post-rainy season, the original sources of seed as well as replacement sources of seed for varieties of sorghum and finger millet grown are even more heavily dominated by purchases. Replacement and transfer rates are higher than those observed in the main rainy season. When farmers supplied the seed of these varieties to others, they did so more often as a "gift," and almost all historical supply transactions for sorghum and finger millet varieties grown in this season were among friends and family, for "token money."

In farm households surveyed, 70-100 percent of seed transactions were handled by men for all seed types, although women were more involved in post-rainy season

transactions, especially for minor millets and traditional varieties of sorghum. Women household members are often seen transacting their produce in the weekly local markets either as grain or as seed.

SEED SUPPLY CHANNELS

Seed supply channels are clearly differentiated by improvement status of the crop variety. Both private and public hybrids and IOPVs are supplied for pearl millet and sorghum. Private varieties are distributed at the state and district level through seed distributors, and at the village level, through traders and dealers. Public varieties may be distributed through the same channel, but also through state seed corporations, seed farms and depots.

Improved pure line selections of finger millet are exclusively public varieties, though they too may be distributed locally by private seed dealers and village traders, as well as through seed depots and occasional government assistance programs for farmers. Seed supply channels for farmers' varieties of finger, little and foxtail millet are "autarkic" in the sense that they have no interface with private companies or public seed corporations. These varieties are traded, like all other types, in *shandies*. *Shandies* are small community markets that operate at weekly intervals. Government programs sometimes purchase leading farmer varieties of minor millets for redistribution to farmers elsewhere.

Seed dealers are a vital link between farmers and the seed supply from the public seed corporations and private companies. They are the retailers in communities and are able to provision relatively large crop areas, given their knowledge of both formal and informal seed networks. Areas of operation usually extend to a radius of 50 km, and

dealers may appoint other retailers to handle the small amounts demanded in remote villages. There is no credit provided to farmer for purchasing seeds, because it is risky and dealers cannot be accountable for poor germination. Seed dealers also sell other agricultural inputs such as fertilizers and pesticides, and rent farm equipment. For 20 of the 29 dealers surveyed, only 25 percent of their business was comprised of seed, and among the remaining 9 dealers, the seed business share varied between 30 to 45 percent. For about half of the dealers (15) millet seed comprised 10-12 percent of seeds handled, and for others, millet seed represented from 15 to 20 percent. The majority of dealers sold only pearl millet and sorghum seed, and only 1 dealer in Chitradurga sold finger millet seeds (Appendix Table 7).

All seed dealers purchase their seeds from seed companies or a dealer who represents a particular seed company at the district/state level. Depending on the volume of their business operations, they work directly either with a seed firm or through a seed distributor at the district level on a commission basis. The distributor handles the product on a wholesale basis. Generally the commission ranges from 10-12 percent of the distributor margin, exclusive of their marketing cost. Dealers sell all kinds of proprietary hybrids and varieties (released by private firms) and in some cases, on demand, public varieties provided by the research system. Since the profit margin is much higher for improved types, dealers typically prefer to sell these. In some cases, dealers do sell "truthfully labeled" seed materials procured from a well-known seed farmer or farm to cater to the local demand.[9] This is more prevalent in the case of finger millet and sorghum varieties grown in the post-rainy season, such as *Maldandi*. The price of IOPV

[9] Well –established enterprises with reputations to protect may sell seed that has no official seed certification. Such seed is often described as 'truthfully labeled' as it bears a label describing minimum seed quality standards, self-certified and not certified by an official agency (Tripp 2001).

seeds is half of that of hybrids both at the farmers and at the traders' level. More detailed analysis of marketing margins can be found in Nagarajan (2004).

The flow of seeds and grains through shandies is thin but the turnover high, especially before planting. They serve as 'exchange markets' where farmers—especially women—bring their produce and transact in order to meet immediate cash needs. Grain and seed cannot be differentiated, and specific varieties are difficult to recognize, though most of the millet grain is from local villages (in and around 10-15 Kms) and some distinct characters are distinguishable (Appendix Table 8).

Farmer seed suppliers were identified by respondents and key informants in each of the village communities (*panchayats*). They were roughly equally distributed among those with expertise in modern varieties, farmers' varieties, or both. Though most experts were more likely to be men, some women experts were found among those with special knowledge about farmers' varieties. Most experts are farmers who own their land and have irrigation. The rest belong to the village but work outside the farm or are traders from that particular village who bring information or knowledge about seeds into the village. Experts in farmers' varieties are older on average, with fewer years of formal schooling, than experts in modern varieties. They are more likely to be farmers and own more land than experts in modern varieties. Experts in both are intermediate between the other two groups with respect to the same characteristics (Appendix Table 9).

Responses to open-ended questions provide some additional information about seed experts. Recognition as an expert in modern varieties appears most related to the exposure individuals have to information from "outside." For example, most of the experts dealing with modern varieties are village headman or have a recognized official

position in the village. Experts in modern varieties have regular access to communication facilities such as the radio and newspaper; and others have regular contacts with the extension agency officials. Many had attended farm schools conducted by agricultural departments (6 to 7 of them) and they update their knowledge periodically. One of the experts has a son who is an agricultural officer who provides him with information.

Recognition as an expert in farmers' varieties refers more to the depth of "inside" knowledge. Most of the seed experts for farmers' varieties explained that they gained their skills from their parents and grandparents and through their own experience growing varieties for as long as 40-50 years. They explain that they produce the best quality seed in their fields and they store it more carefully than other farmers. They share their genetic resources (they sell their seeds) with other farmers from the same village and farmers from nearby areas because the quality of their seed is known to be good. In other words, their "credibility" is good and they are trusted as a source of seed. A summary of the seed system characteristics for villages in the study sites is shown in Table 3, by millet crop and improvement status.

Table 3--Characteristics of village seed systems, by improvement status and crop

Characteristic	Major Millets (Pearl Millet and Sorghum)			Minor Millets (Finger, Little and Fox-tail millet)
	Hybrids	Open-pollinated varieties	Farmers' cultivars	
Seed supply channels	Formal	Formal , Informal and Semi-formal	Informal, semi-formal and formal	Informal, semi-formal and formal
- Formal-Public sector	- National/State seed corporation - State Agriculture Departments - Seed Farms - State agriculture universities (seed centers)	-National/Seed seed corporations -State departments of agriculture -Seed Farms -State agricultural universities (seed centers)	State department – popular local varieties *(Maldandi- post-rainy sorghum variety)*	State departments of agriculture – seed centers for improved selections of finger millet
- Formal-Private sector	- Seed Companies (National and International) - Seed distributors - Seed dealers - Retailers	- Seed Companies (National and International) - Seed distributors - Seed dealers - Retailers	Not Involved	Not Involved
- Informal	Not Involved	- Farmer-to-farmer - Farmer organizations - Village traders	- Farmer –to-farmer - Village traders - Shandies - Farmer organizations	- Farmer-to-farmer, relatives, friends - Village traders - Shandies - Farmer organizations
Seed replacement rate	High - once a year is recommended, but often saved and replanted - mostly formal	Low - once in 5 to 10 years - formal and informal	Very Low - high during drought periods - mostly informal	Very Low - high in drought periods - mostly informal
Seed transfer rate	Very Low	High - during drought periods	High - during drought periods	Moderate - high during droughts
Seed-to-grain price ratio	Very high in Pearl millet Moderate in Sorghum	High in pearl millet Moderate in sorghum	Very low	Very low

Source: Compiled by authors based on field surveys.

4. DETERMINANTS OF MILLET CROP BIODIVERSITY IN VILLAGES

CONCEPTUAL APPROACH

The specification of the regression model is derived conceptually from the household model of on farm crop diversity (fully developed in Van Dusen and Taylor 2004), further elaborated in a number of related case studies (Smale 2005). In these models, crop diversity metrics are constructed over the optimal output choices of farm households. The reduced form equation of the non-separable model expresses crop and variety diversity on farms as a function of exogenous household characteristics, farm physical characteristics, and market characteristics. Here, the same conceptual variables are measured operationally at an aggregated level. Tobit regressions were estimated because of censored dependent variables.

DEPENDENT VARIABLE

Spatial indices adapted from the ecological literature are used as the dependent variables in a regression model explaining the determinants of millet crop biodiversity in villages. The Margalef index is a normalized count of distinct types in the community, expressing richness, or abundance, with all varieties carrying the same weight. The Shannon index, often used as an indicator of evenness, merges richness and relative abundance concepts. The Margalef and Shannon indices have a lower limit of zero if only one variety is grown. The construction of the indices is found Appendix Table 10. The properties of these indices have been described by Magurran (1988) and others (Brock and Xepapadeas 2003), and they have been applied extensively in widely used in related literature (Meng et al. 1998; Smale 2005).

INDEPENDENT VARIABLES AND HYPOTHESES

Data are analyzed for the major rainy season only given missing observations in the post-rainy season and fewer crops grown. The materials grown are entirely different in the post-rainy season, and the there is also less diversity[10]. Variable definitions and hypothesized effects are shown in Table 5, according to findings reported in related literature (Brush, Taylor and Bellon 1992; Meng 1997; Van Dusen and Taylor 2004; Smale, Bellon and Aguirre 2001; related case studies in Smale 2005). 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 a number of ways—through distinct preferences over attributes, or if women have less access to seed or cash to purchase seed than men. In this farming system, livestock ownership measures both the demand for fodder and wealth. Families with less cash income are hypothesized to rely more on a spectrum of crop varieties.

Farm characteristics are the total rainfed cultivated area, number of millet plots and the share of millet area under different soil types. Household variables are *panchayat* averages. 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

[10] In this data, we did run separate and pooled regressions at a preliminary phase. Our recollection is that the results were poor for the post-rainy season, although statistical tests confirmed that they should not be pooled but should be run separately.

allocated depending on soil fertility, availability of irrigation or soil moisture retention Red loamy soils that are more fertile are found in very few communities. Pearl millet is cultivated widely in red loamy and laterite soils, sorghum and minor millets are cultivated mainly in black and laterite soils.

Table 5--Definition of explanatory variables measured at the community level

Variable name	Definition	Sign
I. Household characteristics		
Gender composition of farm labor	Ratio of total adult men to total adults engaged in farming	**(+,-)**
Education	Mean years of school attended by adults	**(+,-)**
Income	Mean annual cash expenditures (Rs.) per household in year preceding survey	**(-)**
Livestock owned	Mean number of bullocks, buffaloes and cows owned in 2002	**(+,-)**
II. 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 black and laterite soils for each millet crop	
III. Market and seed system characteristics		
Road density	Km of structured (all weather) road per community	**(-)**
Off-farm employment	Months worked off-farm by all adults (aged more than 15)	**(+,-)**
Distance to seed source	Mean kms from the farm gate to nearest source of millet varieties	**(+)**
Seed replacement ratio	Number of times the seed of a cultivar planted in the survey season since been replaced since first sowing, averaged over all millet varieties	**(+,-)**
Seed-to-grain price ratio	Mean ratio of purchase price of seed to consumer price of seed	**(+,-)**
Quantity of seed traded	3-year average kg of millet seeds sold by dealers or traded in shandies (2000-2002)	**(+,-)**
IV. Location factors[a]		
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] In the regression analysis, district level fixed effects were analyzed with respect to the omitted communities in the Dharwad district**.**

Market characteristics include the length of the paved road in the village community, representing physical infrastructure, and levels of off-farm employment, reflecting labor market development. Poorer 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 seed replacement rate (historical), quantity of seeds traded (three-year average), distance to seed source, and seed-to-grain price ratios on millet diversity levels for the communities surveyed[11]. No direction of effect is hypothesized a priori for these variables. District level fixed effects control for the unmeasured attributes of the administrative region in which these communities are located (i.e., six districts across two states).

RESULTS

Pearl Millet. Communities with more educated farmers have greater diversity in pearl millet, by either indicator—suggesting that these communities have both more access to seed and more resources for growing them. Similarly, higher income farm communities have a greater richness in pearl millet varieties, since they are able to replace their varieties periodically and introduce new materials from the external markets. More livestock appears to be associated with less evenness and less richness in pearl millet varieties, suggesting specialization in certain varieties to satisfy specific needs such

[11] The seed transfer rate is less comprehensive an indicator than the seed replacement rate. The transaction mode could only be represented as a percentage or share of transactions. Each seed system explanatory variable has an economic interpretation or is used by the seed industry.

as food and fodder. A higher proportion of adult men in the household is positively related to both the richness and the equitability of varieties of pearl millet, perhaps because it signals greater labor availability. A higher share of rainfed lands in the communities reduces the number of individual, distinct varieties grown by the farm households, since irrigated lands enable farmers to grow improved types. As expected, farms with larger number of plots maintained more diversity in pearl millet. Black soils were found in almost all the communities where pearl millet was grown. Known for their moisture retention levels, a higher share of these soils is in a community is associated with growing more varieties of pearl millet, particularly improved types, more evenly distributed. Laterite soils also enhanced diversity—perhaps because of farmers' varieties.

Greater road densities are associated with fewer varieties of pearl millet per community, as hypothesized. Seed replacement rates and the seed quantities traded through dealers are significantly and positively related to greater richness as well as evenness of pearl millet varieties. Since modern varieties of pearl millet constitute a major proportion of the seeds replaced and traded, this result suggests that a more active formal seed market for modern varieties does not imply the widespread cultivation of a single variety (genetic uniformity), but rather more distinct varieties and less dominance of any single variety. Although the seed-to-grain price ratio has no statistically significant effect, distance to seed markets is positively associated with pearl millet diversity, since diversity in this crop is related to improved seed sold farther away. More off-farm employment reduces the richness but enhances the evenness of pearl millet varieties in the community, for reasons that are unclear. District effects in the dominant pearl millet growing areas (Bijapur and Bellary) are statistically significant but reduce pearl millet

diversity. Farming communities in these districts tend to specialize more in growing certain popular varieties and therefore replace varieties more rapidly.

Sorghum. Farm communities with more adult men involved in farming maintain lower levels of sorghum diversity in their fields, perhaps because they specialize, although higher education levels are associated with greater variety richness. Lower income communities have fewer sorghum varieties, but they are more equitably distributed. The land share in laterite soils, which have very low moisture retention levels and nutrients, reduces diversity levels in sorghum; although so do black soil types, which are more fertile. Off-farm employment draws labor out of farm production, with communities specializing more in growing certain varieties. In general, more road infrastructure reduces sorghum diversity.

Distances to seed sources are positively related to richness, since in the major rainy season, improved varieties are grown. Historical rates of seed replacement rate are related positively to both the richness and evenness of sorghum varieties. Higher (three-year) average seed quantities supplied to communities through dealers enhanced the spatial diversity of sorghum varieties. Higher seed-to-grain price ratios had negative effects on sorghum variety richness, since it implies that new varieties cost more. District level effects were significant, indicating the positive influence on variety richness of community location especially in Belgaum, one of the major sorghum growing areas in Northern Karnataka.

Minor Millets. Less is explained in regressions for minor millets, in part because of the structure of their diversity and in part because more of their seed and product transactions take place outside of markets. Higher income households are more likely to

grow minor millets in their cropping system during the rainy season, probably in order to satisfy their specific food and fodder needs. In some cases minor millets are grown as a 'soil cover crop' in this vast stretch of dry lands, which requires minimum tillage[12]. Farms with larger numbers of plots also maintain higher diversity. Since minor millets include a complex of 2 to 3 small millets, farmers allocate different millets to various plots according to soil types and moisture. As in the case of sorghum, more diversity was found in communities with a higher share of red loamy soils relative to black or laterite soils.

Panchayats with more off-farm employment opportunities often tend to specialize in certain minor millet crops, while those with higher road densities maintain lower levels of diversity, as hypothesized. Seed volumes traded through shandies are also a major factor associated with greater diversity in minor millet varieties in the surveyed communities, since shandies are the most important sources of seed exchange. Other seed system variables were not statistically significant, given the near absence of a formal seed supply channel for these crops.

[12] In order to retain moisture in dry, arid lands, the minor millet crops are grown as a cover crop. (Personal communication with Dr.Seetharam, UAS, Bangalore, February 2004).

Table 6--Determinants of community-level variation in indices of variety diversity within crops in rainy season

	Pearl Millet		*Sorghum*		*Minor millets*	
	Shannon	Margalef	Shannon	Margalef	Shannon	Margalef
			Marginal effects			
A. Household characteristics						
Gender composition of farm labor	**0.0804****	**0.0762****	0.0010	**-0.0316***	0.0066	0.0551
Education	**0.5119****	**0.5068*****	-0.0032	**0.4145*****	**-0.1083***	-0.1618
Income	**0.0026****	**0.0040*****	**0.0003***	**-0.0012*****	**0.0012*****	**0.0025*****
Livestock owned	**-0.5089***	**-1.3491*****	0.0020	0.0313	-0.0296	-0.1869
B. Farm Characteristics						
Total rainfed area	**-0.2049****	-0.0416	0.030	0.0713	0.02275	-0.0937
Millet plots	**0.8376***	-0.1272	**-0.1949****	**-0.5045*****	0.0123	**0.4827***
Area share in black soil type	**7.4520***	**5.4488*****	0.5624	**-2.9202****	0.25572	**-6.3549***
Area share in laterite soil type	2.0531	**2.7383****	0.1195	**-2.0321***	-0.3215	**-8.2674****
C. Market Characteristics						
Road density		**-0.7633*****	**-0.2301****	-0.0168	-0.0836	**-0.6477***
Off-farm employment	**0.31054***	**-0.2446****	**-0.0796***	-0.04722	**0.1002***	-0.0751
Distance to source of seed	**0.2859***	**0.2667*****	-0.0448	**0.3522*****	-0.0391	-0.1537
Seed replacement ratio	**0.5056****	**0.7637*****	**0.1279*****	0.06137	0.0109	-0.0707
Seed-to-grain price ratio	0.0986	-0.0056	**-0.2954****	**-0.6313*****	-0.0078	0.7419
Quantity of seed traded[a]	**0.0017****	**0.0024*****	**0.0002***	**0.0013*****	**0.0012***	0.0003
D. Location Characteristics						
Location in Bijapur district	-0.8740	**-10.8123*****				
Location in Bellary district	**3.9751***	**-2.6031*****	**-8.8606*****	-0.8079	-0.0619	**-4.1064***
Location in Chitradurga district			**-1.6589*****	**-3.9828*****	0.4230	-1.0095
Location in Belgaum district			**-0.9968****	**1.0985***	**-1.3261****	**-4.0111***
Location in Mahabubnagar district			-0.7193	0.5353	-0.6791	**-6.0917****
			Test statistics for log likelihood ratio tests of joint hypothesis			
Equation	60.36	86.54	105.24	101.68	51.68	21.92
Seed system effects λ (4,.05)	43.81 **	45.74***	90.28***	68.29***	47.17*	19.66
District fixed effects[b] λ (4,.05)	48.99***	69.39***	82.26**	54.82**	29.29***	12.74*

Note: n=58 communities/ Tobit regressions. Marginal effects are partial derivatives of expected value, computed at the means of variables. (*) denotes 10 percent, (**) 5 percent and (***) 1 percent significant levels. [a] Quantity of seed traded through shandies was used in regressions for minor millets. [b] For pearl millet diversity regressions, district level fixed effects were computed for Bijapur and Bellary districts only as very few communities in other districts grew the crop. Bijapur district was omitted from sorghum and minor millets diversity regressions as only few communities planted during the season. The road density variable was dropped in estimation of the Shannon index for pearl millet.

5. CONCLUSIONS

The research summarized in the three papers of this set represents an initial exploration into the relationships among seed systems, development-related factors and the levels of crop biological diversity maintained by communities. Seed systems convey incentives for farmers to grow one crop variety or another or a set of them as compared to only one. Understanding these systems is critical for designing policies to enable farmers to manage crop varieties in sustainable ways, both as production inputs and as valuable genetic resources. Too often, seed systems for improved materials and farmers' varieties have been treated as disjointed and addressed with different research tools. Seed systems and the population genetics of crop varieties are better modeled at a higher level of aggregation than the household, although most applied economics research about incentives for maintaining biological diversity has been conducted using the household as the unit of observation.

This first paper contributes to the literature by laying out terms and empirical measurements for characterizing seed systems at the community level, drawing and adapting concepts from preceding research about formal and informal seed supply channels, variety change, and farmer seed management in centers of crop diversity. Empirical measurements are then applied to detailed survey data collected in Andhra Pradesh and Karnataka. Previously omitted variables, seed system characteristics are brought into a reduced-form, econometric analysis of the determinants of millet diversity levels at the community level.

In the 60 panchayats (village communities, or clusters of villages) studied, farmers grow a total of 63 distinct varieties of 5 millet crops, including hybrids, improved

open-pollinated varieties, improved pure line selections and farmers' varieties. Diversity is distributed spatially across farms rather than per farm, with households growing an average of only 2-3 varieties of millet crops. There is evidence of seed saving for pearl millet and sorghum hybrids as well as other materials. Seed is replaced for the same varieties and for the purposes of varietal change. The age of varieties is negatively related and the rates of seed replacement positively related to improvement status and whether the millet crop is major or minor; however, the number of seed transfers is higher the less improved the material, and is highest for the minor millets.

Consistent with previous research about seed systems, seed-to-grain prices ratios are related to the extent of breeding effort embodied in the seed type and the rate of out-crossing in the crop. Men appear to be more involved in seed transactions than women, except among local seed experts and during the post-rainy season, when traders in local weekly markets are often women. Unexpectedly, most seed transactions (original, replacement, transfer) appear to be based on money, even when they are described as "gifts", are occurring between family and friends for "token money." Even for farmers' varieties, a larger proportion of transactions are between individuals who are neither family nor friend. Seed supply channels differ by improvement status, though *all* categories of millet genetic resources (by crop and improvement status) exchange hands at the level of the village trader and shandies. We find little evidence of more variety diversity in the post-rainy season compared to the rainy season. The season most intensively using commercially bred varieties is the one with the more temporally and spatially diverse varieties.

Econometric findings generally support hypotheses maintained in the literature, but new results are presented for seed system characteristics, which are shown to be highly significant determinants of millet diversity levels in communities. The higher the rate of seed replacement, the greater is the overall richness of millet crops and varieties. Villages where larger volumes of millet seed are traded through dealers have greater richness in their millet crops. Historical rates of seed replacement, including variety change, are positively correlated with the spatial richness and relative abundance of varieties of major and minor millets. Volumes traded through shandies (informal community markets) are associated with greater diversity in minor millet varieties, and those traded by dealers (formal markets) are significant for pearl millet diversity and rainy season sorghum varieties.

Findings have several implications for seed policy, to be investigated further in the subsequent papers of the set. First, post-rainy season production is also still dominated by farmers' varieties of sorghum and minor millets and the high rate of seed replacement and transfer rates suggest that there are seed shortages. Quality fodder is important to farmers and exploitable niche markets appear to be present for specialized foods. There may be a role for private or publicly-funded research in addressing these product demand and seed supply issues. Also, a more focused, participatory plant breeding initiative may be worth exploring with some of the seed experts in the case of minor millets; formal breeding may wish to investigate whether improvements are possible in the range or performance of materials currently supplied to these farmers.

Second, and perhaps most importantly, while the research has provided interesting descriptive information on informal seed supply channels, a critical component of the

seed system in marginal environments such as these, findings do suggest strongly that market activity and the involvement of formal channel actors contributes positively to the breadth of genetic materials in these communities. Ways should be found to strengthen and improve the overall efficiency of the seed system, including both formal and informal channels, in order to reduce the costs to farmers of procuring and managing diverse crop varieties.

Future work should develop a more complete analytical framework that separates with greater lucidity the demand and supply processes for seed and products, at different points in the market chain. As we have explained, and also the descriptive data show that an entirely different set of materials are used in the post-rainy season, and there are many fewer observations and much less diversity. In the future, the sample design should be such that seasonal dynamics can be analyzed.

APPENDIX

Table 1--Descriptive statistics of the surveyed households

	Mean			All		
Variable	Karnataka	Andhra Pradesh	All	StdDev	Min	Max
Expenditure of the family (Rs.)	2012**	3408	2361	1188	755	5715
Years of schooling of production decision maker (No.)	3.7*	3.4	3.7	3.5	0.0	12
Livestock value (Rs.)	60348***	125466	76628	73276	1200	488692
Buffaloes, Bullocks and Cows (No.)	5.2**	7.5	5.8	3.4	0.0	19
Goats, Sheep and Poultry (No.)	1.6*	3.9	2.2	5.2	0.0	50
Total cultivable area owned per household (Ha)	4.5	3.7	3.8	3.9	0.0	25
Rainfed share of total cultivated owned land per household (%)	74.4	69.9	75.1	25.1	0.0	100
Irrigated share of total millet area cultivated per household (%)	15.4***	31.9	22.6	21.3	0	75
Millet share of the total cultivable area per household, rainy season (%)	49.5	48.7	49.3	27.2	0.0	100
Months off-farm employment per household	1.2***	2.9	1.6	1.0	0.0	5.3
Length of paved road available in the village communities(Kms)	3.3**	2.2	3.0	0.9	1.2	5.2

Source: Field survey conducted in 2002-2003 (Nagarajan 2004).
n=a total of 432 households, 180 in Andhra Pradesh and 252 in Karnataka.
Pair-wise t-tests between households of Karnataka and Andhra Pradesh show significant differences at ***1 %, ** 5% and * 10 % significant levels.

Table 2--Numbers of distinct cultivars grown by the surveyed households, by millet crop and improvement status

Millet crop	Improvement status[a]	Number of varieties		
		Rainy season	Post-rainy season	Total
		(Count)		
Pearl Millet	Hybrid	5	0	5
	IOPVs	2	0	2
	FV	3	0	3
Sorghum	Hybrid	10	4	10
	IOPVs	7	3	7
	FV	10	16	19
Finger Millet	IPLS	7	1	8
	FV	3	0	3
Little Millet	FV	4	0	4
Foxtail Millet	FV	2	0	2
All millet crops		53	24	63

Source: Field survey conducted in 2002-2003 (Nagarajan 2004). See glossary for definition of terms.

Table 3--Varieties grown by the households in the survey areas

Number	Variety Name	Improvement Status
Sorghum		
1	Allina jola	FV
2	Bijapur jola	FV
3	Bili jola	FV
4	Csh-1	HYB
5	Csh-11	HYB
6	Csh-14	HYB
7	Csh-15	HYB
8	Csh-16	HYB
9	Csh-5	HYB
10	Csh-9	HYB
11	Dodda jola	FV
12	Gangavati sorghum	FV
13	Gidda maldandi	FV
14	Gunduteni	FV
15	Hala jola	FV
16	Hombale jowar	FV
17	Itc jowar	HYB
18	Jawari jowar	FV
19	Jk-5	HYB
20	Jk-22	HYB
21	Kenjola	FV
22	Kesari	FV
23	M-35-1	FV
24	Maldandi	FV
25	Mugutheni	FV
26	Muguti maldandi	FV
27	Msh-51	HYB
28	Nandiyal white	FV
29	Pac-501	IOPV
30	Paras jowar	IOPV
31	Pioneer jowar	IOPV
32	Proagro-296	IOPV
33	Sorghum agro	IOPV
34	Tella jola	FV
35	Vikarbad local	IOPV
36	Yaniger	FV

Number	Variety name	Improvement status
Pearl Millet		
1	Local dwarf bajra	
2	Advante hybrid	HYB
3	Bajra kaveri	HYB
4	Bajra paras	IOPV
5	Bajra agro	IOPV
6	Bajra seedtec hyb.	HYB
7	Hybrid bajra mahyco	HYB
8	ICMV-221	HYB
9	ICTP series(5 lines)	IOPV
10	Jawari bajra	FV
11	Jawari sajji	FV
12	Kaveri	IOPV
13	Paras Bajra	HYB
FINGER MILLET		
1	Annapoorna ragi	IPLS
2	Black ragi	FV
3	Dwarf ragi	FV
4	Farm ragi	FV
5	Godavari	IPLS
6	Gpu-22	IPLS
7	Gpu-28	IPLS
8	Indof-5	IPLS
9	Kalyani	IPLS
10	Pr-202	IPLS
11	Short ragi	FV
12	V-20	IPLS
13	White ragi	FV
LITTLE MILLET		
1	Black samai	FV
2	Hali samai	FV
3	Jawari samai	FV
4	Mallige samai	FV
5	Local samai	FV
6	White samai	FV
FOXTAIL MILLET		
1	Hala Navane	FV
2	Local Navane	FV

Source: Field surveys conducted in 2002-2003 (Nagarajan 2004), ICRISAT Gene bank, and ICAR Center for sorghum and finger millet, UAS, Dharwad and Bangalore (2003-04).See glossary for definition of terms.

Table 4--Millet cropping patterns in the surveyed households

Millet cropping patterns	Rainy season		Post rainy season	
	Number	Share	Number	Share
	(Count)	(Percent)	(Count)	(Percent)
No crops grown	*36*	*8.3*	*165*	*38*
One millet crop only	*182*	*42.6*	*259*	*60*
Sorghum	88	20.8	233	54
Pearl millet	64	14.8	0	0
Finger millet	25	5.8	26	6
Little millet	5	1.2	0	0
Major millets only	*21*	*4.9*	*0*	*0*
Pearl millet and sorghum				
Both major and minor millets	*193*	*44.7*	*8*	*2*
Sorghum and finger millet	70	16.2	8	2
Sorghum and little millet	50	11.6	0	0
Pearl and finger millet	23	5.3	0	0
Sorghum and foxtail millet	1	0.2	0	0
Sorghum, pearl and finger millet	11	2.5	0	0
Sorghum, finger, and little millet	10	2.3	0	0
Sorghum, little, and foxtail millet	8	1.9	0	0
Sorghum, finger, and foxtail millet	5	1.2	0	0
Pearl millet, finger and foxtail millet	2	0.5	0	0
Pearl, sorghum, finger, and foxtail	5	1.2	0	0
Sorghum, finger, little, foxtail millet	1	0.2	0	0
Minor Millets only	*5*	*1.1*	*0*	*0*
Finger and little millet	1	0.2	0	0
Finger millet and foxtail millet	4	0.9	0	0

Source: Compiled by author from field surveys conducted in 2002-2003 (Nagarajan 2004). n=432.

Table 5--Relationship between farmers' and scientists' classification of varieties by improvement status

Characteristic	Pearl millet			Sorghum			Finger millet		Little millet	Foxtail millet
	Hybrid	IOPV	FV	Hybrid	IOPV	FV	IPLS	FV	FV	FV
Rainy season										
Number of seed lots planted										
	95	46	24	201	38	142	131	59	77	25
Percentage classified by farmers as:										
Improved	76	93	13	74	37	1	83	17	3	0
Ancestral	12	3	83	17	58	97	15	81	97	100
Mixed	12	4	4	9	5	2	2	2	0	0
	100	100	100	100	100	100	100	100	100	100
Post-rainy season										
Number of seed lots planted										
				14	41	263	13	23		
Percentage classified by farmers as:										
Improved				61	93	14	23	96		
Ancestral				39	7	86	77	4		
				100	100	100	100	100		

Source: Field survey conducted in 2002-2003 (Nagarajan 2004). See glossary for definition of terms.

Table 6--Mode of seed transactions for varieties grown in rainy season, by millet crop

	Pearl Millet				Sorghum				Finger Millet			Little	Foxtail
Historical transactions	Total	Hybrid	IOPV	FV	Total	Hybrid	IOPV	FV	Total	IPLS	FV	Millet	Millet
Number of seed lots for varieties planted	165	95	46	24	381	201	38	142	192	131	59	77	25
Source (%)													
Gift	21	0	41	67	27	9	45	48	40	26	69	39	52
Aid	24	36	11	0	19	34	16	0	20	29	0	0	0
Purchase	55	64	48	33	54	57	39	52	40	45	31	61	48
Number of past seed replacements for varieties planted	165	95	46	24	339	201	28	110	183	123	60	24	25
Replacement (%)													
Gift	18	13	26	21	21	14	25	33	23	14	42	29	60
Aid	22	31	15	0	10	14	14	3	12	18	0	0	0
Purchase	61	57	59	79	69	72	61	65	65	68	58	71	40
Number of past seed transfers for varieties planted	18	0	0	18	189	59	18	113	125	67	57	36	25
Farmer Supply (%)													
Gift	78	0	0	78	75	76	61	77	78	94	60	64	56
Aid	0	0	0	0	4	0	28	3	0	0	0	0	0
Sales	22	0	0	22	21	24	11	20	22	6	40	36	44

See glossary for definition of terms.

Gift denotes that seeds are exchanged among family and friends for money, but at less than the market price (termed “token money").

Seeds supplied through government programs as a part of agri-input subsidies are "aid."

Purchase and sales are exchanges through community markets or dealers.
Source: Field survey conducted in 2002-2003 (Nagarajan 2004).

Table 7--Market profile for seed dealers selling modern varieties

	Districts						All districts
	Dharwad	Bellary	Belgaum	C.Durga	Bijapur	M.Nagar	
				(Count)[a]			
Number of dealers	6	5	4	3	5	6	29
Number of crops sold	2	2	2	2	2	2	3
Number IOPV varieties sold	2	3	2	3	2	3	15
Number hybrids sold	5	4	5	3	5	3	25
Number of clients	300	350	250	300	300	350	2150
Distance covered (Kms)	25	40	25	50	40	45	37.5
Sorghum seed sold (mt)	3.9	3.95	3.4	2.2	1.2	3.2	3.0
Pearl millet seed sold (mt)	1.15	1.8	1.0	0.6	4.4	0.6	1.6
Finger millet seed sold (mt)	0	0.7	0	2	0	1.7	0.8

Source: From the field survey in 2002-2003 (Nagarajan 2004).

[a] Three year averages reported for all figures except number of dealers, 1999-2002.

Table 8--Profile of shandy traders

	Districts					
	Dharwad	Bellary	Belgaum	C.durga	Bijapur	MN Nagar
Shandy characteristics						
Number of shandies sampled	4	5	4	3	3	6
Millet crops sold	Sorghum, pearl and little millet	Sorghum, finger, little and foxtail millet	Sorghum, pearl and little millet	Sorghum, finger and pearl millet	Pearl millet sorghum	Sorghum, pearl, finger and foxtail millet
Varieties traded [a]	5(S), 2(PM) and 1 LM	6(S), 2(PM), 2(LM, FM and FTM)	3(S), 1(PM) 2(LM)	3(S), 4(FM) 1(PM)	3(PM) 2(S)	4(S) 2(PM) 3(FM) 2(LM and FTM)
Quantity sold in peak season (mt)	0.16-0.20	0.24-0.32	0.16-0.20	0.25-0.32	0.15-0.16	0.24-0.32
Quantity sold in lean season (mt)	0.09-0.17	0.07-0.16	0.16-0.17	0.15-0.16	0.15-0.16	0.15-0.16
Trader characteristics						
Number of traders per shandy	6	8	6	5	5	6
Quantity sold/trader in peak season (kg)	10-12	15-20	10	15-20	5	15-20
Quantity sold / trader in lean season (kg)	3-5	2-5	5	5	5	5

Source: Field survey conducted in 2002-2003 (Nagarajan 2004).
Note: The peak season is before rainy season (May-June) and post-rainy season (December-January).
Traders confirm most grain or seed sold in shandies is of farmers' cultivars.
[a] S indicates Sorghum; PM indicates Pearl Millet; FM indicates Finger Millet; LM indicates Little Millet and FTM indicates Fox Tail Millet.

Table 9--Social and economic profile of village seed experts

	Village Seed Experts in		
	Modern varieties	Farmer varieties	Both
Number of observations	19	22	20
Mean			
Age (years)	47.8	62.5	54.2
Education (years in school)	5	2	3.5
Land owned (ha)	2.4	3.6	2.7
Men	100	87	100
Farming with irrigation	50	40	50
Shares		*(Percent)*	
Primary occupation category			
Agriculture	84	95	89
Trade	2	3	5
Other[a]	14	2	6

Source: Field survey conducted during October 2002-June 2003.
[a] Other category includes teachers, government workers, and factory workers.

Table 10--Definition of indices used in the analysis

Index	Concept	Construction	Explanation
Margalef	Richness	$MD = (S-1) / \ln A_i$ $MD \geq 0$	A_i = total area planted to millet *i*th millet crop and or varieties in communities in rainy season; S=total number of crops and/or varieties
Shannon	Evenness	$MD = -\Sigma\alpha_i \ln \alpha_i$ $MD \geq 0$	α_i = area share occupied by *i*th millet crop and/or variety in communities in rainy season.

Source: Adapted from Magurran (1988).
Note: The concept defined here with respect to millet diversity in the surveyed areas.

REFERENCES

Aguirre Gomez J.A. 1999. Análisis Regional de la Diversidad del Maíz en el Sureste de Guanajuato, Ph.D. Thesis, Universidad Nacional Autónoma de México, Facultad de Ciencias, Mexico, D.F.

Almekinders, C.J.M., N.P. Louwaars, and G. H. de Bruijn. 1994. Local seed systems and their importance for an improved seed supply in developing countries. *Euphytica* 78: 207-216.

Apple, J.L. 1977. The theory of disease management. In *Plant disease: An advanced treatise.* ed. J.G. Horsfall. New York, N.Y.: Academic Press.

Bantilan, M.C.S., and U.K. Deb. 2002. Grey to green revolution in India: Role of public-private –international partnership in research and development. Paper presented at the BAEA-IAAE conference on "Public-Private Sector Partnership for Promoting Rural Development" held at Dhaka, October 2-4.

Berthaud, J., G. Pressoir, C.F. Ramirez, and M.R. Bellon. 2002. Farmers' management of maize landrace diversity. A case study in Oaxaca and beyond. Proceedings of the 7th International Symposium on the Biosafety of Genetically Modified Organisms Beijing, October 10-16, 2002.

Brennan, J.P. and D. Byerlee. 1991. The rate of crop varietal replacement on farms: Measures and empirical results for wheat. *Plant Varieties and Seeds* 4: 99-106.

Brock A.W. and A. Xepapadeas. 2003. Valuing Biodiversity from an Economic Perspective: A Unified Economic, Ecological, and Genetic Approach. *The American Economic Review* 93 (5): December.

Brush, S. B., J.E. Taylor, and M.R. Bellon. 1992. Technology adoption and biological diversity in Andean potato agriculture. *Journal of Development Economics* 2: 365-387.

Bellon, M R. and J.E.Taylor. 1993. "Folk" soil taxonomy and the partial adoption of new seed varieties. *Economic Development and Cultural Change* 41(4): 763-786.

Byerlee, D.M., M.L.Morris, and M.A.Lopez-Pereira. 1993. Hybrid maize and the small-scale farmer: Economic and policy issues for Asia. Paper presented at the 5th Asian Regional Maize Workshop, Hanoi and Ho Chi Minh, Socialist Republic of Vietnam, 15-20 November, 1993.

Department of Agriculture. 2003. *AGROSTAT 2002-03*. New Delhi: Department of Agriculture, Government of India.

Edmeades, S., M. Smale, M. Renkow and D. Phaneuf. 2004. Variety demand within the framework of an agricultural household model with attributes: The case of bananas in Uganda EPTD Discussion Paper 125, IFPRI, Washington. D.C.

Evenson, R.E. and D. Gollin. 2003. Review: Assessing the Impact of the Green Revolution, 1960 to 2000. *Science* Vol 300, 2 May: 758-762.

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.

Hardaker, J.B., Huirne, R.B.M. and Anderson, J.R. (1997), Coping with Risk in Agriculture. CAB International, Oxon, United Kingdom. ISBN 0 85199 199 X.

Heisey, P.W., and J.P. Brennan. 1991. An analytical model of farmers' demand for replacement seed. *American Journal of Agricultural Economics* 73(4): 1044-1052.

Heisey, P., Smale, M., Byerlee, D. & Souza, E. 1997. Wheat rusts and the costs of genetic diversity in the Punjab of Pakistan. *American J. Agricultural Economics*, 79: 726-737.

Heisey, P.W., M.Morris, D.Byerlee, and M.Lopez-Pereira. 1998. Economics of hybrid maize adoption. In M.L.Morris (ed.,), Maize Seed Industries in Developing Countries. Boulder,Colorado:Lynne Rienner.

Louette, D. and M. Smale. 2000. Farmers' seed selection practices and maize variety characteristics in a traditional Mexican community." *Euphytica* 113: 25-41.

Li, Y., and S. Yu. 1996. Traditional maintenance and multiplication of foxtail millet. *Euphytica* 87: 38-48.

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

Maredia, M., J. Howard, and D. Boughton, with A. Naseem, M. Wanyala, and K. Kajisa. 1999. *Increasing seed system efficiency in Africa: Concepts, strategies and issues.* MSU International Development Working Paper No.77, Department of Agricultural Economics. East Lansing, Michigan: Michigan State University.

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, 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 *Farmers, gene banks and crop breeding: Economic analyses of diversity in*

wheat, maize, and rice, ed. M. Smale. , Dordrecht and Mexico, D.F.: Kluwer Academic Press and CIMMYT

Morris, M.L., Rusike, J., and Smale, M. 1998. Maize seed industries: A conceptual framework. In *Maize seed industries in developing countries*, ed. M. Morris 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.

Prasada Rao, K.E., and V.Gopal Reddy. 1980. Kharif sorghum germplasm collection in karnataka and adjoining areas. Genetic Resources Progress Report 29. India: ICRISAT,

Pray, C.E., Scott Rozelle, and Huang Jikun. 1998. China. In *Maize seed industries in developing countries*, ed. M. Morris Boulder, CO: Lynne Reiner Press.

Rozelle, Scott D. C. E. Pray, and H. Jikun. 1997. Agricultural research policy in China: Testing the limits of commercialization-led reform. In *Comparative economic studies* 39 (2) Summer 1997: 37-71.

Seetharam, A., K.W. Riley and G. Harinarayana. 1989. *Small Millets in Global Agriculture*. New Delhi, India: Oxford and IBH,.

Smale, M. (ed.) 2005 (in press). *Valuing crop biodiversity: On-farm genetic resources and economic change.* Wallingford, UK: CABI.

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

Sperling, L., and M. E. Loevinsohn. 1993. The dynamics of adoption: Distribution and mortality of bean varieties among small farmers in Rwanda. *Agricultural Systems* 41(4): 441-453.

Sperling, L., U. Scheidegger and R. Buruchara. 1996. *Designing seed systems with small farmers: Principles derived from bean research in the great lakes region of africa.* Agricultural Research and Extension Network Paper No. 60. London: Overseas Development Agency.

Sperling, Louise, Tom Remington, Jon M. Haugen, and Sigrid Nagoda. 2005. *Addressing seed security in disaster response: Linking relief with development*. CIAT,CRS,CARE,USAID,Norwegian Ministry of Foreign Affairs.

Thiele G. 1999.Informal potato seed systems in the Andes: Why are they important and what should we do with them? *World Development* 27(1): 83-99.

Van Dusen, M.E. 2003. A metapopulation approach to farmer seed systems: methodology for agricultural biodiversity conservation policy. Paper presented at the Fourth BIOECON Workshop on Economic Analysis of Policies for Biodiversity Conservation, 28-29 August, 2003. Venice International University, Venice, Italy.

Van Dusen, E., and J.E. Taylor. 2004 (Forthcoming) Missing markets and crop diversity: Evidence from Mexico. *Environment and Development Economics.*

vom Brocke, K. 2001. Effects of farmers' seed management on performance, adaptation, and genetic diversity of pearl millet (*Pennisetum glaucum* [L.] R.Br.) populations in Rajasthan, India. Ph.D. Dissertation. Germany: University of Hohenheim.

Zimmerer, K. S. 2003. Geographies of seed networks for food plants (potato, Ulluco) and approaches to agrobiodiversity conservation in the Andean countries. *Society & Natural Resources* 16(3): 583–601.

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