Scottish Journal of Political Economy, Vol. 50, No. 2, May 2003
© Scottish Economic Society 2003, Published by Blackwell Publishing, 9600 Garsington Road, Oxford OX4 2DQ, UK and 350 Main Street, Malden, MA 02148, USA

CROP GENETIC DIVERSITY, PRODUCTIVITY AND STABILITY OF AGROECOSYSTEMS. A THEORETICAL AND EMPIRICAL INVESTIGATION

Salvatore Di Falco, and Charles Perrings***

Abstract

This paper purports a model of farmers' crop choices in an uncertain environment. The model shows that profit maximizing farmers will choose a crop mix characterised by greater crop diversity if diversity is positively related to productivity and negatively correlated with production and income variability. An application using data from a Vavilov megadiversity spot, southern Italy, from 1970 up to 1993 is provided to test model hypotheses. It is found that interspecies crop genetic diversity is positively related to mean income and negatively related to the variance of income.

I Introduction

Both the Biodiversity Convention and the International Treaty on Crop Genetic Resources encourage signatory countries to promote on-farm conservation of agrobiodiversity. Crop Genetic Conservation generally involves one of two strategies: *ex situ* germ plasm preservation in gene and seed banks, and *in situ* conservation of crops and wild relatives. *Ex situ* conservation ensures against the loss of genetic material from rapidly changing systems. On the other hand, *in situ* conservation protects both dynamic, evolutionary genetic processes and the complexity of genetic interactions in the agricultural ecosystem, both of which are lost in *ex situ* conservation (Brush, 1995). Crop genetic diversity is important at both global and local levels. At the global level, plant genetic resources are valued for their role in the genetic 'improvement' of cultivated species to meet the challenges posed by changing levels of demand, due to population growth, and changing supply conditions, due to climate change and attendant changes in pest and pathogen risks. At the local level, Interspecies Crop Genetic Diversity (ICGD, hereafter) plays an important role in supporting the productivity and stability of agroecosystems.

The evidence on the relationship between interspecies crop genetic diversity and mean farm incomes is mixed. There is some limited evidence that diverse

*University of York (UK)
**University of York (UK)

crop species systems may have higher mean yields than single crop species systems. For example, Davis (1986) noted that inter-cropped systems yield a higher level of (combined) output per hectare than systems in which crops were separated. This is because the crops 'segment' the use of resources either spatially or temporally in order to reduce competition. In a set of grass land experiments, Tilman and Downing (1994) and Tilman et al. (1996) also showed that the average amount of biomass grown per year in a plot increased with the diversity of functional groups represented in the grass sward. The gains from intercropping cereals with cereals may not be as obvious – given the heavy nutrient requirements of both. However, where there is a time difference between the nutrient demands of intercropped cereals, intercropping may still produce higher mean yields than sole cropping, and should certainly produce less variable yields (Rao, 1986).

There is more systematic evidence that diverse crop species systems offer less variable yields than single crop species systems. Since the performance of different species varies with climatic and other environmental conditions, greater species diversity enables the system to maintain productivity over a wider range of conditions (Naeem et al., 1995; Chapin et al., 1997). It follows that the variance in yields from a more diverse crop system will be less than for an individual crop. ICGD reduces the probability of absolute crop failure (Singh, 1981), and increases the stability of both yields and income (Trenbath, 1986; Abalu, 1976; Walker et al., 1983). One reason why ICGD affects the stability of yields is because it increases resistance to pests and pathogens. The greater the diversity between or within species and functional groups, the greater the tolerance or resistance to pests. Sumner et al. (1981), for instance, noted that a reduction of crop genetic diversity promoted the build up of crop pest and pathogen populations. Pests are more likely to spread when crops have a similar genetic base. Genetic variability within and between species confers at least the potential to resist stress, both in the short and long term (Giller et al., 1997). It follows that the promotion of diversity in agriculture may be expected to increase the resilience and sustainability of agroecosystems.

The vulnerability of agriculture due to the narrow genetic base of most major crops is currently recognized to be a source of risk. The vast bulk of global food supply is derived from a small number of crops – wheat, rice, corn, oats, tomatoes and potatoes. Locally, other crops may be important, but do not contribute much in global terms. The problem has been exacerbated by the abandonment of traditional varieties and landraces in favour of newer high yielding varieties. In most crops the number of varieties planted has been substantially reduced. The result is increasing variability in farm incomes, particularly amongst farmers in low-income countries without access to alternative methods of insuring against crop failure. This is because the correlation between agricultural risks typically varies inversely with crop genetic diversity. In the limit – in monocultures – agricultural risks may be perfectly correlated (Perrings and Gadgil, 2002).

There are a number of agroecological regions that are especially rich in biodiversity, including crop genetic diversity. We hypothesise that in these regions the mean and variance of yields will be respectively increasing and decreasing in crop genetic diversity. This paper considers the link between crop genetic diversity and farm incomes in one such agroecological region: southern Italy. We recognise that crop genetic diversity is only one aspect of biodiversity in agroecosystems. Apart from crops, the diversity of agroecosystems includes pests, competitors, predators and pathogens that inhibit plant growth, sub-soil organisms and microorganisms that enable nutrient cycling and plants that provide shelter or buffering from adverse conditions. The management of biodiversity in farmlands involves not only crop choices, but the regulation of all other organisms through, for example, the use of pesticides, herbicides, fertilizers, crop rotation, ploughing practices and the like (Conway, 1993). Nevertheless, the choice of crop genetic diversity may be the most important of the biodiversity choices made in agroecosystems.

The paper is structured as follows. In the next section we propose a simple model of crop diversity decisions in farms allowing for stochasticity in at least the production process. For this purpose we adopt the approach taken by Just and Pope (the mean-variance model). The model shows that optimal crop genetic diversity varies with the impact of crop diversity on the mean variance of both output and income. In Section III we estimate a stochastic model of farm incomes using data for eight regions in southern Italy over a period of twenty four years. We find a strong positive correlation between crop genetic diversity and both the mean and variance of farm incomes in the regions. A final section offers some conclusions.

II The Model

In the standard agricultural economics literature, models of crop diversity choices tend to be static (e.g. Barkley and Porter, 1996; Hesey et al., 1997; Smale et al., 2001). However, farmers decide the level of biodiversity in the agroecosystem by allocation of land among crops (interspecies diversity) and farming decisions have implications for the stock of diversity available in the future. Let $\mathbf{g}_t$ be a vector describing the farmers' land allocation at time t, and let D_t be a measure of crop genetic diversity derived from $\mathbf{g}_t$. For simplicity, it is assumed that each land allocation decision embeds decisions with respect to all the other inputs (e.g. fertilizers, pesticides). Therefore, once the land allocation strategy is decided, the corresponding fertilizer and pesticide regime follows. We thus have a very simple production function:

$$Q_t = Q(\mathbf{g}_t, D_t). \tag{1}$$

Production, Q_t, is a function of land allocation decisions $\mathbf{g}_t$, and the associated crop genetic diversity D_t. The function is assumed to be continuous, twice differentiable and concave. Crop genetic diversity depends on the relative area under each crop variety. The ith element of the vector $\mathbf{g}_t$ describes the share of land allocated to the ith crop, implying that $0 < g_t^i \leqslant 1$ If $g_t^i = 1$, $D_t = 1$ and the farmer's land is devoted to a single crop or species. If a multicropping strategy is chosen, $g_t^i < 1$ for all i and $D_t < 1$. The technological properties of the production function are the following, neglecting time indices:

$$Q_{g^i} > 0; Q_{g^i g^i} \leqslant 0;$$
$$C_{g^i} > 0.$$

Farmers face risks that affect either the output of agricultural activities (the risk affects the quantity or quality of crops produced) or agricultural markets (the risk affects the prices of agricultural inputs or outputs)[1]. They hedge risks by their land allocation decisions. It follows that different degrees of risk will affect the level of crop genetic diversity observed in the agroecosystem. To capture risk, the model includes a multiplicative random term. The problem for the farmer may be stated as follows:

$$\mathrm{Max}_{\mathbf{g}_t} = \int_{t=0}^{\infty} \pi(Q_t, p_t, \theta_t) e^{-rt} dt \tag{2}$$

where the revenue function, $\pi(Q_t, p_t, \theta_t)$, now depends upon the quantity produced, price and a stochastic component. The latter is assumed to be identically, independently and normally distributed, and to affect the output of Q only. To see how output risk affects land use decisions we need an appropriate specification of the production function. A popular specification is that due to Just and Pope (1978, 1979), who suggest a stochastic function of the form:

$$Q(D_t, \mathbf{g}_t, \theta_t) = f(\mathbf{g}_t, D_t) + h(\mathbf{g}_t, D_t)\theta_t \tag{3}$$

where $f(\mathbf{g}t, D_t)$ is a deterministic function of land allocation in period t, $\mathbf{g}_t$, and the diversity of crops in the agroecosystem in that period, D_t. The term $h(\mathbf{g}_t, D_t)\theta_t$ is a stochastic component that depends upon the same arguments as the deterministic function together with θ_t – a stochastic disturbance. Farmers are assumed to be risk averse, their preferences being represented by a Von Neumann Morgenstern utility function, which is twice differentiable and concave in revenues. The farmer's problem in the face of output uncertainty is to:

$$\mathrm{Max}_{g_t} \int_{t=0}^{\infty} \{[pt(f(\mathbf{g}_t, D_t) + h(\mathbf{g}_t, D_t)\theta_t) - C(\mathbf{g}_t)]\} e^{-rt}\, dt \tag{4}$$

$$\dot{D} = D_t - D(\mathbf{g}_t), \overset{s.t.}{\text{and}}\ D(0) = D_0 > 0.$$

Setting price equal to unity, the first order necessary conditions imply that:

$$\begin{aligned} f(\mathbf{g}_t^*, D_t^*) &+ \left[h_g(\mathbf{g}_t^*, D_t^*) - \frac{D_{\mathbf{g}}(\mathbf{g}_t^*)}{r} h_D(\mathbf{g}_t^*, D_t^*)\right] \frac{\mathrm{Cov}\{\pi\}}{E\{\pi\}} \\ &- C_{\mathbf{g}}(\mathbf{g}_t^*) = \frac{D\mathbf{g}(\mathbf{g}_t^*)}{r} f_D(\mathbf{g}_t^*, D_t^*) \end{aligned} \tag{5}$$

---

[1] This paper is concerned only with output uncertainty. This is because the level of price for cereals have been set from the European Union in the time span considered.

The term:

$$\frac{\mathrm{Cov}\{\pi\}}{E\{\pi\}}$$

reflects the structure of profit risks. The term:

$$h_g(\mathbf{g}_t, D_t) - \frac{D_g(\mathbf{g}_t)}{r} h_D(\mathbf{g}_t,\ D_t)$$

represents the risk factor. It reflects both the marginal productivity of a change in the land allocation decision $h_g(\mathbf{g}_t,\ D_t)$ and the impact of a change in land allocation on the diversity of crops $h_g(\mathbf{g}_t,\ D_t)$.

Assuming D to be equal to a Simpson's index for biodiversity $\sum(g^i)^2$, and assuming that g^i is the share of farmland allocated to the i^{th} crop then we have that $D_g = 2g^i$. Substituting the latter in (5) implies that for each crop:

$$g^{i*} = \frac{1}{2}\left[\frac{C_g(g) - h_g \frac{\mathrm{cov}\{\pi_g\}}{E\{\pi_g\}} - f_g}{f_D + h_D \frac{\mathrm{cov}\{\pi_g\}}{E\{\pi_g\}}}\right]. \tag{6}$$

We can use this to evaluate the effect of biodiversity on the mean and variance of yields on the area planted g^i, that is:

$$\frac{\partial g^{i*}}{\partial f_D} = -\left[\frac{2(C_g(g) - h_g \frac{\mathrm{cov}\{\pi_g\}}{E\{\pi_g\}} - f_g)}{\left[f_D + h_D \frac{\mathrm{cov}\{\pi_g\}}{E\{\pi_g\}}\right]^2}\right] \tag{7}$$

and

$$\frac{\partial g^{i*}}{\partial h_D} = -\left[\frac{2\frac{\mathrm{cov}\{\pi_g\}}{E\{\pi_g\}}(C_g - h_g \frac{\mathrm{cov}\{\pi_g\}}{E\{\pi_g\}} - f_g)}{\left[f_D + h_D \frac{\mathrm{cov}\{\pi_g\}}{E\{\pi_g\}}\right]^2}\right]. \tag{8}$$

Aside from the structure of profits risks, the effect of biodiversity on farm incomes depends on the sign of the numerator given by:

$$\left(C_g(g) - h_g \frac{\mathrm{cov}\{\pi_g\}}{E\{\pi_g\}} - f_g\right).$$

If it is positive:

$$\frac{\partial g^{i*}}{\partial h_D} < 0 \quad \text{and} \quad \frac{\partial g^{i*}}{\partial h_D} > 0.$$

If it is negative:

$$\frac{\partial g^{i*}}{\partial h_D} > 0 \quad \text{and} \quad \frac{\partial g^{i*}}{\partial h_D} < 0.$$

The area optimally allocated to a given crop will increase if the marginal effect on mean yields is negative and vice versa. It will also increase if the impact of greater diversity on the variance of yields is positive and vice versa. In the next section we test the impact of crop genetic diversity on both mean and variance of income.[2]

III Empirical Analysis

In order to test the relation between crop genetic diversity and the mean variance of farm income a dataset from ISTAT, the Italian National Institute of Statistics is used. The data are drawn from periodicals *Statistiche Agrarie* for the period 1970 – 1993. The observations are on the Southern Italian regions: Abruzzo, Molise, Campania, Puglia, Basilicata, Calabria, Sicilia and Sardegna. These regions differ somewhat in climate and topography, but the agricultural sectors, and particularly the cereals production sectors, are reasonably homogeneous. They all have Objective 1 status in the European Union – i.e. they are considered to be 'backward' and to have high development priority. The data relate both to farm incomes and the intraspecies diversity of cereals. To capture crop genetic diversity and land allocation strategies, we apply a Shannon diversity index. This allows us to relate the farmers' land allocation strategy to the resulting interspecies crop genetic diversity. The index is calculated on the acreage devoted to each cereal, g_t^i, and the total acreage G_t:

$$D_t = D(g_t^i, G_t)$$

It is an index commonly used for spatial diversity and it combines indicators of crop population richness as well as abundance (Magurran, 1988; for a discussion on measurement of crop diversity see Meng et al., 1998). Specifically, we use the measure:

$$D(\mathbf{g}_t) = -\sum_i \left(\frac{g^i(g^i-1)}{G(G-1)}\right) \ln \left(\frac{g^i(g^i-1)}{G(G-1)}\right).$$

This measure has the characteristic that $D(\mathbf{g}t)$ increases as diversity decreases. As the land devoted to single species increases the crop genetic diversity of the agroecosystem decreases. The data set is a combination of cross sectional and time series. This suggests the appropriateness of a panel data analysis, which has the advantage of both improving the reliability of the estimates and of controlling for individual heterogeneity and unobservable or missing values (Baltagi, 2001). The use of fixed and random effects eliminate problems arising from stochastic trends that are specific to a variable, but cannot eliminate those related to specific regions. In order to eliminate regional stochastic trends in the variables we take the changes in the series between adjacent observations, so we use a First Difference Estimator:

$$\Delta y_{it} = \beta \Delta x_{it} + \Delta \varepsilon_{it}.$$

To test the impact of the land allocation strategy and the resulting crop diversity regime on the net benefit (at constant prices) of cereal production using the first difference estimator on the farmers' profit.

---

[2] Reminding that price are assured constant.

We are interested in both the mean and variance of agricultural incomes. The estimation is in three stages. First we estimate the production function without the stochastic component in order to identify the impact of diversity on income. Second, in order to capture the effect of stochasticity in production, we estimate the variance of agricultural incomes. In the third stage we re-estimate the effect on mean income given the variability observed in the second stage. The standard Just and Pope procedure output is reported in Tables 1 and 2. Table 1 displays the impact of the interspecies crop diversity loss on the mean income. Table 2 displays the impact of the interspecies crop diversity loss on the variance of income.

The general fit of both models is quite good given the type of analysis. The R^2 is equal to 0.4 for the mean model and 0.6 for the variance model. The individual significance of the coefficients is very high. To interpret the results on the effect of crop genetic diversity on the mean and variance of yields reported here, recall that as the diversity index gets smaller, the greater the interspecific diversity being measured. Interspecific crop genetic diversity is positively related to mean income and negatively related to the income variance. The value of the coefficients and their significance indicate that agricultural output bears a strong, positive and highly significant correlation with crop genetic diversity. This result is matched by the result on mean income.

The result on mean incomes is surprisingly strong. It is not intuitively obvious whether it stems from market or production effects in the income model, but estimation of the production function confirms that a high proportion of the impact of crop genetic diversity on income does in fact work through production. The marginal productivity of crop genetic diversity is positive, at least in the long run. The result on the variance of income is also very strong, but less surprising. In fact, existing studies show a negative relation between intraspecies crop genetic diversity and the stability of yields (e.g. Widawsky and Rozelle, 1998; Smale et al., 1997), then supporting the hypothesis that a high-diversity strategy reduces both output and market risks. A strong positive and significant correlation between the variance of farm incomes and crop genetic

Table 1
Interspecies diversity loss effect on mean income

Variables	Coefficients	Std. Errors	*t*-ratios	*P*-values
Intraspecies diversity loss	– 2.764838199	0.69345198	– 3.987	0

Table 2
Interspecies diversity loss effect on variance of income

Variables	Coefficients	Std. Errors	*t*–ratios	*P*-values
Intraspecies diversity loss	0.9569438615	0.20698629	4.623	0

diversity indicates that the greater the diversity of crops, the lower are the risks of crop failure and/or price collapse. Diversity is a risk reducing input of the production function.

IV Discussion

A number of farming system research and agroecological studies have investigated the impact of diverse cropping regimes (multicropping, intercropping, rotation) on both mean productivity and the stability of yields. There is some evidence that an inter-cropped system may generate a higher level of mean output than a single crop system (Davis, 1986); and that the variance of yields in a more diverse crop system is almost certainly less than in a single crop system (Trenbath, 1986, Abalu, 1976). Part of the yield gain from intercropping is due to pest pressure reduction either through allelopathic effects of crops or through the reduced densities of pests in a mixed stand of crops. Pests have more ability to spread through crop with the same genetic base (Gleissman, 1986; Altieri and Lieberman, 1986; Brush, 2000). The potential for disease and insect tolerance gained through plant breeding can also complement the effects of cropping systems to reduce losses to crop pests (Francis, 1986), while agroecological heterogeneity encourages variation in crop characteristics due to the creation of different production niches and unique sets of selection pressures (Bellon, 1996). Variation in rainfall and soil moisture, temperature and potential evaporation all have the potential to shape the development of major crops such as wheat (Loss and Siddique, 1994, Pecetti et al., 1992). More diversity in crops also implies more diversity amongst complementary species. There are important interactions between the fungal communities associated with the roots of the plants and the diversity of the fungi in the soil. This improves the effectiveness of nutrient uptake, builds the soil through increased biomass production and protects the soil from erosion (because it is covered for most of the cropping cycle), all of which are important benefits in terms of resilience and sustainability.

This paper has presented a model of farmers' crop genetic choices in an uncertain environment. The model shows that farmers will choose a crop mix characterised by greater crop diversity if the latter is positively related to the productivity, and negatively correlated with production variability and income. Furthermore, if allocating land to different crops is a risk reducing strategy and if crop genetic diversity is negatively associated with the stochastic component, the more risk sensitive are profits the more diverse is the agroecosystem. A mean variance approach has been undertaken in order to investigate the risk properties of interspecies crop genetic diversity and its impact on the long run mean income using data on cereals diversity in southern Italy. We find that interspecies crop genetic diversity is positively related to mean income and negatively related to the variance of income.

The result on the variance of income is consistent with research findings in both ecology and agriculture, since it confirms that greater genetic diversity makes a system more resilient to rainfall and temperature fluctuations. The use of a Just and Pope production function is somewhat limiting, but it does provide a straightforward way of testing the effect of crop genetic diversity on income risks. Finally, we note that the impact of diversity on expected incomes means that we are unable to infer a great deal about the risk aversion of farmers, since they have an incentive to opt for a high diversity strategy irrespective of the impact on the variance of income. However, any degree of risk aversion will strengthen the appeal of a high diversity strategy.

REFERENCES

ABALU, G. (1976). A note on crop mixtures under indigenous conditions in northern Nigeria. *Journal of Development Studies*, 12.

ALTIERI, M. and LIEBMAN, M. (1986). Insect, weed, and plant disease management in multiple cropping systems. In C. Francis (ed.), *Multiple cropping systems*. New York: Macmillan.

BALTAGI, B. H. (2001). *Econometric of Panel Data Analysis*. Chirchester, England: John Wiley & Sons, Ltd.

BARKLEY, A. P. and PORTER, L. L. (1996). The determinants of wheat variety selection in Kansas, 1974 to 1993. *American Journal of Agricultural Economics*, 78.

BELLON, M. R. (1996). The dynamic of crop infraspecific diversity: a conceptual framework at the farmer level. Economic Botany, 50.

BRUSH, S. B. (1995). In situ conservation of landraces in centers of crop diversity. Crop Science, 35.

BRUSH, S. B. (2000). *Genes in the Field, on – Farm Conservation of Crop Diversity*. Boca Raton, USA: co-published by International Development research centre and International Plant Genetic Resources Institute and Lewis Publishers.

CHAPIN, F. S., WALKER, B. H., HOBBS, R. J., HOOPER, D. U., LAWTON, J. H., SALA, O. E. and TILMAN, D. (1997). Biotic control over the functioning of the Ecosys-tem, Science 277.

CONWAY, G. R. (1993). Sustainable agriculture: the trade-offs with productivity, stability and equitability. in E. B. Barbier (ed.), *Economics and Ecology: New Frontiers and Sustainable Development*. London: Chapman and Hall.

DEFRIES, R., HANSEN, M. C., TOWNSHEND, J. R. G., JANETOS, A. C., FAETH, P. and LOVELAND, T. R. (2002) Growing Green: Enhancing Environmental and Economic Performance in U.S. Agriculture, WRI Press.

FRANCIS, C. (1986). Distribution and importance of multiple cropping. In C. Francis (ed.), *Multiple Cropping Systems*. NY: Macmillan.

GADGIL, M., HEMAM, N. S. and REDDY, B. M. (1997). People, refugia and resilience. In C. Folke and F. Berkes (eds.), *Linking Social and Ecological System*. Cambridge: Cambridge University Press, pp. 30–47.

GILLER, K. E., BEARE, M. H., LAVELLE, P., IZAC, A. M. N. and SWIFT, M. J. (1997). Agricultural intensification, soil biodiversity and agroecosystem function, Applied Soil Ecology 6.

GLIESSMAN, S. (1986). Plant interactions in multiple cropping systems. In C. Francis (ed.), *Multiple Cropping Systems*. NY: Macmillan.

GREPPERUD, S. (2000). Optimal soil depletion with output and price uncertainty, *Environment and Development Economics* 5.

HARTELL, J., SMALE, M., HEISEY, P. W. and SENAUER, B. (1998). The contribution of genetic resources and diversity to wheat productivity in the Punjab of Pakistan. In M. Smale (ed.), *Farmers, Gene Banks, and Crop Breeding*. Boston: Kluwer.

HEISEY, P. W., SMALE, M., BYERLEE, D. and SOUZA, E. (1997). Wheat rusts and the costs of genetic diversity in the Punjab of Pakistan. American Journal of Agricultural Econonomics, 79.

HEYWOOD, V. (ed.) (1995). *Global Biodiversity Assessment*. Cambridge: Cambridge University Press.

ISTAT, *Annuario Di Statistica Agraria*, 1970–1993.

JUST, R. E. and POPE, R. D. (1978). Stochastic representation of production functions and econometric implications. *Journal of Econometrics*, 7.

JUST, R. E. and POPE, R. D. (1979). Production function estimation and related risk considerations, *American Journal of Agricultural Econonomics*, May.

LOSS, S. P. and SIDDIQUE, K. H. M. (1994). Morphological and physiological traits associated with wheat yield increases in Mediterranean environment, *Adv. Agron.* 52.

MAGURRAN, A. E. (1988). *Ecological Diversity and Its Measurement*. London: Croom Helm.

MENG, E. C. H., SMALE, M., BELLON, M. R. and GRIMANELLI, D. (1998). Definition and measurement of crop diversity for economic analysis. In M. Smale (ed.), *Farmers, Gene Banks, and Crop Breeding*. Boston: Kluwer.

NAEEM, S. and LI, S. (1997). Biodiversity enhances ecosystem reliability, *Nature*, 390.

NAEEM, S., THOMPSON, L. J., LAWLER, S. P., LAWTON, J. H. and WOODFIN, R. M. (1994). Declining biodiversity can affect the functioning of ecosystems, *Nature*, 368.

PECETTI, L., DAMANIA, A. B. and KASHOUR, G. (1992). Geographic variation for spike and grain characteristics in durum wheat germplasm adapted to dryland conditions, *Genetic Resources and Crop Evolution*, 39.

PERRINGS, C. (2001). The economics of biodiversity loss and agricultural development of low income countries. In D. R. Lee and C. B. Barrett (eds) Agricultural intensification economic development and the environment, Cabi.

PERRINGS, C. and GADGIL, M. (2002). Conserving biodiversity: reconciling local and global public benefits. In I. Kaul (ed.), *Providing Global Public Goods: Making Globalization Work for All*. Oxford: OUP. Forthcoming.

RAO, M. R. (1986). Cereals in multiple cropping. In C. Francis (ed.), *Multiple Cropping Systems*. NY: Macmillan.

SINGH, R. P. (1981). Crop failure and intercropping in the semi arid tropics of India. Economic Program Progress report. 21 ICRISAT, Patancheru, India.

SMALE, M., BELLON, M. R. and AGUIRRE GOMEZ, J. A. (2001). Maize diversity variety attributes and farmers choices in Southeastern Guanajuato Mexico. *Economic Development and Cultural Change*, 50, 1.

SMALE, M., HARTELL, J., HEISEY, P. W. and SENAUER, B. (1997). The contribution of genetic resources and diversity to wheat production in the Punjab of Pakistan. *American Journal of Agricultural Economics*, 80.

SUMNER, D. R., DOUPNIK, B. and BOOSALIS, M. G. (1981). Effects of tillage and multicropping on plant diseases, *Annual Review of Phytopathology*, 19.

TILMAN, D. and DOWNING, J. A. (1994). Biodiversity and stability in grass-lands. *Nature*, 367, pp. 363–65.

TILMAN, G. D., WEDIN, D. and KNOPS, J. (1996). Productivity and sustainability influenced by biodiversity in grassland ecosystems. *Nature*, 379.

TRENBATH, R. (1986). Resouce use for intercrops. In C. Francis (ed.), *Multiple Cropping Systems*. NY: Macmillan.

WALKER, T. S., SINGH, R. P. and JODHA, N. S. (1983). Dimensions of farm level diversification in the semi arid tropics of rural south India. Economic Program Progress Report, 51. ICRISAT, Patancheru, India.

WIDAWSKY, D. and ROZELLE, S. (1998). Varietal diversity and yield variability in Chinese rice production. In M. Smale (ed.), *Farmers, Gene Banks, and Crop Breeding*. Boston: Kluwer.