Crop biodiversity, risk management and the implications of agricultural assistance

Di Falco, Salvatore; Perrings, Charles

How to cite

DI FALCO, Salvatore, PERRINGS, Charles. Crop biodiversity, risk management and the implications of agricultural assistance. In: Ecological economics, 2005, vol. 55, n° 4, p. 459–466. doi: 10.1016/j.ecolecon.2004.12.005

This publication URL: https://archive-ouverte.unige.ch/unige:42218
Publication DOI: 10.1016/j.ecolecon.2004.12.005

Available online at www.sciencedirect.com

SCIENCE DIRECT®

Ecological Economics 55 (2005) 459–466

ECOLOGICAL ECONOMICS

www.elsevier.com/locate/ecolecon

ANALYSIS

Crop biodiversity, risk management and the implications of agricultural assistance

Salvatore Di Falco[a,b,*], Charles Perrings[c,1]

[a]CSERGE, School of Environmental Sciences, University of East Anglia
[b]Department of Economics, National University of Ireland, Galway, Ireland
[c]Environment Department, University of York, United Kingdom

Received 10 November 2003; received in revised form 2 September 2004; accepted 13 December 2004
Available online 20 April 2005

Abstract

This paper presents a theoretical and empirical analysis of the impact of financial assistance to farms on crop biodiversity in an uncertain setting. The findings reveal that risk aversion is an important driving force for crop biodiversity conservation. Risk-averse farmers can hedge against the uncertainty they face by allocating land to different crop species. However, policies intended to stabilize revenues by supporting particular species may alter this link by *delinking* crop biodiversity from the management of revenues risk.

Keywords: Crop biodiversity; Risk management; Agricultural assistance

1. Introduction

After the seminal contributions of Brush et al. (1992), Heisey et al. (1997) and Smale et al. (1998), a number of studies focusing on the importance of crop biodiversity[2] have been published in the agricultural and resource economics literature. A first strand of literature analyzed the contribution of crop biodiversity to the mean and the variance of agricultural yields (Smale et al., 1998, 2003; Widawsky and Rozelle, 1998) and to the mean and variance of farm income (Di Falco and Perrings, 2003). A second strand provided both theoretical and empirical investigation

* Corresponding author. Department of Economics, National University of Ireland, Galway, Ireland. Tel.: +353091524411; fax: +353091524130.
E-mail addresses: s.difalco@nuigalway.ie (S. Di Falco), cap8@york.ac.uk (C. Perrings).
[1] Tel.: +441904432997; fax: +441904432998.

[2] Crop biodiversity is defined as a component of agricultural biodiversity, referring to all diversity within and among wild and domesticated species domesticated species, including crop plants that continue to evolve under natural and farmer selection (Qualset et al., 1995; Wood and Lenné, 1999; Smale et al., 2003).

0921-8009/$ - see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.ecolecon.2004.12.005

of the determinants of crop biodiversity (e.g. Meng, 1997; Van Dusen, 2000; Smale et al., 2001; Birol et al., forthcoming; Smale et al., 2003). Market integration, agroecological conditions, the adoption of high yielding varieties and farmers' risk aversion were found to be key variables in crop biodiversity conservation. Surprisingly, the impact of agricultural policies on agro-biodiversity has been neglected. Financial assistance to farms affects directly farmers' production decisions, which in turn have impacts on crop biodiversity and environmental quality (Just and Antle, 1990; Just and Bockstael, 1991; Abler and Shortle, 1992; La France, 1992; Fraser, 1994; Lewandrowski et al., 1997).

The connection between agricultural assistance and crop biodiversity considered in this paper relates to the trade-off between farm support and crop choice in the management of production and marketing risks.[3] The risky nature of the agricultural business is a key factor in farmers' acreage allocation and inputs use decisions (e.g. Chavas and Holt, 1990; Leathers and Quiggin, 1991). Further, risk-averse farmers will use more of the risk-reducing input than the risk-neutral farmers. In this paper these issues are exploited in order to shed light on the connection between financial assistance to farmers and crop biodiversity when farmers are risk averse. Risk may play a pivotal role in determining crop biodiversity. In fact, if allocating land to different species is a risk-reducing strategy, the risk-averse farmer would grow a higher number of crop species to hedge against uncertainty. This would result in a more diverse agroecosystem (Di Falco and Perrings, 2003).

At the same time, policies aiming to support or stabilize farmers' revenues – such as price support, grants, financial compensation – offer an alternative means of hedging against risks. Increasing financial support to one crop affects positively its profitability, expands its acreage and reduces the acreage of substitute crops (Chavas and Holt, 1990). Table 1 reports the different types of policies offered by the European Common Agricultural Policy (CAP, hereafter) for different cereals. For over 20 years, durum wheat producers benefited from a large set of policy instruments aimed at supporting and stabilizing their revenues. This may have created a clear incentive to grow the most supported crop, leading to a reduction in crop biodiversity. To manage risk farmers may decide to allocate their land to the single most supported crop instead of growing more species and maintaining crop biodiversity. This results in *delinking* crop biodiversity from risk management.

Table 1
Types of intervention per different crops, South of Italy 1970–1992

Crop	Type of intervention
Oat	Import protection
Soft wheat	Price support
Rye	Price support
Rice	Price support
Corn	Price support
Barley	Price support
Durum wheat	Import protection, subsidies, price support

The objective of this study is to provide a theoretical and empirical analysis of the interface between crop biodiversity loss and agricultural policies when uncertainty is taken into account. The paper proceeds as follows. The next section presents a simple dynamic model of farmer's crop choices, where yields and revenues are uncertain. This is followed by a description of the data sources and variables. The fourth section introduces the empirical approach and the fifth section reports the estimation results. The concluding remarks are presented in the final section.

2. The model

Farmers allocate their land among different crops taking into account the characteristics of the land, the characteristics of the crops, relative prices and the financial incentives offered under the CAP. By choosing the share of land to be allocated to different crops, farmers determine the level of crop biodiversity in the agroecosystem. Farmers' crop choices are affected by the sources of uncertainty. Uncontrollable factors, such as weather, pest infestations or disease outbreaks all affect yield (*production uncertainty*). The production function is accordingly stochastic. The time taken for the crop to mature causes a gap between

[3] In this paper we use the term uncertainty to describe the environment in which decision are made. The term risk is used to characterize the relevant implications of uncertainty (see Robinson and Barry, 1987; Moschini and Hennessy, 2001).

the market price when production decision are taken and when the goods are actually sold (*price uncertainty*).[4] Since, different crops respond differently to environmental or market risks, risk-averse farmers may choose to control their risk exposure through diversification (Meng, 1997; Heal, 2000; Di Falco and Perrings, 2003). This will ordinarily lead to a more diverse agroecosystem. However, this strategy may be modified by policy interventions designed to support either prices or incomes. If some species receive more financial support (e.g. price support, subsidies) than others, farmers may choose to stabilise their revenue by growing only the "most protected" species. Hence, an undesirable outcome of financial assistance to farmers may be a reduction in crop biodiversity.

Let Ω represent farmers' revenues that are dependent on the choice of farming strategy. It consists of a land allocation decision and a vector of technical inputs (such as machinery and fertilizers). It is assumed that once the land allocation decision is made the decision on technical input choice will follow. For simplicity, let us consider a farmer choosing between two sets of land management strategies. Strategy A (hereafter the 'diversity strategy') leads to crop diversification and higher aggregate crop biodiversity. Strategy B (hereafter the 'benefit strategy') implies more reliance on financial assistance from the policy maker.[5] Under this strategy farmers allocate their land to those species that receive more protection. This can have the effect of reducing crop biodiversity. In order to analyze the impact of different strategies on the crop biodiversity the function $\eta(A_t, B_t)$ is defined. This is a biodiversity loss function, where it is assumed that $\eta_A<0$ and $\eta_B>0$ and subscripts stand for partials. The dynamic connection between the strategies and the crop biodiversity level of the agroecosystem, D, is represented by the following equation;

$$\dot{D} = D_t - \eta(A_t, B_t) \tag{1}$$

where $\dot{D}$ represents the change through time of crop biodiversity and the intercept represents the cumulative past behaviour of D. The important feature of this formulation is that the level of crop biodiversity in the agroecosystem is determined by the allocation of land between crops. In order to allow for stochasticity in farmers' revenues, a Just and Pope (1978) specification is adopted.

$$\Omega(D_t, A_t, B_t) = p[f(D_t, A_t, B_t) + g(D_t, A_t, B_t)\theta] \tag{2}$$

where p is a price vector and θ is a stochastic term. The revenue function consists of two additive components. A deterministic component defined over crop biodiversity together with the two strategies, and a stochastic component that depends on the same arguments and a stochastic term that enters multiplicatively. This formulation assumes that risk affects revenues through production and provides a straightforward way to study the impacts of the two strategies on the mean and variance of the revenues. The assumptions on the function are the following:

$\Omega_D>0, \Omega_{DD}<0$

$\Omega_A>0, \Omega_{AA}<0$

$\Omega_B>0, \Omega_{BB}<0$

where the subscripts denote partial derivatives. Both cropping strategies and crop biodiversity are assumed to be positively related to farmers' revenues, although at a decreasing marginal rate. The farmer is assumed to be risk averse, displaying a Von Neumann Morgenstern utility function U, assumed to be twice differentiable, increasing and concave in revenue Ω. Therefore, the farmer's problem is to:

$$\mathrm{Max}_{A,B} \int_{t=0}^{\infty} E\{U[p(f(D_t, A_t, B_t) + g(D_t, A_t, B_t)\theta)]\}e^{-rt} \tag{3}$$

s.t. Eq. (1), $D(0)=D_0>0$, $A_t>0$ and $B_t>0$. Where E is the expectation operator with respect to θ, and r is the discount factor. The stochastic disturbance is normally distributed.[6] Setting the prices equal to one, the current value Hamiltonian for this standard optimal control problem is

$$\tilde{H} = E\{U(f(D_t, A_t, B_t) + g(D_t, A_t, B_t)\theta)\} + \lambda[D_t - \eta(A_t, B_t)] \tag{4}$$

[4] See Moschini and Hennessy (2001).

[5] The two farming activities for land allocation are assumed to be $n<A<m$ and $b<B<d \forall n, m, b, d \in \mathbb{R}^+$. It is assumed that all the available land is allocated to A and B.

[6] $\theta=dV_t$ where V_t is a Brownian motion.

where λ is the current value shadow price for the crop biodiversity state equation. The Hamiltonian is strictly concave both in A and B. Assuming an interior solution, the sufficient conditions for an optimal solution (Leonard and Van Long, 1992) are:

$$\tilde{H}_A = E\{U_\Omega[\Omega][f_A(D_t, A_t, B_t) + g_A(D_t, A_t, B_t)\theta] - \lambda\eta_A(A_t, B_t)\} = 0 \quad (5)$$

$$\tilde{H}_B = E\{U_\Omega[\Omega][f_B(D_t, A_t, B_t) + g_B(D_t, A_t, B_t)\theta] - \lambda\eta_B(A_t, B_t)\} = 0 \quad (6)$$

$$\tilde{H}_D = E\{U_\Omega[\Omega][f_D(D_t, A_t, B_t) + g_D(D_t, A_t, B_t)\theta]\} = r\lambda - \dot{\lambda} \quad (7)$$

$$\dot{D} = D_t - \eta(A_t, B_t)$$

Along the optimal path, the expected marginal increase in utility associated with an increase in one of the farming activities must be equal to the marginal change in the crop biodiversity function evaluated at the shadow price λ. Following Grepperud (1997, 2000), the above equations can be combined in the steady state equilibrium to

$$f_A(D^*, A^*, B^*) + \left[g_A(D^*, A^*, B^*) - \frac{1}{r}\eta_A(A^*, B^*)g_A(D^*, A^*, B^*)\right]\frac{\mathrm{Cov}(U_\Omega(\Omega^*, \theta)}{E(U_\Omega(\Omega^*))} = \frac{1}{r}\eta(D^*, A^*, B^*)f_D(D^*, A^*, B^*)$$

and

$$f_B(D^*, A^*, B^*) + \left[g_B(D^*, A^*, B^*) - \frac{1}{r}\eta_B(A^*, B^*)g_B(D^*, A^*, B^*)\right]\frac{\mathrm{Cov}(U_\Omega(\Omega^*, \theta)}{E(U_\Omega(\Omega^*))} = \frac{1}{r}\eta_B(D^*, A^*, B^*)f_D(D^*, A^*, B^*)$$

and D_t=$\eta_A(A^*, B^*)$. This formulation has the advantage of isolating the risk structure in each of the optimality conditions. The term $\frac{Cov(U_\Omega(\Omega*, \theta)}{E(U_\Omega(\Omega*))}$ represents the security equivalent for the stochastic component θ. The terms $g_A(D^*, A^*, B^*)-(1/r)\eta_A(A^*, B^*)g_A(D^*, A^*, B^*)$ and $g_B(D^*, A^*, B^*)-(1/r)\eta(A^*, B^*)g_B(D^*, A^*, B^*)$ represent the overall risk effect and are called the risk factors for each strategy. They are determined by the risk properties of the agricultural activity, given by the partial derivatives of the stochastic component with respect to the control variables, and the impact of the stock variable on the same component. The interaction between these is given by η_A and η_B respectively. In order to analyze the reactions of risk-averse farmers in an uncertain environment, the problem is split into two partial models. The first ignores f_B and η_B, the second ignores f_A and η_A. This reduces the complexity of the setting and provides a straightforward analysis of the forces at play. Since Ω is assumed to be normally distributed, the expected utility function may be presented as a separable function of mean and variance

$$E[U(\Omega)] = E(\Omega) - \delta\mathrm{var}(\Omega) \quad (8)$$

where δ represents risk aversion. Replacing the original objective function with Eq. (8) and setting var(Ω)=$g(x)$, where x=A, B the restated problem leads to:

$$\frac{\partial D^*}{\partial \delta} = \frac{g_x - \frac{\eta_x}{r}g_D}{H_{xD} - \frac{\eta_x}{r}H_{DD}} = \frac{g_x - \frac{\eta_x}{r}g_D}{D} \quad (9)$$

The impact of the risk factor, along with the risk property of the stock variable, determines the sign on Eq. (9). If η_x<0 it follows that D<0. If crop biodiversity has a negative impact on the stochastic component, a risk-averse farmer will hedge risk by diversifying their portfolio of crops and, in so doing will increase crop biodiversity generally.

Let us turn now to the case of the 'benefit strategy,' B. The 'benefit strategy' will dominate the 'diversity strategy' if policy stabilizes revenues more effectively (g_x<(η_x/r)g_D). In this case, the best farmer strategy will not be to rely on diversity of crops, but to focus on the crops that attract subsidies or grants. Farm financial support provided by the policy maker can be an effective way of stabilizing revenues. Therefore, farmers aware of the potential benefits of biodiversity in the management of revenue risk can switch from a more diverse to a less diverse farming regime. The role of crop

diversification in reducing farmers' risk exposure can be substituted by farm financial support and crop biodiversity is *delinked* from its potential beneficial role in risk management. Furthermore, higher degrees of risk aversion will strengthen this result.[7]

3. Data sources and variables

Assuming that the representative farmer's decision making process described in the previous section scales up to the aggregate level, the hypotheses stemming from the model results can be tested by using aggregate data. The data are drawn from the *Annuario di Statistica Agraria* (ISTAT) and from the *Bollettino Statistico* (Banca d'Italia) and are about the cereal production in the South of Italy. This geographical area is known to be a *megadiversity* area for cereals (Vavilov, 1951; Harlan, 1971) and is composed of eight regions.[8] The time span is from 1970 to 1993. In the period considered, all the regions had high development priority (Objective 1 areas under the CAP). For the purpose of the empirical analysis variables are defined in the following way. The role of crop biodiversity in supporting and stabilizing revenues (diversity strategy) is measured through an index of spatial crop diversity: the Shannon index (Magurran, 1988; Meng et al., 1998). This is a widely applied index of spatial diversity and is equal to $H=-\sum_i p_i \ln p_i$ where p_i is the share of land planted to the ith crop. The role of agricultural policy in supporting and stabilizing revenues (benefit strategy) is captured by total financial assistance to farms offered by the CAP, in Italian Lire. Table 2 reports the definition of variables.

Table 2
Definition of Variables

Variables	Definition
Farm revenues	Cereals revenue in Italian Lire
Diversity strategy	Shannon index for spatial biodiversity
Benefit strategy	Total financial assistance to farms offered by the CAP, in Italian Lire

4. Empirical approach

In order to test the role of the two farming strategies on revenues, a Just and Pope (1978, 1979) stochastic specification is adopted. The empirical strategy involves two steps. In the first step, the impact of the strategies on the stochastic revenue function is estimated. The mean and the variance functions are estimated using a three-stage feasible generalized least squares (GLS) procedure (Judge et al., 1982, pp. 439–441). In the second step, the hypothesis of substitutability between crop biodiversity and policy in the management of revenue risk is tested by the calculation of the elasticity of substitution. Both variable definitions and an auxiliary regression between the explanatory variables signalled the presence of severe collinearity. To avoid the impact of collinearity on the estimates an auxiliary regression between the diversity strategy and the benefit strategy and their residuals are used to "instrument" for the diversity strategy. Assuming that both mean and variance functions are Cobb–Douglas

$$\Omega = e^{\beta_0}\left(\prod_{i=1}^{2} X_i^{\beta_i}\right)\left(\prod_{h=1}^{8} e^{\delta L}\right)\left(\prod_{k=1}^{24} e^{\gamma Y}\right) + u \qquad (10)$$

$$u^2 = [h(X_i, \phi, \theta]^2 = e^{\phi_0}\left(\prod_{i=1}^{2} X_i^{\phi_{1i}}\right)e^{\upsilon} \qquad (11)$$

$i=A, B$.

Hence, the mean equation is set to Eq. (10) and the variance function is set to Eq. (11). Furthermore, a set of locational and time dummies are added to take account of regional and time effects. The results are reported in Table 2.[9] The Cobb–Douglas revenue function has an important shortcoming. The elasticity of substitution the crop biodiversity and policy intervention is constrained to be identically equal to one (Chambers, 1988). This constraint has been relaxed by adding an interaction term.

5. Estimation results

Eqs. (10) and (11) are estimated to test the role of the two strategies on the mean and variance of the

[7] Note that this is a very general result that holds without specifying any form of risk aversion.

[8] The regions include Abruzzo, Molise, Campania, Basilicata, Puglia, Calabria, Sicily and Sardinia.

[9] Data are scaled by their geometric means.

Table 3
Estimation results of the mean and variance function

Variables	Mean function	Variance function
Diversity strategy	0.38* (0.013)	−0.19* (0.36)
Benefit strategy	0.18* (0.015)	−1.63* (0.41)
Interaction term	0.44* (0.032)	3.5* (0.74)
Constant	0.018 (0.021)	
Sigma		0.26* (0.013)

N=192; Adj-R^2=0.38; F-test=20.57*; Wald test=405*.
Breusch–Pagan test=44.09*; Significance level: *=1%.
Standard errors are in parentheses.

farm revenues. Table 3 reports the estimation results. The estimation of the stochastic revenue function indicates that the estimated coefficients for the diversity strategy and for the benefit strategy are statistically significant. Both strategies are positively correlated to the mean revenue function and negatively correlated to the variance of the revenues. Crop biodiversity, at least in the long run, has a role in sustaining and stabilizing farm revenues. However, it is not possible to determine whether this result arises from market risk or from production risk. Therefore, it can be concluded that both of the strategies support mean income and, more importantly, they are both risk-reducing strategies.

In order to assess the trade-off between the two strategies, the elasticity of substitution between A and B is measured. In addition, an interaction term (ϕ_{int})[10] between land management regimes has been inserted in the estimated function. This provides a partial measure of the influence of the benefit strategy relative to the diversity strategy. This is a straightforward methodology for calculating the elasticity of substitution from the estimated coefficients Boisvert (1982). Hence,

$$\in_{A,B} \frac{-(\phi_A+\phi_B)}{-(\phi_A+\phi_B)-(2\phi_{\text{int}}\phi_B\phi_A)/\phi_B\phi_A}$$

and the elasticity of substitution of the two strategies with respect to the variance function is

$$e_{A,B} = -1.3$$

This suggests that there is a substantial potential for substituting diversity and benefit strategies. The estimated coefficient on the interaction terms ϕ_{int} is significant in the variance function, suggesting that higher levels of farm support dampens the revenue stabilizing effect of crop biodiversity.

[10] The interaction term is constructed by multiplying the crop biodiversity variable with the policy variable.

6. Concluding remarks

This study has presented a framework for analyzing the impact of agricultural price and income support schemes on crop biodiversity. A simple dynamic model of farmers' choices over crop biodiversity in an uncertain setting has been estimated by using data on cereal production in the South of Italy. To test the potential substitutability between crop biodiversity and financial assistance, a Just and Pope revenue function is specified, and the impacts of crop biodiversity and financial assistance to farmers on the mean and the variance of revenues are estimated. It is found that both crop biodiversity and financial assistance are significant determinants of farm revenues, and that risk aversion is an important driving force to crop biodiversity conservation. Compared to the existing literature, the result of the estimated coefficient of crop biodiversity is statistically more robust. This is possibly due to the fact that this study focuses on a *Vavilov megadiversity* area and that the time span considered is considerably longer than those in the previous studies.

The negative and significant relationships found between crop biodiversity and variance of revenues, and financial assistance and variance of revenues reveal that both crop biodiversity and financial assistance are equally viable means of stabilizing farmers' revenues. This indicates that they are both risk-reducing strategies. Risk-averse farmers reduce the uncertainty they face by allocating land to different crop species. Other things being equal, a risk-averse farmer will choose a higher level of crop biodiversity than a risk-neutral farmer. However, policies intended to stabilize income by supporting particular species may change this behaviour. If the support is concentrated on a few crops, farmers will specialize on these few crops, causing a reduction in crop biodiversity.

In other words, the results reported in this paper disclose that risk aversion and crop biodiversity can be *delinked*. Data limitations prevented an analysis of

the multiple sources of revenue uncertainty. Nevertheless, this paper has an important message for the ongoing debate about the relationship between agricultural assistance and the environment. Agricultural intensification is not the only 'side effect' of agricultural policies. Agricultural policies also impact farmers' risk attitudes, thereby affecting their land management strategies and crop choices. This is an important link that stresses the need for coordination between environmental and agricultural policies in an uncertain environment.

Acknowledgement

The authors acknowledge the helpful comments of two anonymous reviewers. We would also like to thank Sverre Grepperud, Jim Shortle, Ekin Birol, Eoghan Garvey and Michael Cuddy for their helpful comments and suggestions. The usual disclaimer applies.

References

Abler, D., Shortle, J., 1992. Environmental and farm commodity policy linkages in the U.S. and the E.C. European. Journal of Agricultural Economics 19 (2).

Banca d'Italia, Bollettino statistico, Various years.

Birol, E., Smale, M., and Gyovoi, A., forthcoming. Farmer management of agricultural biodiversity in Hungary's transition economy. In: Smale M., (Ed.), Valuing Crop Biodiversity: On-farm Genetic Resources and Economic Change. CAB International Publishing, Wallingford, Ox-fordshire, UK.

Boisvert, R.N., 1982. The translog production function: its properties, its several interpretations and estimation problems. Department of Agricultural Economics, Cornell University. Research Bulletin: A.E. Res. 82–88.

Brush, S.B., Taylor, J.E., Bellon, M.R., 1992. Technology adoption and biological diversity in Andean potato agriculture. Journal of Development Economics 39 (2).

Chambers, R.G., 1988. Applied Production Analysis: A Dual Approach. Cambridge University Press, Cambridge.

Chavas, J.P., Holt, T., 1990. Acreage decisions under risk: the case of corn and soybeans. American Journal of Agricultural, 72.

Di Falco, S., Perrings, C., 2003. Crop genetic diversity, productivity and stability of agroecosystems: a theoretical and empirical investigation. Scottish Journal of Political Economy 50, n.2.

Fraser, R., 1994. Land heterogeneity and the effectiveness of cap set-aside. Journal of Agricultural Economics 47 (2).

Grepperud, S., 1997. Poverty, Land Degradation and Climatic Uncertainty. Oxford Economic Papers, 49.

Grepperud, S., 2000. Optimal soil depletion with output and price uncertainty. Environment and Development Economics 5 (3).

Harlan, J.R., 1971. Agricultural origins: centers and noncenters. Science 174, 468–474.

Heal, G., 2000. Nature and the Marketplace: Capturing the Value of Ecosystem Services. Island Press, New York.

Heisey, P.W., Smale, M., Byerlee, D., Souza, E., 1997. Wheat rusts and the costs of genetic diversity in the Punjab of Pakistan. American Journal of Agricultural, 79.

Istat, Annuario dell' Agricoltura italiana, Various years.

Judge, G.G., Hill, R.C., Griffiths, W., Lutkepohl, H., Lee, T.-C., 1982. Introduction to the Theory and Practise of Econometrics. John Wiley and Sons, New York.

Just, R.E., Antle, J.M., 1990. Interaction between environmental and agricultural policies: a conceptual framework. American Economic Review 80, 2.

Just, R.E., Bockstael, N. (Eds.), 1991. Commodity and Resource Policies in Agricultural Systems. Spinger Verlag, Berlin.

Just, R.E., Pope, R.D., 1978. Stochastic representation of production functions and econometric implications. Journal of Econometrics, 7.

Just, R.E., Pope, R.D., 1979. Production function estimation and related risk considerations. American Journal of Agricultural Economics.

La France, J., 1992. Do increased commodity prices lead to more or less soil degradation? Australian Journal of Agricultural Economics 2 (1).

Leathers, H.D., Quiggin, J.C., 1991. Interaction between agricultural and resource policy: the importance of attitude toward risk. American Journal of Agricultural Economics.

Leonard, D., Van Long, N., 1992. Optimal Control Theory and Static Optimization in Economics. Cambridge University Press, Cambridge.

Lewandrowski, J., Tobey, J., Cook, Z., 1997. The interface between agricultural assistance and the environment: chemical fertilizer consumption and area expansion. Land Economics 73 (3).

Magurran, A.E., 1988. Ecological Diversity and its Measurement. Croom Helm, London, UK.

Meng, E.C.H., 1997. Land Allocation Allocation Decisions and In situ Conservation of Crop Genetic Resources: The Case of Wheat Landraces in Turkey. Agricultural and resource economics. University of California, Davis.

Meng, E.C.H, Smale, M., Bellon, M.R., and Grimanelli, D., 1998. Definition and measurement of crop diversity for economic analysis. In: Smale M. (Ed.), Farmers, Gene Banks, and Crop Breeding. Kluwer and International Maize and Wheat Improvement Center, Dordrecht and Mexic; Meyer, D.F.J., 1988. Two moment decision models and expected utility maximization, American Economic Review, 77.

Moschini, G., Hennessy, D.A., 2001. Uncertainty, risk aversion, and risk management for agricultural producers. In: Gardner, Rausser, G. (Eds.), Handbook of Agricultural Economics. Elsevier Science, Amsterdam, The Netherlands.

Qualset, C.O., McGuire, P.E., Warburton, M.L., 1995. 'Agro-biodiversity': key to agricultural productivity. California Agriculture 49 (6).

Robinson, L.J., Barry, P.J., 1987. The Competitive Firm's Response to Response to Risk. Mac Millan, New York.

Smale, M., Hartell, J., Heisey, P.W., Senauer, B., 1998. The contribution of genetic resources and diversity to wheat production in the Punjab of Pakistan. American Journal of Agricultural, 80.

Smale, M., Bellon, M.R., 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., Meng, E., Brennan, J.P., Hu, Ruifa, 2003. Determinants of spatial diversity in modern wheat: examples from Australia and China. Agricultural Economics, 28.

Van Dusen, E., 2000. In situ Conservation of Crop Genetic Resources in the Mexican Milpa System. Agricultural and Resource Economics. University of California, Davis.

Vavilov, N.I., 1951. The origin, variation, immunity and breeding of cultivated plants. Chronica of Botanica, 13.

Widawsky, D., Rozelle, S., 1998. Varietal diversity and yield variability in Chinese rice production. In: Smale, M. (Ed.), Farmers, gene banks, and crop breeding. Kluwer, Boston.

Wood, D., Lenné, J.M., 1999. Agrobiodiversity: Characterization, Utilization and Management. CABI, Wallingford.