The World's Largest Open Access Agricultural & Applied Economics Digital Library

This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.

Help ensure our sustainability.

Give to AgEcon Search

AgEcon Search
http://ageconsearch.umn.edu
aesearch@umn.edu

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

INTERNATIONAL FOOD
POLICY RESEARCH INSTITUTE
sustainable solutions for ending hunger and poverty
IFPRI®

ENVIRONMENT AND PRODUCTION TECHNOLOGY DIVISION OCTOBER 2005

EPT Discussion Paper 143

Impact of Global Warming on Chinese Wheat Productivity

Liangzhi You, Mark W. Rosegrant, Cheng Fang, and Stanley Wood

---

2033 K Street, NW, Washington, DC 20006-1002 USA • Tel.: +1-202-862-5600 • Fax: +1-202-467-4439 ifpri@cgiar.org
www.ifpri.org

IFPRI Division Discussion Papers contain preliminary material and research results. They have not been subject to formal external reviews managed by IFPRI's Publications Review Committee, but have been reviewed by at least one internal or external researcher. They are circulated in order to stimulate discussion and critical comment.

Copyright 2005, International Food Policy Research Institute. All rights reserved. Sections of this material may be reproduced for personal and not-for profit use without the express written permission of but with acknowledgment to IFPRI. To reproduce the material contained herein for profit or commercial use requires express written permission. To obtain permission, contact the Communications Division at ifpri-copyright@cgiar.org.

ABSTRACT

Climate change continues to have major impact on crop productivity all over the world. While many researchers have evaluated the possible impact of global warming on crop yields using mainly indirect crop simulation models, there are relatively few direct assessments on the impact of observed climate change on past crop yield and growth. We use a 1979-2000 Chinese crop-specific panel dataset to investigate the climate impact on Chinese wheat yield growth. We find that a 1 percent increase in wheat growing season temperature reduces wheat yields by about 0.3 percent. This negative impact is less severe than those reported in other regions. Rising temperature over the past two decades accounts for a 2.4 percent decline in wheat yields in China while the majority of the wheat yield growth, 75 percent, comes from increased use of physical inputs. We emphasize the necessity of including such major influencing factors as physical inputs into the crop yield-climate function in order to have an accurate estimation of climate impact on crop yields.

Keywords: global warming, wheat yield, production function, marginal impact, panel data

TABLE OF CONTENTS

Impact of Global Warming on Chinese Wheat Productivity

Liangzhi You,* Mark W. Rosegrant,[1] Cheng Fang, † and Stanley Wood[1]

1. INTRODUCTION

The adoption of modern varieties and the increased use of irrigation and fertilizers during Green Revolution dramatically increased crop yields all over the world (Evenson and Gollins 2003b; Rosegrant and Cline 2003). The Green Revolution enabled food production in developing countries to keep pace with population growth (Conway and Toenniessen 1999). Crop yield growth has slowed since 1990s (Evenson and Gollins 2003b; Rosegrant and Cline 2000). But continued crop yield increases are required to feed the world in the 21st century (Rosegrant and Cline 2003; Cassman 1999) given the continuing decline of area suitable for grain production due to urbanization and industrialization. Food security, in particular in developing countries, remains a challenge. This challenge is made worse by the adverse effect of predicted climate change in most food insecure developing countries (Rosenzweig and Parry 1994).

Given the large body of research that has been done to quantify the contributions of crop productivity (Evenson and Gollins 2003a; Evenson and Gollin 2003b), we know factors such as modern varieties, increasing input use, and better farm management contribute greatly to crop yield growth. However, our knowledge on the impact of climate on crop productivity remains quite uncertain. While many researchers have evaluated the possible impact of global warming

---

*Liangzhi You, Senior Scientist, Environment and Production Technology, IFPRI, l.you@cgiar.org; Mark Rosegrant, Division Director and Senior Research Fellow, Environment and Production Technology Division, IFPRI, m.rosegrant@cgiar.org; Stanley Wood, Senior Scientist, , Environment and Production Technology Division, IFPRI, s.wood @cgiar.org

† Cheng Fang, Asia Officer/Economist, Economic and Social Development, Food and Agriculture Organization of the United Nations, Via delle Terme di Caracalla- 00100, Rome, D-875, Italy

on crop yields using mainly indirect crop simulation models (e.g., Rosenzweig and Parry 1994; Brown and Rosenberg 1997; Reilly *et al*. 2003), there are relatively few direct assessments on the impact of observed climate change on past crop yield and growth except for a few studies (Nichalls 1997; Carter and Zhang 1998; Naylor *et al.* 2002; Lobell and Asner 2003; Peng *et al*. 2004). In a recent study, Peng *et al* (2004) reported that rice yields decline with higher night temperatures. Lobell and Asner (2003) showed that corn and soybean yields in the US could drop by as much as 17 percent for each degree increase in the growing season temperature. Though climate is the major uncontrollable factor that influences crop development, it is difficult to separate this influence from other factors such as the increased use of modern inputs and intensified crop management that were introduced during the Green Revolution. In fact, one major concern for the above-mentioned studies is the simplification of approximating such non-climate contributions as a linear trend (Gu 2003; Godden, Gatterham and Drynan 1998).

In this paper, we use crop-specific panel data to investigate the climate contribution to Chinese wheat yield growth. We find that global warming has a significantly negative impact on wheat yield in China, but the magnitude of impact is less than those reported by previous studies in other regions.

2. DATA AND METHOD

We use time series and cross-section data from 1979 to 2000 for twenty-two major wheat producing provinces in China and the corresponding climate data such as temperature, rainfall, and solar radiation during this period. Wheat input and output data are from State Statistics Yearbook (1979-2002) and China's Rural Statistical Yearbook (1979-2002) published by China's National Statistical Bureau, and China Agricultural Cost and Return Yearbook (1979-2002) published by China's Price Bureau. Climate data are from Climate Research Unit at

University of East Anglia. The dataset used is CRU TS 2.0 (Mitchell et al. 2004). The provincial climate parameters are calculated by averaging all the values of those pixels within the provinces. China grows both winter wheat and spring wheat. The majority of wheat production in China, about 80-90 percent, is winter wheat. Winter wheat is grown throughout most of eastern and southern China while spring wheat in northeast and western China. Both winter and spring wheat are grown in Northern China. The growing season for wheat varies from province to province. The annual climate data are monthly averages during the wheat growing seasons, taking account of the changing growing seasons by province.

The analytical challenge is to separate the non-climate effect on crop yields from the climate change effect. We hypothesize the crop yield as a function of crop inputs, technology, management, land quality, and climate factors. The initial explanatory variables for the yield equation include inputs such as land, labor, chemical fertilizer, seeds, pesticide, machinery, irrigation and other physical inputs; regional production specialization; climate variables such as temperature, precipitation and solar radiation; a set of regional dummy variables; and two institutional change dummy variables. In this study, the labor input is measured in terms of working days from the survey data. Previous study (Stavis 1991) found the marginal return to labor input was negligible due to the huge labor surplus in agricultural in China. Our own estimation confirms this finding: labor and draft animals have a negative sign for wheat yield equation, indicating the impact of these two variables on yield were negligible. Therefore the inputs of labor and draft animal are not included in the model. The physical inputs are measured in expenses per unit harvested area, and are selected based upon the sign and level of statistical significance. We included chemical fertilizer, seeds, pesticide, machinery, individually and combined the rest of inputs into an aggregated category of “other inputs”. The regional production specialization variable is represented by the share of wheat area in total crop area in that province. This variable is created to reflect the other factors such as soil quality and other regional government supports to wheat production. It is expected that the regions with a higher share of the crop production have better suitable land and better environment for wheat production and therefore higher wheat yield. Admittedly, this variable may be a potentially endogenous variable, as the trade-off between how much area to grow in a grain crop and how much to grow in a cash crop depends on trade-offs that involve yields and relative productivity and profitability. The Hausman-Wu procedure (Wu 1973; Hausman 1978) was used to test the exogeneity of the share of area under wheat. Predicted wheat areas are not significant in the test equation, indicating that it is exogenous for the yield equation. A set of regional dummy variables are used to represent time-persistent, regional differences in social, economic, and natural endowments not accounted for by the other variables. During our study period (1979 – 2000) China undertook major policy reforms: the Household Responsibility System in the early 1980s and the new development in agricultural policy in late 1990s. We used time-specific dummy variables to reflect these two major policy changes. Finally, a time trend is used to represent the factor due to technological change during this period.

Finally, a Cobb-Douglas form of wheat yield function is specified as follows:

$$\ln Yield_{it} = (\alpha_0 + \alpha_1 t) + \sum_j \beta_j \ln X_{jit} + \gamma \ln S_{it} + w \ln Climate_{it} + \sum_{r=2}^{7} \delta_r D_r + \sum_{I=1}^{2} r_I D_I + \varepsilon_{it} \qquad (1)$$

where ln is natural log, $t = 1, 2, \ldots, 22$ denotes observations from the years from 1979 to 2000. $Yield_{it}$ refers to wheat yield for Chinese province i at time t (the time trend from 1979 to 2000); X represents the conventional inputs per hectare of sown wheat area including seeds, fertilizer, pesticide, machinery, and other inputs such as irrigation, manure, and animal power; S denotes the share of wheat area in total sown area, reflecting the regional specialization (including land quality) in wheat production; *Climate* is the climate variables including temperature, rainfall and solar radiation during wheat growing season. We approximate the solar radiation with cloud cover expressed in percentage. Therefore, the higher the cloud cover, the weaker the run radiation. We include a set of regional dummy variables, D_r, to represent time-persistent, regional difference in social, economic and natural endowments not accounted for by other variables[‡]. Time-specific dummy variables, D_l, capture the effects of two major policy reforms in agriculture from 1979 to 1985, and from 1995 to 2000. $\alpha, \beta, \gamma, w, \delta, r$ are parameters to be estimated and ε is the error term.

3. ESTIMATION AND RESULTS

We first perform Augmented Dickey-Fuller Unit Root Test to test the stationarity of both dependent and independent variables. No problems are found. The model is estimated by SAS package. Since the OLS (ordinary linear square) estimation has autocorrelation problems, we also estimated Equation (1) using an autoregressive error model with one year lag (AR1). The constant variance error (no heteroscedasticity) assumptions are examined by plots between the predicted values and residuals using AR1 estimation. The plot (not reported here) shows that the assumptions for Equation (1) is reasonably held. We also examine another plot between predicted value and time trend and found no autocorrelation problem. Another potential problem may be omitted variable bias where some temperature-related variables (such as disease or pests) that affect wheat yield but have been left out of Equation (1). We perform the Ramsey (1969) regression specification error test (RESET) for omitted variables. The test is passed (P> 28 percent). The assumptions of normal distribution for errors, outliers, and linearity are also

---

[‡] The seven regions in China are: Northeast (Heilongjiang, Liaoning, Jilin), North (Beijing, Tianjin, Hebei, Henan, Shandong, Shanxi, Shaanxi), Northwest (Nei Mongguo, Ningxia, Xinjiang, Tibet, Qinghai, Gansu), Central (Jianxi, Hunan, Hubei), Southeast (Shanghai, Jiangsu, Zhejiang, Anhui), Southwest (Sichuan, Guizhou, Yunnan), South (Gangxi, Fujian, Hainan, Guangdong).

diagnosed and these assumptions are found to still hold. In addition, we estimate the equation with both fixed-effects and random-effects but found little difference.

The estimated results are reported in Table 1. The OLS (ordinary linear square) estimates for all parameters for physical inputs are significant at the 10 percent level or below with the expected signs.

Table 1--Estimated wheat yield function in China 1979-2000. Dependent variable =Ln(wheat yield). Numbers in parentheses are t-values. *, ** and * represent 0.10, 0.05 and 0.01 levels of statistical significance, respectively.**

Explanatory variables	OLS	AR1
Constant	7.534(32.12)***	7.482(33.22)***
Ln Fertilizer	0.127(1.60)***	0.136(4.47)***
Ln Seeds	0.180(4.64)***	0.153(4.19)***
Ln Pesticide	0.056(4.71)***	0.051(4.66)***
Ln Machinery	0.024(1.95)**	0.027(2.29)**
Ln Other inputs	0.043(1.60)*	0.042(1.76)*
Ln Share of wheat	0.065(2.32)**	0.057(2.41)**
Ln Temperature	-0.269(-10.01)***	-0.268(-11.97)***
Ln Precipitation	-0.043(-1.34)	-0.039(-1.26)
Ln Cloud cover	0.083(0.96)	0.067(0.78)
Time	0.021(4.96)***	0.021(4.15)***
Regional Dummy (Northeast)	-0.141(-2.29)**	-0.193(-3.44)***
Regional Dummy (North)	-0.113(-0.29)	-0.120(-0.35)
Regional Dummy (Northwest)	-0.414(-9.88)***	-0.407(-9.47)***
Regional Dummy(Central)	-0.119(-2.49)***	-0.107(-2.63)***
Regional Dummy(Southeast)	-0.011(-0.27)	-0.015(-0.43)
Regional Dummy(Southwest)	-0.387(-7.74)***	-0.403(-9.16)***
Institutional Dummy (1979-1985)	0.051(1.40)	0.048(1.03)
Institutional Dummy (1995-2000)	-0.093(-2.54)***	-0.098(-2.11)*
Degree of freedom	462	461
Adjusted R^2	0.801	0.835

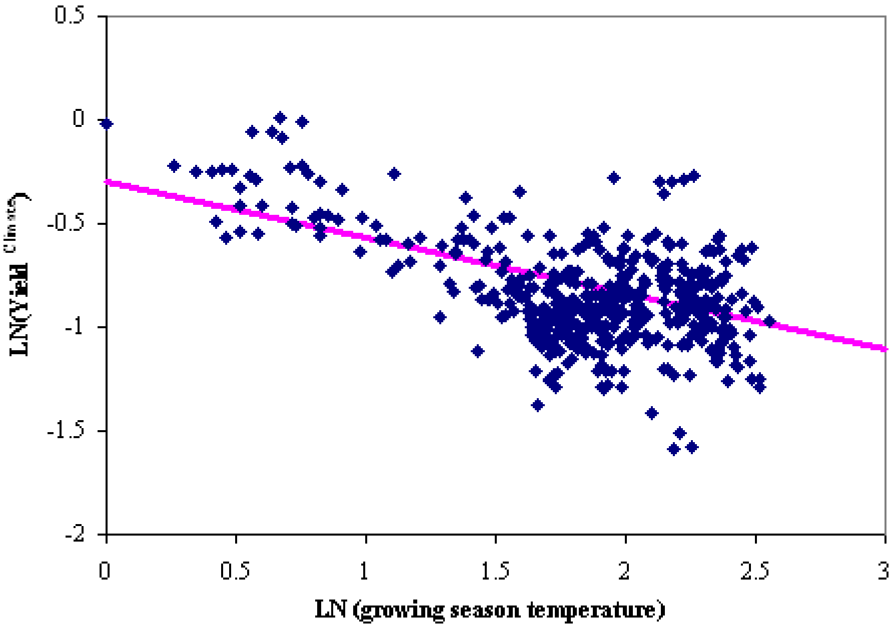
The AR1 estimates differ slightly from OLS with some improvements, and all parameters are still significant at the 10 percent level or below. So we will only refer to the AR1 results in the rest of the paper. As expected, the regional specialization is positively correlated with wheat productivity. The regional dummies in Northeast, Northwest, Central, Southwest China are statistically significant. While the institutional dummy between 1979 -1985 has a positive sign, meaning the policy reform during this period does contribute to the wheat productivity growth, it is not significant. On the other hand, the change in agricultural policy after 1995 has a negative impact on wheat productivity that is measurable at the 10 percent level of statistical significance. We find no significant relationships between wheat yield and rainfall or solar radiation. However, the temperature has a significantly negative effect on wheat yield. Because we use double-log functional form, the estimated coefficients are elasticities in the above equation. The coefficient for temperature, –0.27, means a one percent increase of growing season temperature could reduce wheat yield by 0.27 percent.

Since our major focus is to measure the contribution of growing season temperature on wheat yield, it is convenient to treat other terms in Equation (1) as “residual” effect. By subtracting the non-climate terms from the wheat yield, we single out the wheat yield change due to climate change. We define $Yield^{Climate}$ as:

$$\ln Yield^{C\lim ate} = \ln Yield_{it} - (\alpha_0 + \alpha_1 t) - \sum_{j=1}^{5} \beta_j \ln X_{jit} - \gamma \ln S_{it} - \sum_{r=2}^{7} \delta_r D_r - \sum_{I=1}^{2} r_I D_I \qquad (2)$$

The following figure shows the relationship between this net wheat yield change and the relative change of wheat growing season temperature. The downward slope of the trend line clearly shows the negative impact of rising temperature on wheat yield in China.

Figure 1--Correlation between growing season temperature and wheat yield change due to climate change. The slope for the regression line is –0.268, R^2=0.84, n=461.



Across wheat growing provinces in China, the growing season temperatures vary from 5 to18°C. Therefore, 1°C increase of temperature is equivalent to 5.6 to 20 percent of relative change. Since our result shows one percent increase of growing season temperature could reduce wheat yield by 0.27 percent, this means 1.5 to 5.4 percent decline of wheat yield for each 1°C increase of temperature in China. This estimated effect of temperature on wheat yield is smaller than the previous three studies: rice in Philippines (Peng *et al. 200*4), wheat in Australia (Nichalls 1997), corn and soybean in USA (Lobell and Asner 2003). Table 2 shows the comparison among these studies. The reason for this is two-fold: this might reflect the nonlinear effect of physical inputs and crop management on crop yields (Gu 2003; Godden, Batterham and Drynan 1998), or imply that the temperature effect on crop yields varies from one region to another, or from crop to crop.

Table 2--Comparison: Impact of $1^{o}C$ increase of growing season temperature

Study	Crop	Location	Impact
Nichalls (1997)	Wheat	Australia	+30~+50%
Lobell & Asner (2003)	Corn, Soybean	USA	-17%
Peng et al (2004)	Rice	Philippines	-10%
Our Study	Wheat	China	-2%~-5%

To assess the relative contribution of rising growing season temperature on the wheat yield, we take the first derivative of Equation (1) with respect to *t* (Lin 1992; Fan and Pardey 1997).

$$\frac{\partial \ln Yield_{it}}{\partial t} = \alpha_1 + \sum_j \beta_j \frac{\partial \ln X_{jit}}{\partial t} + \gamma \frac{\partial \ln S_{it}}{\partial t} + w \frac{\partial \ln C\lim ate_{it}}{\partial t} + \sum_{r=2}^{7} \delta_r \frac{\partial D_r}{\partial t} + \sum_{r=1}^{2} r_I \frac{\partial D_I}{\partial t} + \frac{\partial \varepsilon_{it}}{\partial t} \tag{3}$$

Table 3 reports the growth accounting based on the estimate of the wheat yield function in column 1 of Table 1. The total wheat yield growth from 1979 to 2000 was 85.41 percent. From the accounting in Table 3, it appears that 75.23 percent of this yield growth comes from increased use of physical inputs. Rising temperature attributed to 2.37 percent of decline in wheat yield. This negative contribution is relatively small compared to that of physical inputs, which underlines the necessity of including physical inputs in the regression analysis of crop yield-climate interactions.[§]

Table 3--Accounting for wheat yield growth. The estimated coefficients are taken from Table 1, and the change in explanatory variable refers to percentage growth of that variable from 1979-81 to 1998-2000 (three year averages are taken to avoid atypical year). The numbers in parentheses are the percentage shares of contribution to total wheat yield growth, with total yield growth set at 100.

			1979-2000	
				Contribution to growth
Explanatory variable		Estimated coefficient (1)	Change in explanatory variable (2)	(percentage) (3)=(1)X(2)
INPUTS				**64.25** **(75.23)**
	Chemical fertilizer	0.136	255.00	34.68 (40.60)
	Pesticide	0.051	220.33	11.13 (13.03)
	Machinery	0.027	324.62	8.70 (10.19)
	Seeds	0.153	64.39	9.85 (11.53)
	Other inputs	0.043	-2.43	-0.10 (-0.12)
SPECIALIZATION		0.057	-7.80	**-0.44** **(-0.52)**
TEMPERATURE		-0.268	7.57	**-2.03** **(-2.37)**
RESIDUAL*				**23.63** **(27.67)**
TOTAL GROWTH				**85.41** **(100)**

Note: *An accounting residual derived by netting out the effects of inputs, specialization and temperature. Here it mainly reflects the impact of agricultural R&D and institutional change.

[§] Simple de-trending of wheat yield and temperature while ignoring the physical inputs finds no significant relationship between wheat yield and temperature ($R^2 < 0.001$).

4. CONCLUSION

Since the introduction of rural reforms in China in the late 1970s, agricultural production and productivity for wheat has increased significantly. While the majority of wheat productivity increase is due to increase use of physical inputs and the institutional change, the gradual increase in growing season temperature in the last few decades has had a measurable effect on wheat productivity. In this paper, we have evaluated the impacts of climate and non-climate factors on wheat yield growth in China, and find that a one percent increase in wheat growing season temperature reduces the yield by about 0.3 percent. The rising temperature from 1979-2000 cut wheat yield growth by 2.4 percent. There is a deficiency in the current literature about how to measure the influence of climate on productivity. Authors frequently fail to distinguish between climate factors and the influence of modern inputs and management practice on productivity. We emphasize the necessity of including such major influencing factors as physical inputs into crop yield-climate functions in order to have an accurate estimation of climate impact on crop yields. With so much uncertainty on the potential impacts of climate change, it is essential to first evaluate what past climate changes have had on agricultural productivity. Our study demonstrates a clear need to synthesize climate and crop-specific management and inputs data in order to investigate the impact of climate change.

In China, providing enough food to feed over 13 billion people is always a challenge. There is an increasing concern about the impacts of climate change on Chinese food security. Our study shows that climate change does have a measurable negative impact on wheat productivity. This negative impact would probably become worse with accelerating change of future climate. Our study demonstrates the need to consider climate change and its effects on crop productivity in order to meet the food security goals in China as well as in other developing countries. There is also a need to extend such studies to other regions, in particular to food insecure countries where climate change would have the most severe adverse impact on crop productivity.

REFERENCES

Brown, R. A. and N. J. Rosenberg. 1997. Sensitivity of crop yield and water use to change in a range of climatic factors and CO_2 concentrations: a simulation study applying EPIC to the central USA. *Agricultural and Forest Meteorology* 83: 171-203.

Carter, C. and B. Zhang. 1998. Weather factor and variability in China's grain supply. *J Comparative Econ* 26: 529-543.

Cassman, K.G. 1999. Ecological intensification of cereal production systems: yield potential, soil quality, and precision agriculture. *Proc. National Academies of Science USA* 96: 5952-5959

Conway, G. and G. Toenniessen. 1999. Feeding the world in the twenty-first century. *Nature* 402: C55-C58.

Evenson, R.E. and D. Gollin. 2003. *Crop variety improvement and its effect on productivity: the impact of international agricultural research*. CAB International, Wallingford, UK.

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

Fan, S. and P. Pardey. 1997. Research, productivity, and output growth in Chinese agriculture. *J. of Development Economics* 53: 115-137.

Godden, D., R. Batterham, and R. Drynan. 1998. Comment on 'Climate change and Australian wheat yield' *Nature* 391: 447.

Gu, L. 2003. Comment on 'Climate and management contributions to recent trends in U.S. agricultural yields' *Science* 300: 1505b.

Hausman, J. 1978. Specification tests in econometrics. *Econmetrica* 46: 1251-1271.

Lin, J.Y. 1992. Rural reforms and agricultural growth in China. *American Economic Review* 82: 34-51.

Lobell, D. and G. Asner. 2003. Climate and management contributions to recent trends in U.S. agricultural yields. *Science* 299: 1032.

Mitchell, T.D., T.R. Carter, P.D. Jones, M. Hulme, and M. New. 2005. A comprehensive set of climate scenarios for Europe and the global. *Journal of Climate* (submitted).

Naylor, R., W. Falcon, N. Wada, and D. Rochberg. 2002. Using El Niño-southern oscillation climate data to improve food policy planning in Indonesia. *Bulletin Indonesian Economic Studies* 38: 75-88.

Nichalls, N. 1997. Increased Australian wheat yield due to recent climate trends. *Nature* 387, 484-485, 1997

Peng, S., J. Huang, J.E. Sheehy, R.C. Laza, R.M. Visperas, X. Zhong, G.S. Centeno, G.S. Khush, and K.G. Cassman. 2004. Rice yields decline with higher night temperature from global warming. *Proc. National Academies of Science USA* 101, 9971-9975, 2004

Ramsey, J. B. 1969. Tests for specification error in classical linear least squares regression analysis. Journal of the Royal Statistical Society. B31: 250-271.

Reilly, J., F. Tubiello, B. McCarl, D. Abler, R. Darwin, K. Fuglie, S. Hollinger, C. Izaurralde, S. Jagtap, J. Jones, L. Mearns, D. Ojima, E. Paul, K. Paustian, S. Riha, N. Rosenberg, and C. Rosenzweig. U.S. agriculture and climate change: new results. *Climatic Change* 57: 43-69, 2003.

Rosegrant, M.W., Cline, S. A., Global food security: challenge and policies. *Science* 302, 1917-1920, 2003

Rosenzweig, C., Parry, M., Potential impact of climate change on world food supply. *Nature* 367, 133-138, 1994

Stavis, B., Market reforms and changes in crop productivity: insight from China. *Pacific Affairs*, Vol.64:371-383, 1997

Wu, D. 1973. Alternative Tests of Independence Between Stochastic Regressors and Disturbances. *Econmetrica,* 41: 733-750, 1973

LIST OF EPTD DISCUSSION PAPERS

01 Sustainable Agricultural Development Strategies in Fragile Lands, by Sara J. Scherr and Peter B.R. Hazell, June 1994.

02 Confronting the Environmental Consequences of the Green Revolution in Asia, by Prabhu L. Pingali and Mark W. Rosegrant, August 1994.

03 Infrastructure and Technology Constraints to Agricultural Development in the Humid and Subhumid Tropics of Africa, by Dunstan S.C. Spencer, August 1994.

04 Water Markets in Pakistan: Participation and Productivity, by Ruth Meinzen-Dick and Martha Sullins, September 1994.

05 The Impact of Technical Change in Agriculture on Human Fertility: District-level Evidence from India, by Stephen A. Vosti, Julie Witcover, and Michael Lipton, October 1994.

06 Reforming Water Allocation Policy through Markets in Tradable Water Rights: Lessons from Chile, Mexico, and California, by Mark W. Rosegrant and Renato Gazri S, October 1994.

07 Total Factor Productivity and Sources of Long-Term Growth in Indian Agriculture, by Mark W. Rosegrant and Robert E. Evenson, April 1995.

08 Farm-Nonfarm Growth Linkages in Zambia, by Peter B.R. Hazell and Behjat Hoijati, April 1995.

09 Livestock and Deforestation in Central America in the 1980s and 1990s: A Policy Perspective, by David Kaimowitz (Interamerican Institute for Cooperation on Agriculture. June 1995.

10 Effects of the Structural Adjustment Program on Agricultural Production and Resource Use in Egypt, by Peter B.R. Hazell, Nicostrato Perez, Gamal Siam, and Ibrahim Soliman, August 1995.

11 Local Organizations for Natural Resource Management: Lessons from Theoretical and Empirical Literature, by Lise Nordvig Rasmussen and Ruth Meinzen-Dick, August 1995.

EPTD DISCUSSION PAPERS

12 Quality-Equivalent and Cost-Adjusted Measurement of International Competitiveness in Japanese Rice Markets, by Shoichi Ito, Mark W. Rosegrant, and Mercedita C. Agcaoili-Sombilla, August 1995.

13 Role of Inputs, Institutions, and Technical Innovations in Stimulating Growth in Chinese Agriculture, by Shenggen Fan and Philip G. Pardey, September 1995.

14 Investments in African Agricultural Research, by Philip G. Pardey, Johannes Roseboom, and Nienke Beintema, October 1995.

15 Role of Terms of Trade in Indian Agricultural Growth: A National and State Level Analysis, by Peter B.R. Hazell, V.N. Misra, and Behjat Hoijati, December 1995.

16 Policies and Markets for Non-Timber Tree Products, by Peter A. Dewees and Sara J. Scherr, March 1996.

17 Determinants of Farmers' Indigenous Soil and Water Conservation Investments in India's Semi-Arid Tropics, by John Pender and John Kerr, August 1996.

18 Summary of a Productive Partnership: The Benefits from U.S. Participation in the CGIAR, by Philip G. Pardey, Julian M. Alston, Jason E. Christian, and Shenggen Fan, October 1996.

19 Crop Genetic Resource Policy: Towards a Research Agenda, by Brian D. Wright, October 1996.

20 Sustainable Development of Rainfed Agriculture in India, by John M. Kerr, November 1996.

21 Impact of Market and Population Pressure on Production, Incomes and Natural Resources in the Dryland Savannas of West Africa: Bioeconomic Modeling at the Village Level, by Bruno Barbier, November 1996.

22 Why Do Projections on China's Future Food Supply and Demand Differ? by Shenggen Fan and Mercedita Agcaoili-Sombilla, March 1997.

23 Agroecological Aspects of Evaluating Agricultural R&D, by Stanley Wood and Philip G. Pardey, March 1997.

24 Population Pressure, Land Tenure, and Tree Resource Management in Uganda, by Frank Place and Keijiro Otsuka, March 1997.

25 Should India Invest More in Less-favored Areas? by Shenggen Fan and Peter Hazell, April 1997.

26 Population Pressure and the Microeconomy of Land Management in Hills and Mountains of Developing Countries, by Scott R. Templeton and Sara J. Scherr, April 1997.

27 Population Land Tenure and Natural Resource Management: The Case of Customary Land Area in Malawi, by Frank Place and Keijiro Otsuka, April 1997.

28 Water Resources Development in Africa: A Review and Synthesis of Issues, Potentials, and Strategies for the Future, by Mark W. Rosegrant and Nicostrato D. Perez, September 1997.

29 Financing Agricultural R&D in Rich Countries: What's Happening and Why? by Julian M. Alston, Philip G. Pardey, and Vincent H. Smith, September 1997.

30 How Fast Have China's Agricultural Production and Productivity Really Been Growing? by Shenggen Fan, September 1997.

31 Does Land Tenure Insecurity Discourage Tree Planting? Evolution of Customary Land Tenure and Agroforestry Management in Sumatra, by Keijiro Otsuka, S. Suyanto, and Thomas P. Tomich, December 1997.

32 Natural Resource Management in the Hillsides of Honduras: Bioeconomic Modeling at the Micro-Watershed Level, by Bruno Barbier and Gilles Bergeron, January 1998.

33 Government Spending, Growth, and Poverty: An Analysis of Interlinkages in Rural India, by Shenggen Fan, Peter Hazell, and Sukhadeo Thorat, March 1998. Revised December 1998.

34 Coalitions and the Organization of Multiple-Stakeholder Action: A Case Study of Agricultural Research and Extension in Rajasthan, India, by Ruth Alsop, April 1998.

35 Dynamics in the Creation and Depreciation of Knowledge and the Returns to Research, by Julian Alston, Barbara Craig, and Philip Pardey, July 1998.

36 Educating Agricultural Researchers: A Review of the Role of African Universities, by Nienke M. Beintema, Philip G. Pardey, and Johannes Roseboom, August 1998.

EPTD DISCUSSION PAPERS

---

37 The Changing Organizational Basis of African Agricultural Research, by Johannes Roseboom, Philip G. Pardey, and Nienke M. Beintema, November 1998.

38 Research Returns Redux: A Meta-Analysis of the Returns to Agricultural R&D, by Julian M. Alston, Michele C. Marra, Philip G. Pardey, and T.J. Wyatt, November 1998.

39 Technological Change, Technical and Allocative Efficiency in Chinese Agriculture: The Case of Rice Production in Jiangsu, by Shenggen Fan, January 1999.

40 The Substance of Interaction: Design and Policy Implications of NGO-Government Projects in India, by Ruth Alsop with Ved Arya, January 1999.

41 Strategies for Sustainable Agricultural Development in the East African Highlands, by John Pender, Frank Place, and Simeon Ehui, April 1999.

42 Cost Aspects of African Agricultural Research, by Philip G. Pardey, Johannes Roseboom, Nienke M. Beintema, and Connie Chan-Kang, April 1999.

43 Are Returns to Public Investment Lower in Less-favored Rural Areas? An Empirical Analysis of India, by Shenggen Fan and Peter Hazell, May 1999.

44 Spatial Aspects of the Design and Targeting of Agricultural Development Strategies, by Stanley Wood, Kate Sebastian, Freddy Nachtergaele, Daniel Nielsen, and Aiguo Dai, May 1999.

45 Pathways of Development in the Hillsides of Honduras: Causes and Implications for Agricultural Production, Poverty, and Sustainable Resource Use, by John Pender, Sara J. Scherr, and Guadalupe Durón, May 1999.

46 Determinants of Land Use Change: Evidence from a Community Study in Honduras, by Gilles Bergeron and John Pender, July 1999.

47 Impact on Food Security and Rural Development of Reallocating Water from Agriculture, by Mark W. Rosegrant and Claudia Ringler, August 1999.

48 Rural Population Growth, Agricultural Change and Natural Resource Management in Developing Countries: A Review of Hypotheses and Some Evidence from Honduras, by John Pender, August 1999.

EPTD DISCUSSION PAPERS

---

49 Organizational Development and Natural Resource Management: Evidence from Central Honduras, by John Pender and Sara J. Scherr, November 1999.

50 Estimating Crop-Specific Production Technologies in Chinese Agriculture: A Generalized Maximum Entropy Approach, by Xiaobo Zhang and Shenggen Fan, September 1999.

51 Dynamic Implications of Patenting for Crop Genetic Resources, by Bonwoo Koo and Brian D. Wright, October 1999.

52 Costing the Ex Situ Conservation of Genetic Resources: Maize and Wheat at CIMMYT, by Philip G. Pardey, Bonwoo Koo, Brian D. Wright, M. Eric van Dusen, Bent Skovmand, and Suketoshi Taba, October 1999.

53 Past and Future Sources of Growth for China, by Shenggen Fan, Xiaobo Zhang, and Sherman Robinson, October 1999.

54 The Timing of Evaluation of Genebank Accessions and the Effects of Biotechnology, by Bonwoo Koo and Brian D. Wright, October 1999.

55 New Approaches to Crop Yield Insurance in Developing Countries, by Jerry Skees, Peter Hazell, and Mario Miranda, November 1999.

56 Impact of Agricultural Research on Poverty Alleviation: Conceptual Framework with Illustrations from the Literature, by John Kerr and Shashi Kolavalli, December 1999.

57 Could Futures Markets Help Growers Better Manage Coffee Price Risks in Costa Rica? by Peter Hazell, January 2000.

58 Industrialization, Urbanization, and Land Use in China, by Xiaobo Zhang, Tim Mount, and Richard Boisvert, January 2000.

59 Water Rights and Multiple Water Uses: Framework and Application to Kirindi Oya Irrigation System, Sri Lanka, by Ruth Meinzen-Dick and Margaretha Bakker, March 2000.

60 Community natural Resource Management: The Case of Woodlots in Northern Ethiopia, by Berhanu Gebremedhin, John Pender and Girmay Tesfaye, April 2000.

EPTD DISCUSSION PAPERS

---

61 What Affects Organization and Collective Action for Managing Resources? Evidence from Canal Irrigation Systems in India, by Ruth Meinzen-Dick, K.V. Raju, and Ashok Gulati, June 2000.

62 The Effects of the U.S. Plant Variety Protection Act on Wheat Genetic Improvement, by Julian M. Alston and Raymond J. Venner, May 2000.

63 Integrated Economic-Hydrologic Water Modeling at the Basin Scale: The Maipo River Basin, by M. W. Rosegrant, C. Ringler, DC McKinney, X. Cai, A. Keller, and G. Donoso, May 2000.

64 Irrigation and Water Resources in Latin America and he Caribbean: Challenges and Strategies, by Claudia Ringler, Mark W. Rosegrant, and Michael S. Paisner, June 2000.

65 The Role of Trees for Sustainable Management of Less-favored Lands: The Case of Eucalyptus in Ethiopia, by Pamela Jagger & John Pender, June 2000.

66 Growth and Poverty in Rural China: The Role of Public Investments, by Shenggen Fan, Linxiu Zhang, and Xiaobo Zhang, June 2000.

67 Small-Scale Farms in the Western Brazilian Amazon: Can They Benefit from Carbon Trade? by Chantal Carpentier, Steve Vosti, and Julie Witcover, September 2000.

68 An Evaluation of Dryland Watershed Development Projects in India, by John Kerr, Ganesh Pangare, Vasudha Lokur Pangare, and P.J. George, October 2000.

69 Consumption Effects of Genetic Modification: What If Consumers Are Right? by Konstantinos Giannakas and Murray Fulton, November 2000.

70 South-North Trade, Intellectual Property Jurisdictions, and Freedom to Operate in Agricultural Research on Staple Crops, by Eran Binenbaum, Carol Nottenburg, Philip G. Pardey, Brian D. Wright, and Patricia Zambrano, December 2000.

71 Public Investment and Regional Inequality in Rural China, by Xiaobo Zhang and Shenggen Fan, December 2000.

72 Does Efficient Water Management Matter? Physical and Economic Efficiency of Water Use in the River Basin, by Ximing Cai, Claudia Ringler, and Mark W. Rosegrant, March 2001.

EPTD DISCUSSION PAPERS

---

73 Monitoring Systems for Managing Natural Resources: Economics, Indicators and Environmental Externalities in a Costa Rican Watershed, by Peter Hazell, Ujjayant Chakravorty, John Dixon, and Rafael Celis, March 2001.

74 Does Quanxi Matter to NonFarm Employment? by Xiaobo Zhang and Guo Li, June 2001.

75 The Effect of Environmental Variability on Livestock and Land-Use Management: The Borana Plateau, Southern Ethiopia, by Nancy McCarthy, Abdul Kamara, and Michael Kirk, June 2001.

76 Market Imperfections and Land Productivity in the Ethiopian Highlands, by Stein Holden, Bekele Shiferaw, and John Pender, August 2001.

77 Strategies for Sustainable Agricultural Development in the Ethiopian Highlands, by John Pender, Berhanu Gebremedhin, Samuel Benin, and Simeon Ehui, August 2001.

78 Managing Droughts in the Low-Rainfall Areas of the Middle East and North Africa: Policy Issues, by Peter Hazell, Peter Oram, Nabil Chaherli, September 2001.

79 Accessing Other People's Technology: Do Non-Profit Agencies Need It? How To Obtain It, by Carol Nottenburg, Philip G. Pardey, and Brian D. Wright, September 2001.

80 The Economics of Intellectual Property Rights Under Imperfect Enforcement: Developing Countries, Biotechnology, and the TRIPS Agreement, by Konstantinos Giannakas, September 2001.

81 Land Lease Markets and Agricultural Efficiency: Theory and Evidence from Ethiopia, by John Pender and Marcel Fafchamps, October 2001.

82 The Demand for Crop Genetic Resources: International Use of the U.S. National Plant Germplasm System, by M. Smale, K. Day-Rubenstein, A. Zohrabian, and T. Hodgkin, October 2001.

83 How Agricultural Research Affects Urban Poverty in Developing Countries: The Case of China, by Shenggen Fan, Cheng Fang, and Xiaobo Zhang, October 2001.

84 How Productive is Infrastructure? New Approach and Evidence From Rural India, by Xiaobo Zhang and Shenggen Fan, October 2001.

EPTD DISCUSSION PAPERS

85 Development Pathways and Land Management in Uganda: Causes and Implications, by John Pender, Pamela Jagger, Ephraim Nkonya, and Dick Sserunkuuma, December 2001.

86 Sustainability Analysis for Irrigation Water Management: Concepts, Methodology, and Application to the Aral Sea Region, by Ximing Cai, Daene C. McKinney, and Mark W. Rosegrant, December 2001.

87 The Payoffs to Agricultural Biotechnology: An Assessment of the Evidence, by Michele C. Marra, Philip G. Pardey, and Julian M. Alston, January 2002.

88 Economics of Patenting a Research Tool, by Bonwoo Koo and Brian D. Wright, January 2002.

89 Assessing the Impact of Agricultural Research On Poverty Using the Sustainable Livelihoods Framework, by Michelle Adato and Ruth Meinzen-Dick, March 2002.

90 The Role of Rainfed Agriculture in the Future of Global Food Production, by Mark Rosegrant, Ximing Cai, Sarah Cline, and Naoko Nakagawa, March 2002.

91 Why TVEs Have Contributed to Interregional Imbalances in China, by Junichi Ito, March 2002.

92 Strategies for Stimulating Poverty Alleviating Growth in the Rural Nonfarm Economy in Developing Countries, by Steven Haggblade, Peter Hazell, and Thomas Reardon, July 2002.

93 Local Governance and Public Goods Provisions in Rural China, by Xiaobo Zhang, Shenggen Fan, Linxiu Zhang, and Jikun Huang, July 2002.

94 Agricultural Research and Urban Poverty in India, by Shenggen Fan, September 2002.

95 Assessing and Attributing the Benefits from Varietal Improvement Research: Evidence from Embrapa, Brazil, by Philip G. Pardey, Julian M. Alston, Connie Chan-Kang, Eduardo C. Magalhães, and Stephen A. Vosti, August 2002.

96 India’s Plant Variety and Farmers’ Rights Legislation: Potential Impact on Stakeholders Access to Genetic Resources, by Anitha Ramanna, January 2003.

97 Maize in Eastern and Southern Africa: Seeds of Success in Retrospect, by Melinda Smale and Thom Jayne, January 2003.

98 Alternative Growth Scenarios for Ugandan Coffee to 2020, by Liangzhi You and Simon Bolwig, February 2003.

99 Public Spending in Developing Countries: Trends, Determination, and Impact, by Shenggen Fan and Neetha Rao, March 2003.

100 The Economics of Generating and Maintaining Plant Variety Rights in China, by Bonwoo Koo, Philip G. Pardey, Keming Qian, and Yi Zhang, February 2003.

101 Impacts of Programs and Organizations on the Adoption of Sustainable Land Management Technologies in Uganda, Pamela Jagger and John Pender, March 2003.

102 Productivity and Land Enhancing Technologies in Northern Ethiopia: Health, Public Investments, and Sequential Adoption, Lire Ersado, Gregory Amacher, and Jeffrey Alwang, April 2003.

103 Animal Health and the Role of Communities: An Example of Trypanasomosis Control Options in Uganda, by Nancy McCarthy, John McDermott, and Paul Coleman, May 2003.

104 Determinantes de Estrategias Comunitarias de Subsistencia y el uso de Prácticas Conservacionistas de Producción Agrícola en las Zonas de Ladera en Honduras, Hans G.P. Jansen, Angel Rodríguez, Amy Damon, y John Pender, Juno 2003.

105 Determinants of Cereal Diversity in Communities and on Household Farms of the Northern Ethiopian Highlands, by Samuel Benin, Berhanu Gebremedhin, Melinda Smale, John Pender, and Simeon Ehui, June 2003.

106 Demand for Rainfall-Based Index Insurance: A Case Study from Morocco, by Nancy McCarthy, July 2003.

107 Woodlot Devolution in Northern Ethiopia: Opportunities for Empowerment, Smallholder Income Diversification, and Sustainable Land Management, by Pamela Jagger, John Pender, and Berhanu Gebremedhin, September 2003.

108 Conservation Farming in Zambia, by Steven Haggblade, October 2003.

109 National and International Agricultural Research and Rural Poverty: The Case of Rice Research in India and China, by Shenggen Fan, Connie Chan-Kang, Keming Qian, and K. Krishnaiah, September 2003.

110 Rice Research, Technological Progress, and Impacts on the Poor: The Bangladesh Case (Summary Report), by Mahabub Hossain, David Lewis, Manik L. Bose, and Alamgir Chowdhury, October 2003.

111 Impacts of Agricultural Research on Poverty: Findings of an Integrated Economic and Social Analysis, by Ruth Meinzen-Dick, Michelle Adato, Lawrence Haddad, and Peter Hazell, October 2003.

112 An Integrated Economic and Social Analysis to Assess the Impact of Vegetable and Fishpond Technologies on Poverty in Rural Bangladesh, by Kelly Hallman, David Lewis, and Suraiya Begum, October 2003.

113 Public-Private Partnerships in Agricultural Research: An Analysis of Challenges Facing Industry and the Consultative Group on International Agricultural Research, by David J. Spielman and Klaus von Grebmer, January 2004.

114 The Emergence and Spreading of an Improved Traditional Soil and Water Conservation Practice in Burkina Faso, by Daniel Kaboré and Chris Reij, February 2004.

115 Improved Fallows in Kenya: History, Farmer Practice, and Impacts, by Frank Place, Steve Franzel, Qureish Noordin, Bashir Jama, February 2004.

116 To Reach The Poor – Results From The ISNAR-IFPRI Next Harvest Study On Genetically Modified Crops, Public Research, and Policy Implications, by Atanas Atanassov, Ahmed Bahieldin, Johan Brink, Moises Burachik, Joel I. Cohen, Vibha Dhawan, Reynaldo V. Ebora, José Falck-Zepeda, Luis Herrera-Estrella, John Komen, Fee Chon Low, Emeka Omaliko, Benjamin Odhiambo, Hector Quemada, Yufa Peng, Maria Jose Sampaio, Idah Sithole-Niang, Ana Sittenfeld, Melinda Smale, Sutrisno, Ruud Valyasevi, Yusuf Zafar, and Patricia Zambrano, March 2004

117 Agri-Environmental Policies In A Transitional Economy: The Value of Agricultural Biodiversity in Hungarian Home Gardens, by Ekin Birol, Melinda Smale, And Ágnes Gyovai, April 2004.

118 New Challenges in the Cassava Transformation in Nigeria and Ghana, by Felix Nweke, June 2004.

EPTD DISCUSSION PAPERS

---

119 International Exchange of Genetic Resources, the Role of Information and Implications for Ownership: The Case of the U.S. National Plant Germplasm System, by Kelly Day Rubenstein and Melinda Smale, June 2004.

120 Are Horticultural Exports a Replicable Success Story? Evidence from Kenya and Côte d'Ivoire, by Nicholas Minot and Margaret Ngigi, August 2004.

121 Spatial Analysis of Sustainable Livelihood Enterprises of Uganda Cotton Production, by Liangzhi You and Jordan Chamberlin, September 2004

122 Linkages between Poverty and Land Management in Rural Uganda: Evidence from the Uganda National Household Survey 1999/00, by John Pender, Sarah Ssewanyana, Kato Edward, and Ephraim Nkonya, September 2004.

123 Dairy Development in Ethiopia, by Mohamed A.M. Ahmed, Simeon Ehui, and Yemesrach Assefa, October 2004.

124 Spatial Patterns of Crop Yields in Latin America and the Caribbean, by Stanley Wood, Liangzhi You, and Xiaobo Zhang, October 2004.

125 Variety Demand within the Framework of an Agricultural Household Model with Attributes: The Case of Bananas in Uganda, by Svetlana Edmeades, Melinda Smale, Mitch Renkow and Dan Phaneuf, November 2004.

126 Assessing the Spatial Distribution of Crop Production Using a Cross-Entropy Method, Liangzhi You and Stanley Wood, November 2004.

127 Water Allocation Policies for the Dong Nai River Basin in Vietnam: An Integrated Perspective, by Claudia Ringler and Nguyen Vu Huy, December 2004.

128 Participation of Local People in Water Management: Evidence from the Mae Sa Watershed, Northern Thailand, by Helene Heyd and Andreas Neef, December 2004.

129 Improved Water Supply in the Ghanaian Volta Basin: Who Uses it and Who Participates in Community Decision-Making? by Stefanie Engel, Maria Iskandarani, and Maria del Pilar Useche, January 2005.

130 Improved Fallows in Eastern Zambia: History, Farmer Practice and Impacts, by Freddie Kwesiga, Steven Franzel, Paramu Mafongoya, Olu Ajayi, Donald Phiri, Roza Katanga, Elias Kuntashula, Frank Place, and Teddy Chirwa, February 2005.

EPTD DISCUSSION PAPERS

---

131 The Case of Smallholder Dairying in Eastern Africa, by Margaret Ngigi, February 2005.

132 Incorporating Project Uncertainty in Novel Environmental Biotechnologies: Illustrated Using Phytoremediation, by Nicholas A. Linacre, Steven N. Whiting, and J. Scott Angle, May 2005.

133 Ecological Risks of Novel Environmental Crop Technologies Using Phytoremediation as an Example, by J. Scott Angle and Nicholas A. Linacre, May 2005.

134 Policy Options for Increasing Crop Productivity and Reducing Soil Nutrient Depletion and Poverty in Uganda, Ephraim Nkonya, John Pender, Crammer Kaizzi, Kato Edward, and Samuel Mugarura, March 2005.

135 Local Seed Systems and Village-Level Determinants of Millet Crop Diversity in Marginal Environments of India, by Latha Nagarajan and Melinda Smale, June 2005.

136 The Emergence of Insect Resistance in Bt-Corn: Implication of Resistance Management Information under Uncertainty, by Nicholas A. Linacre and Colin J. Thompson, June 2005.

137 Incorporating Collateral Information Using an Adaptive Management Framework for the Regulation of Transgenic Crops, by Nicholas Linacre, Mark A. Burgman, Peter K. Ades, And Allen Stewart-Oaten, August 2005.

138 Security Analysis for Agroterrorism: Applying the Threat, Vulnerability, Consequence Framework to Developing Countries, by Nicholas A. Linacre, Joanne Gaskell, Mark W. Rosegrant, Jose Falck-Zepeda, Hector Quemada, Mark Halsey, and Regina Birner, August 2005.

139 Comparing Farm and Village-Level Determinants of Millet Diversity in Marginal Environments of India: The Context of Seed Systems, Latha Nagarajan, Melinda Smale, and Paul Glewwe, August 2005.

140 Analysis for Biotechnology Innovations Using Strategic Environmental Assessment (SEA), by Nicholas A. Linacre, Joanne Gaskell, Mark W. Rosegrant, Jose Falck-Zepeda, Hector Quemada, Mark Halsey, and Regina Birner, July 2005.

EPTD DISCUSSION PAPERS

141 Water Pricing and Valuation in Indonesia: Case Study of the Brantas River Basin, by Charles Rodgers and Petra J.G.J. Hellegers, August 2005.

142 Farmer Willingness to Pay for Seed-Related Information: Rice Varieties in Nigeria and Benin, by J. Daniela Horna, Melinda Smale, and Matthias von Oppen, September 2005.