Cover Page

Project title:	Agriculture, climate change, and socioeconomic dislocation	
Investigators:	Raymond W. Arritt, Professor, Dept. of Agronomy, ISU	
	Kenneth J. Moore, Dept. of Agronomy, ISU	
	Michael Thompson, Dept. of Agronomy, ISU	
	Mark Westgate, Dept. of Agronomy, ISU	
Type of Project:	Regular Project (scholarly exchange and workshop)	
Initiative Area:	Institute for Global Innovation in Agricultural Science, Technology and Policy	
Start Date:	June 1, 2001	
Duration:	18 months	
Funds Requested:	Year 1	$21,600
	Year 2	$26,500
	Total	$48,100

Table of Contents

1. Nontechnical Summary

Many of the effects of climate variations on society result from the influence of climate on agricultural production. The goal of this project is to study the role that agronomists in general and the Iowa State University agronomy program in particular might play in alleviating the social and economic consequences of climate change. This role is not a simple one of breeding the right kinds of crops or accurately predicting climate variations, because of the profound influence of political and economic systems in ameliorating or worsening the effects of natural fluctuations. Thus, we are especially interested in the perspectives brought by the social sciences and humanities in order to provide a context for our Department's expertise in the physical and biological sciences. This will be accomplished through a program of scholarly exchanges culminating in an international workshop hosted by ISU.

2. Narrative Summary

2.A. Background

The most recent report on *Foodcrops and Shortages,* a regular publication of the UN Food and Agricultural Organization, lists 33 countries presently facing exceptional food emergencies (FAO, 2001). When these emergencies persist they can result in severe social and economic dislocations with consequences extending far beyond the region that is immediately affected. Often accompanying these crises are migrations of large numbers of people and animals. As animals migrate to more adequate yet still marginal grazing areas there is danger of overgrazing and environmental damage. Typical human migration patterns induced by food shortages are from rural areas to urban areas, with occasional international or even intercontinental migrations (there is now a thriving trade in smuggling people from drought-stricken Central Asia to southern Europe). The resulting concentration of people displaced from their customary economic and social systems can overwhelm local resources and worsen problems in regions that already are the politically and economically unstable.

Failure to produce sufficient food to sustain a population often is a result of climate variations. Shortages in 21 of the 33 countries noted in the FAO report are attributed in whole or in large part to climate extremes, most often drought. One of the most notable emergencies in recent years was in the Sahel region of Africa, which experienced extended droughts in 1964-74 (peaking around 1972-74) and again in 1981-85 leading to widespread famine and social unrest. Presently a wide swath of Central Asia from Armenia and Georgia eastward to Afghanistan is in a multiyear drought, the effects of which have both contributed to and been exacerbated by the region's political and economic instability.

While the environment has profound effects on food production and human activity, there is in turn potential for human activity to affect the physical environment. As people and animals move to new areas land cover is removed by cultivation, and in marginal areas livestock can promote overgrazing. Removal of vegetative cover by these activities can raise albedo, leading to reduced rainfall and further reduction in plant growth. This positive feedback cycle was widely studied in the 1970's as possibly leading to increased desertification (e.g., Otterman 1975; Charney et al. 1975), though more recent evidence indicates that observed changes in

albedo have mostly been localized and relatively short-term rather than widespread and sustained (Dregne and Tucker 1988; Hulme and Kelly 1993). Other negative environmental impacts include effects on soil and water quality, as well as spread of disease in humans and animals.

Climate has varied substantially throughout human history (and before) and will vary in the future, because nonlinearities in the coupled atmosphere-ocean-land system make a steady-state global climate impossible (Lorenz 1963). Superimposed on these natural fluctuations, humanity also faces the possibility of significant climate shifts owing to changes it has made to the chemical composition of the atmosphere that alter the strength of the so-called "greenhouse effect." We know that climate variations capable of producing food emergencies will continue to occur, whether these variations are completely natural or partly anthropogenic. The greatest impacts of global climate change are likely to be felt first by those in climates that already are marginal for food production, and especially in the poorest, least resilient economies.

The question we pose is, What is the role for agronomists in mitigating the social and economic dislocations that can result from climate variability? This is not a problem that is amenable to a straightforward technological "fix" owing to the constraints imposed by political and economic systems. In two current examples, the civil war and economic collapse in Afghanistan has exacerbated the regional decline in cereal production and shortages of drinking water due to drought, while the effects of drought in North Korea are greatly worsened by that country's political and economic isolation. In other instances climate-related famine adds to the consequences of pre-existing political instability, as occurred during the civil war in Rwanda (Percival and Homer-Dixon 1995). It is imperative that climatologists, crop scientists and other agronomists take into account the ways in which political and economic structures influence the practical application of their research.

2.B. Project Objectives

The objective of this project is to enable our Department to make informed decisions about the role that agronomists might play in mitigating the economic and social dislocations that result from global environmental change, and to provide international leadership in fulfilling that role. We recognize the need to broaden our focus from the biological and physical sciences in order to understand the linkages between climate fluctuations, food production and socioeconomic structures. For example, is there need to develop new varieties of crops that are more drought-resistant? Even if those varieties are developed, are there cultural or economic

constraints that would inhibit their use? Furthermore, it is clear that many of the issues are economic ones; for example, diversification of small-scale agriculture instead of tying the economy of a country too closely to international markets. We will address this goal through a program of scholarly exchanges that culminates in an international workshop on the topic of agriculture as a mediator between environmental change and socioeconomic dislocation.

2.C. Strategies

The project will be undertaken in two stages: (1) scholarly exchanges between ISU and other institutions and (2) an international workshop hosted by ISU. We will first assemble an advisory panel of 4 to 6 internationally recognized experts in subject areas relevant to this problem. The panel will be constituted so as to include expertise in the natural sciences, social sciences, and humanities. Each advisory panel member will be asked to visit ISU during the 2001-2002 academic year to present a public lecture and confer with ISU faculty, staff, and students. This speaker series will be widely announced throughout the community. Additionally, ISU faculty and staff will be funded to attend conferences or visit other institutions in order to gain familiarity with the current status of leading-edge work in subject areas related to this project. Knowledge gained and, more importantly, questions formulated in these exchanges will then be applied in planning in an international workshop that will be hosted by ISU.

We have begun to solicit persons to serve on the advisory panel, but owing to the very short timeline for the current round of proposals we are only in the early stages of this process. Confirmed or solicited advisors include:

- (Confirmed) Prof. Martin Parry, Director, Jackson Environmental Institute, University of East Anglia (United Kingdom). Prof. Parry would like to visit ISU in September 2001. He is an excellent speaker and would be a good choice to lead our speakers series.
- (Confirmed) Prof. Dale Jamieson, Professor of Philosophy, Henry R. Luce Professor in Human Dimensions of Global Change, Carleton College, Northfield, Minnesota.
- Dr. Michael Glantz, Senior Scientist, Environmental Sciences Impacts Group, National Center for Atmospheric Research, Boulder, Colorado. Author of numerous books including *Drought Follows the Plow,* on feedbacks between agricultural practice and climate.

In addition to the advisory panel, a local organizing group will be assembled in order to help focus the program and carry out logistical tasks. The local organizers will be drawn from participants in this project, and perhaps from others who express interest in the project at a later date.

In the second year of the project we will hold a workshop. Tentatively we plan to hold the workshop early in the 2002-2003 academic year. We are willing to adjust timing of the workshop (earlier or later) depending on the financial position of the endowment.

2.D. Cooperative Interaction

Investigators for this project and their areas of expertise presently include the following:

Raymond Arritt	Climatology
Ken Moore	Forages; also Master of Agronomy program
Michael Thompson	Soils
Mark Westgate	Crop development and reproductive physiology

The investigators will serve or will recommend others to serve on the local arrangements committee for this project. The investigators listed above represent a cross-section of the disciplines within the Agronomy Department. This by no means should be taken as a final list and we will actively solicit involvement by others in the Agronomy Department as well as other relevant disciplines at ISU, for example, economics, sociology, and philosophy.

Travel obligations will be spread across participating investigators as opportunities for exchanges arise. All staff willing to contribute through scholarly exchange will be apprised of their obligation to serve in the project, including a brief written summary of information gathered during their travel. These summaries will be posted to a web site to be constructed for this project. We already have identified one relevant international meeting where the role of climate in forced human migration will be discussed, though not from an agricultural perspective.

2.E. Initiative Involvement

This proposal is submitted for the Institute for Global Innovation in Agricultural Science, Technology and Policy. Our project directly addresses the initiative goals of "foster[ing] interdisciplinary and interorganizational collaboration in the study of agricultural issues and the development of potential courses of action" as well as "investigat[ing] the relationship between (1) agriculture and cultures, (2) global food supplies and distribution systems, and (3) Iowa's

view of and participation in global agriculture." With respect to strategies, our project follows the initiative priorities of enhancing the human resource base through scholarly exchanges, building links with policymakers by providing opportunities for them to become knowledgeable about the scientific, social and economic aspects of agricultural issues, and engaging the public.

Although this project is not specifically directed to the other initiatives, it is relevant to certain aspects of them, for example the program in the Integrated Approaches to Plant Improvement initiative that focuses on improving yield stability across environments. We are eager to engage faculty and staff in all initiatives as well as those outside the Department and at other institutions.

3. Literature Cited

Charney, J., W. Quirk and P. Stone, 1975: Drought in the Sahara: A biogeophysical feedback mechanism. *Science* 187, 435-436.

Dregne, H.E. and C.J. Tucker, 1988. Desert encroachment. Desertification Control Bulletin 23, 243-251.

FAO, 2001: *Foodcrops and Shortages*, No. 1 (March 2001). Global Information and Early Warning Service, Food and Agriculture Organization of the United Nations, Rome, 49 pp.

Hulme, M. and P.M. Kelly, 1993: "Climate Change, Desertification and Dessication, and the case of the African Sahel." Working Paper GEC 93-17, The Centre for Social and Economic Research on the Global Environment , University of East Anglia, Norwich, UK, 37 pp.

Lorenz, E.N., 1963: Deterministic nonperiodic flow. *J. Atmospheric Sci.* 20, 130.

Otterman, J., 1975: Baring high-albedo soils by overgrazing. *Science* 186, 531-33

Percival, V. and T. Homer-Dixon, 1995: *Environmental Scarcity and Violent Conflict: The Case of Rwanda.* Project on Environment, Population and Security, American Association for the Advancement of Science, Washington, D.C. and the University of Toronto.

4. Budget

4.A. Year 1

Travel by advisors to ISU	
M. Parry, University of East Anglia	$2500
Two additional advisors (International)	$5000
Three additional advisors (Domestic)	$3600
Travel by ISU staff	
R. Arritt to Wengen Workshop on Climate Change and Forced Human Migration, Sept. 19-21, 2001, Wengen, Switzerland	$2000
Additional ISU traveler (International)	$2000
Two additional ISU travelers (Domestic)	$2000
Total travel	$17,100
Publicity and logistics for speaker series	$4500
Total Year 1 budget	$21,600

4.B. Year 2

Travel by advisory panel to ISU for workshop	
Three international advisors	$7500
Three domestic advisors	$3600
Travel by additional invited speakers	
Two international speakers	$5000
Two domestic speakers	$2400
Workshop logistics and related expenses (facilities rental, refreshments, promotion, etc)	$8000
Total Year 2 budget	$26,500

5. Qualifications of Investigators

Raymond W. Arritt

Professor, Department of Agronomy, Iowa State University, Ames, Iowa 50011
tel. (515) 294-9870, fax (515) 294-3163, electronic mail: rwarritt@iastate.edu

Education

Ph.D., 1985, Department of Atmospheric Science, Colorado State University.

M.S., 1982, Department of Environmental Sciences, University of Virginia.

B.A. (With Distinction), 1979, University of Virginia. Completed two majors, Economics and Environmental Sciences.

Recent Research Grants

Dynamics of the Great Plains low-level jet and its effect on mesoscale precipitation systems. Principal Investigator, NSF, 1997-2000, $273,914.

Diurnal modulation of moist processes in summertime droughts and floods over the Central U.S. Principal Investigator, NSF, $215,717, 1999-2002.

Regional climate simulations for impact assessment. Co-PI (with E.S. Takle and W. J. Gutowski), Electric Power Research Institute, $589,742, 1996-2001.

Impact of improved initialization on warm-season mesoscale rainfall prediction in non-hydrostatic Eta model. Co-PI (with W. Gallus and M. Segal), NSF/NOAA/USWRP $257,597, 1999-2002.

Coupled atmosphere-snow model evaluation of sub-regional snowmelt. Co-PI (with W. Gutowski, W. A. Gallus, Jr., M. Segal and Z. Pan), NASA, $270,000, 1998-2001.

Evaluation of climate change scenarios for the central U.S. Principal Investigator, Center for Global and Regional Environmental Research, $19,172, 1999-2000.

Significant Recent Professional Service

Associate Editor, Monthly Weather Review, 1996-1998

Associate Editor, Journal of Applied Meteorology, 2001-present

Committee on Clouds and Precipitation, American Geophysical Union, 1996-present

Contributing Author, Third Assessment Report of the Intergovernmental Panel on Climate Change, to be published April 2001

Frequent reviewer of journal articles and research proposals.

Selected Recent Publications

Pan, Z., R.W. Arritt, W.J. Gutowski, Jr. and E.S. Takle, 2001: Soil moisture in a regional climate model: simulation and projection. Submitted to *Geophysical Research Letters.*

Laird, N.F., D.A.R. Kristovich, X.-Z. Liang, R.W. Arritt and K. Labas, 2001: Lake Michigan lake breezes: Climatology, local forcing, and synoptic environment. Submitted to *J. Appl. Meteor.*

Chen, T.-C., S.-P. Weng, S. Schubert, J. Susskind and R.W. Arritt, 2001: Diurnal variations in the global water vapor flux. Submitted to *J. Climate.*

Pan, Z., R.W. Arritt, M. Segal, T.-C. Chen, and S.-P. Weng, 2001: Effects of quasi-stationary large-scale anomalies on some mesoscale features associated with 1993 flood: A regional model simulation. *J. Geophysical Research* 105, 29551-29564.

Arritt, R.W., D.C. Goering and C.J. Anderson, 2000: The North American monsoon system in the Hadley Centre coupled ocean-atmosphere GCM. *Geophys. Research Lett.,* 27, 565-568.

Wilby, R.L., L.E. Hay, W.J. Gutowski, Jr., R.W. Arritt, E.S. Takle, Z. Pan, G.H. Leavesley and M.P. Clark, 2000: Hydrological responses to dynamically and statistically downscaled climate model output. *Geophys. Research Letters,* 27, 1199-1202.

Anderson, C.J. and R.W. Arritt, 2000: Representation of summertime low-level jets in the central United States by the NCEP/NCAR reanalysis. *J. Climate,* in press.

Takle, E.S., W.J. Gutowski, Jr., R.W. Arritt, Z. Pan, C.J. Anderson, R. Silva, D. Caya, S.-C. Chen, F. Giorgi, J.H. Christensen, S.-Y. Hong, H.-M. H. Juang, J.J. Katzfey, W.M. Lapenta, R. Laprise, G. Liston, P. Lopez, R.A. Pielke, Sr., J. McGregor and J.O. Roads, 1999: Project to Intercompare Regional Climate Simulations (PIRCS): Description and initial results. *J. Geophys. Research,* 104, 19443-19461.

Daniel, C.J., R.W. Arritt and C.J. Anderson, 1999: Accuracy of 404 MHz radar profilers for detection of low level jets over the central United States. *J.Appl. Meteorol.*, 38, 1391-1396.

Pan, Z., M. Segal, R.W. Arritt, T.-C. Chen and S.-P. Weng, 1999: A method for simulating effects of quasi-stationary wave anomalies on regional climate. *J. Climate,* 12, 1336-1346.

Pan, Z., M. Segal, E.S. Takle and R.W. Arritt, 1999: Simulation of potential impacts of man-made land use changes on U.S. summer climate under various synoptic regimes. *J. Geophys. Research,* 104, 6515-6528.

Anderson, C.J. and R.W. Arritt, 1998: Mesoscale convective complexes and persistent elongated convective systems during 1992 and 1993. *Mon. Wea. Rev.,* 126, 578-599.

Arritt, R.W., T.D. Rink, M. Segal, D.P. Todey, C.A. Clark, M.J. Mitchell and K.M. Labas, 1997: The Great Plains low-level jet during the warm season of 1993. *Mon. Wea. Rev.,* 125, 2176-2192.

Segal, M., R.W. Arritt, J. Shen, C. Anderson and M. Leuthold, 1997: On the clearing of cumulus clouds downwind from lakes. *Mon. Wea. Rev.,*125, 639-646.

Kunkel, K.E., S.A. Changnon, B.C. Reinke and R.W. Arritt, 1996: The July 1995 heat wave in the Midwest: a climatic perspective and critical weather factors. *Bulletin of the American Meteorological Society,* 77, 1507-1518.

Mitchell, M.J., R.W. Arritt and K. Labas, 1995: A climatology of the warm season Great Plains low-level jet using wind profiler observations. *Weather and Forecasting,* 10, 576-5

Kenneth J. Moore

Professor, Agronomy Department, Iowa State University

Expertise: Forage Quality and Utilization

Education:
B. S. Agriculture, Arizona State University, Summa Cum Laude, 1979
M.S. Agronomy, Purdue University, 1981
Ph.D. Agronomy, Purdue University, 1983

Professional Experience:
Assistant Professor of Agronomy, Univ. of Illinois, 1983-87.
Assoc. Prof. of Agronomy and Horticulture, New Mexico State Univ., 1988-89.
Research Agronomist, USDA-ARS, 1989-93.
Adjunct Assoc. Prof. of Agronomy, University of Nebraska, 1989-93.
Adjunct Professor of Agronomy, University of Nebraska, 1993-96.
Professor of Agronomy, Iowa State University, 1993-present.
Senior Research Fellow, AgResearch Grasslands, New Zealand, 1998.

Professional Memberships:

American Society of Agronomy	Gamma Sigma Delta
Crop Science Society of America	Phi Kappa Phi
American Society of Animal Science	Sigma Xi
American Dairy Science Association	Phi Theta Kappa
American Forage and Grassland Council	

Professional Activities:
Associate Editor, *Agronomy Journal*, 1989-93.
Special Liaison Representative, ASA and ASAS, 1988-90.
Crop Quality and Utilization, Division C6, Chair, CSSA, 1990-92.
Board of Directors, Crop Science Society of America, 1990-92.
Editorial board, Trends in Agricultural Sciences-Agronomy, 1991-95.
1992 Program Planning Committee, Crop Science Society of America, 1991-92.
Forage, Grassland, and Range Resource Committee (ACS824), ASA, 1991-94.
Budget Committee, National Conference on Forage Quality Evaluation and Util., 1990-94.
Program Planning Committee, Division C6 Program Chair, CSSA, 1991-92.
Nominations Committee (C101), Crop Science Society of America, 1992-93.
Organization, Policy, and Bylaws Committee (A201), ASA, 1992-.
Editor, CSSA Special Publication, Post-Harvest Physiology and Preservation of Forages, 1992-94.
Associate Editor, *Crop Science*, 1993-94.
Technical Editor, *Agronomy Journal*, 1993-1997.

Chair, Silage Monograph Feasibility Committee, American Society of Agronomy, 1994-95.
Editor, CSSA Special Publication, Native Warm-Season Grasses: Research Trends and Issues , 1996-99.

Awards: Outstanding Young Scientist, American Forage and Grassland Council, 1982
Merit Award, American Forage and Grassland Council, 1991
USDA Point of Light Award, 1991
Young Crop Scientist Award, Crop Science Society of America, 1993
Fellow, American Society of Agronomy, 1995
Raymond and Mary Baker Agronomic Excellence Award, Iowa State Univ., 1996.
Fellow, Crop Science Society of America, 1996.
Senior Research Fellowship, AgResearch Grasslands, New Zealand, 1998.

Current Research: Research involves identifying factors which limit the nutritive value of forages and development of systems for improved utilization of forages. Current research efforts are concentrated on studying species diversity in pastures and its relationship to spatial and temporal variation in available nutrients for grazing livestock, development of complementary grazing systems, and the impact of various legumes grown in mixtures with grasses on forage protein quality and availability.

Teaching Experience:

Courses at ISU: Agronomy 434, Pasture and Grazing Management, ISU, 1993
Agronomy 434, Forage Quality and Utilization, ISU, 1995
Economics / Agronomy 496, Sustainable Agricultural and Economic Development in Costa Rica, ISU, 1997, 2001
Agronomy 526, Field Plot Technique, ISU, 1997,1998, 1999, 2000

Other: AID-OICD Seed Improvement Short Course, UIUC, 1986
Field and Furrow (Agronomy) Club Co-advisor, UIUC, 1985-87
Chair, Professional Agronomy M.S. Degree Program, ISU, 1995-present

Publications:

Refereed:	88
Proceedings:	35
Book Chapters:	5
Books:	2
Books Edited:	2
Technical Articles:	51
Multimedia:	2
Abstracts:	124

CURRICULUM VITAE

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http://www.agron.iastate.edu/agronomy/userspage.asp?ID=689

Education

Ph.D. (Plant Physiology)	1984, University of Illinois, Urbana, IL
M.S. (Biology)	1977, University of Dayton, Dayton, OH
B.S. (Biology)	1974, University of Dayton, Dayton, OH

Employment Experience

1998-present	Associate Professor, Agronomy Department, Iowa State University, Ames, IA
1992-1993	Visiting Research Scientist, CSIRO, Canberra, Australia
1983-1998	Plant Physiologist, USDA-ARS, Morris, MN
1983-1984	Visiting Research Associate, Working Group for Membrane Research, Nuclear Research Center, Jülich, West Germany
1979-1983	Research Fellow and Graduate Research Assistant, Department of Agronomy, University of Illinois, Urbana, IL
1976-1979	Research Chemist II, Monsanto Agricultural Products Co., St. Louis, MO
1974-1976	Research Assistant, Department of Biology, University of Dayton, Dayton, OH

Current Research Funding

United Soybean Board, "Molecular regulation of soybean seed composition", coPI with Wurtele and Nikolau, $238,464, 2000-2002

Iowa Soybean Promotion Board, "Integrated Program to improve the composition and value of Iowa soybeans", coPI with Wurtele and Nikolau, $124,592, 2000-2001

Soybean Research and Development Council, “Managing Interactive Stresses to Increase Soybean Yields”, coPI with Batchelor, Owen, Tylka, Munkvold, Horton, Meyer, $302,910, 2000–2003

Soybean Research & Development Council, “Soybean composition database management”, $40,000, 2000-2001.

Honors and Awards

Science Fellow of the Australian National University, 1992

CSIRO Visiting Scientist Award, 1992

University Fellowship in Agronomy, University of Illinois, 1981

Monsanto "Management by Results" review received the highest rating (Exceptional), Monsanto Agricultural Products Co., 1979

Ralph and Mabel Hunter Fellowship in Agronomy, Agronomy Dept., U of Illinois, 1979

John E. Dlugos, Jr. Memorial Award for Outstanding Senior in Biology, Univ. of Dayton, 1974.

Refereed Publications past 4 years (total ~ 45)

Cárcova, J., Uribelarrea, M., Borrás, L., Otegui, M., and M.E. Westgate. 2000. Synchronous pollination within and between ears improves kernel set in maize. Crop Science 40:1056-1061.

Saini, H.S., and Westgate, M.E. 2000. Reproductive Development in Grain Crops During Drought. Advan. Agron. 68: 59-96.

Zinselmeier, C., Habben, J.E., Westgate, M.E., and J.S. Boyer. 2000. Carbohydrate metabolism in setting and aborting maize ovaries. *In* M.E. Westgate and K.J. Boote (eds.) Physiology and Modeling Kernel Set in Maize. CSSA Special Publication 29:1-13.

Edmeades, G.O., Bolanos, J., Elings, A., Banziger, M., and M.E Westgate. 2000. The role and regulation of the anthesis-silking interval. *In* M.E. Westgate and K.J. Boote (eds.) Physiology and Modeling Kernel Set in Maize. CSSA Special Publication 29:43-73.

Westgate, M.E., Passioura, J., and Munns, R. 1996. Water status and ABA content of floral tissues in drought stressed wheat. Aust. J. Plant Physiol. 23:763-772.

Dybing, C.D., and Westgate, M.E. 1996. Genotypic variations in raceme-applied cytokinin effects on pod set and seed yield in soybean (Glycine max. L.). Plant Growth Reg. Soc. Quarterly. 24:177-187.

Flenet, F., Kiniry, J.R., Board, J.E., Westgate, M.E., and Reicosky, D.C. 1996. Row spacing effects on light extinction coefficients of corn, sorghum, soybean, and sunflower. Agron. J. 88:185-190.

Westgate, M.E. Forcella, F., Reicosky, D.C., and Somsen, J. 1996. Rapid canopy closure for maize production in the northern US corn belt: Radiation-use efficiency and grain yield. Field Crops Res. 49:249-258.