Final Progress Report
Sustainability Science Program, Harvard University
Term: September 1, 2010 – August 31, 2011
Submitted: July 2011

Name: Matthew Gilbert

Your field(s):
Plant and crop physiology

Your degree program, institution and graduation date:
Ph.D., Botany, Rhodes University, South Africa, 2008

Faculty host(s) at Harvard name and department:
Prof. Missy Holbrook, Organismic and Evolutionary Biology

Description of SSP-related research activity:

Title: Rain-fed subsistence farm diversification by plant functional types: A physiological ecologist's perspective

Abstract: Diversification of agricultural systems is a standard suggestion for increasing the resilience of rain-fed subsistence farming to drought. However, grain crops share many physiological characteristics, potentially forming a plant functional type (PFT), a term ecologists apply to groups of species that respond in functionally similar ways to environmental variation. Here we test whether grain crops are a PFT, and whether diversification between grain crops, to other crops or livestock that feed on natural plants results in sufficient physiological variation to form a diversified agricultural portfolio. The response of these groups to rainfall variation was simulated using a custom plant growth model. We then generated predictions of subsistence farmer allocation with a safety-first economic analysis and compared these to observed allocations at 78 sites across a rainfall gradient in South Africa. We demonstrate that there are shifts from crop to livestock farming with aridity, and that this is correlated with the extant PFT's at each site. That is, as the simulated probability of crop failure diverges from that of the natural vegetation, there is a shift to livestock farming. Diversifying within grain crops would lead to little increase in resilience due to limited physiological variation – an indication that grain crops are one PFT – while other crops had some potential for greater diversification advantages, and livestock feeding on natural plants the greatest. Thus, a plant functional type approach is vital in understanding the developmental economics of subsistence farmer diversification with the goal of increasing resilience to drought.

Identification of the problem you address:
I acknowledge the fact that plant physiologists often "do not feed people" - the search for the mechanisms of plant response to the environment are often divorced from practice. My project is designed as a first step in bridging this gap. I aim to establish for myself, and development practitioners, the theoretical (physiological) basis for subsistence farmer agricultural choices. As I believe this represents a simple general principle, I think it is of practical importance.

Key question asked about the problem:
How does plant physiology affect the agricultural choices of subsistence farmers in Southern Africa?

The methods by which you answered that question:
Largely through GIS and plant physiology based modeling of crop production, with site specific validation of model output.

Principle literature upon which the research drew (methodological and substantive, e.g., innovation, incentive-based environmental management, science and technology studies): a combination of the crop modeling theory literature and local (Southern African) reports of subsistence farming activities.

Empirical data acquisition description:
A combination of digitization of satellite imagery and GIS data for Southern Africa.

Geographical region studied:
South Africa – specifically the former Transkei and Ciskei homelands in the Eastern Cape Province

Recommendations that might be relevant for your problem:
That ultimately the support of local field-based trials is necessary to establish the environmental and social utility of a specific agricultural option (models are not sufficient to prove that a crop is beneficial in a specific circumstance).

A description of the final product(s) you have/are aiming to produce:
An article published in either Agricultural Systems or Ecology and Society.

Description of major other intellectual or professional advancement activity(ies) over the past academic year, including working title(s):
I have published two papers this year associated with a past fellowship with SSP listed in the next question. Currently a collaborator has submitted a paper, with my name on it, to *PNAS*: "Transcriptome response to embolism formation in stems of *Populus trichocarpa* provides insight into signaling and biology of refilling". A short collaboration with Tom Buckley resulted in a paper in *Plant Physiology*: "The role of bundle sheath extensions and life form in stomatal responses to leaf water status". I am in the process of finalizing a submission (SSP related) to the *Journal of Experimental Botany*: "On measuring the response of mesophyll conductance to carbon dioxide with the variable J method". All of these are major papers, with the latter being led by myself. I applied for two jobs this year (Stanford and Rhodes Universities), but obtained neither. Both were an important experience in preparing myself for the current year's job application season.

Please list citations for reports, papers, publications and presentations that built on your fellowship research:
Gilbert, ME. Holbrook, NM. Zwieniecki, MA. Sadok, W. Sinclair, TR. (accepted). Field confirmation of genetic variation in soybean transpiration response to vapor pressure deficit and photosynthetic compensation for this effect. *Field Crops Research.* URL and PDF unavailable as yet
Abstract: Plants with limited transpiration rate (TR) under high vapor pressure deficit (VPD) offer the potential to conserve soil water and thus decrease the occurrence of soil water deficit. Genetic variability in TR response to VPD has been observed in the greenhouse for soybean (*Glycine max* (L.) Merr.) genotypes related to PI 416937, but these differences have yet to be measured in the field. The objective of this study was to observe under field conditions leaf gas exchange properties of PI 416937 in comparison to nine other genotypes to determine if it expressed limited TR at high VPD. Genotypic differences in stomatal conductance measurements (a proxy for TR) matched those obtained under controlled environment conditions. Genotypes varied from no stomatal response to VPD, to strong negative responses resulting in full stomata closure at ~ 4 kPa. There was a greater proportional genetic variability in stomatal conductance in the field (75% at high VPD) than was observed in the greenhouse, but this variation was correlated with greenhouse TR. However, photosynthesis was considerably limited in genotypes that had a stomatal response to VPD. Although field differences in photosynthetic capacity among genotypes were not correlated with greenhouse measurements, there was sufficient genetic variation to allow the possibility of selection of high photosynthetic capacity to overcome about a 34% decrease in stomatal conductance. Thus, a targeted breeding program to combine the water conserving TR-VPD response with increased photosynthetic capacity has the potential to increase soybean yields in field water-deficit environments.

Gilbert, ME. Zwieniecki, M. Holbrook, NM. (2011). Independent variation in photosynthetic capacity and stomatal conductance leads to differences in intrinsic water use efficiency in eleven soybean genotypes before and during mild drought. *Journal of Experimental Botany* DOI: 10.1093/jxb/erq461
URL to PDF: http://jxb.oxfordjournals.org/content/62/8/2875.full.pdf+html

Abstract: Intrinsic water use efficiency (WUE_{intr}), the ratio of two processes: photosynthesis and stomatal conductance to water, is often used as an index for crop water use in breeding projects. However, WUE_{intr} conflates variation in these two processes, and thus may be less useful as a selection trait for breeders than knowledge of both components. The goal of this study was to determine whether the contribution of photosynthetic capacity and stomatal conductance to WUE_{intr} varies independently between soybean genotypes and whether this pattern is interactive with mild drought. We defined the contribution of photosynthetic capacity (WUE_{PC}) as the WUE_{intr} that would occur if genotypes of interest had the same g_{H2O} as a reference genotype and only differed in photosynthetic capacity; the contribution of stomatal conductance (WUE_{gH2O}) was defined as the WUE_{intr} attributable to only differences in stomatal conductance. WUE_{gH2O} had the greatest variation between genotypes (26% when well watered), while WUE_{PC} was uncorrelated with WUE_{gH2O}, and photosynthetic advantages of 8.3% were maintained under drought. The maximal rate of Rubisco carboxylation, generally the limiting photosynthetic process for soybeans, was shown to correlate well with WUE_{PC}. As this parameter was not interactive with leaf temperature, and WUE_{PC} was maintained under mild drought, the observed patterns of WUE_{PC} advantage for particular genotypes are likely to be consistent across a range of environmental conditions. This suggests that it is possible to employ a selection strategy of breeding water-saving soybeans with high photosynthetic capacities to compensate for otherwise reduced photosynthesis in genotypes with lower stomatal conductance.

Principal collaborators outside Harvard:
SSP-related: Tom Sinclair (North Carolina State in Rayleigh), Walid Sadok (Université Catholique de Louvain, Belgium) and Maciej Zwieniecki (Arnold Arboretum of Harvard)