Sustainable Production Systems

Economic and Sustainability Evaluation of New Technologies in Sorghum and Millet Production in INTSORMIL Priority Countries

Project PRF 205
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Summary

The Marketing-Processing Project has demonstrated in Niger that sorghum yields can be consistently raised to two to three tons and that it is very profitable for farmers to do so. In the two other countries (Mali and Senegal) improvements are being made in the basic cultivars but similar sorghum yield gains are expected. Millet yields of 1.3 to 1.9 yields are being regularly obtained in all three countries. Millet is grown on poorer soils (lower principal nutrient levels and more sandy) than sorghum so yields of 1.5 to 2 tons/ha are very respectable, whereas we expect 2.5 to 3.5 tons/ha for sorghum from improved technologies.

Two marketing strategies of improving the grain quality and selling later after the recovery from the post harvest price collapse raised prices received 10 to 37% in the 2005 crop year[1]. There are two more marketing strategies including the development of increased demand from the food and feed processing sector and convincing policy makers not to depress prices in adverse rainfall years.

In Thiare, a major millet zone in Senegal, millet food processors negotiate contracts with the farmers' groups and pay a quality premium of 20 to 30 CFA/kg. for the clean millet.The marketing activities for millet with food processors are progressing well in all three countries. There continues to be some resistance to paying a quality premium in Mali but we will be doing further extension activities to explain to food processors the importance of paying for the additional grain if they expect farmers to regularly incur the additional costs to achieve higher yields of a uniform cultivar and to reduce impurities. With ANCAR extension we will quadruple our area in Thiare in 2007-08 since both the technology and the marketing components are functioning well.

For sorghum the major potential market is to substitute for maize in the cereal for the poultry ration. Sorghum yields needs to be increased, as in Niger, so that the sorghum price can undercut that of maize. Surveys of poultry producers in three countries of the Sahel (Senegal, Burkina Faso, and Mali) are either underway (first two countries above) or being planned (Mali). Approximately 10 % of the intensive poultry producers either are mixing or plan to mix their own purchased cereals with the other feed components. This is the group targeted to buy small lots 10 to 40 tons of sorghum from the farmers' groups.

Objectives, Production and Utilization Constraints

During the past five years we have worked in four Sahelian countries (Senegal, Mali, Niger, and Burkina Faso) to extend our research activities. The Marketing-Processing Project is a regionally supported West African AID activity. This project has the ob-

1. Normally part of these sales occur in the spring and summer of 2007 so we have to wait until the summer after the crop season to evaluate their marketing strategy.

jective of getting new production technologies onto the farms of sorghum and millet producers in West Africa by providing credit for inputs to farmers' groups plus introducing marketing strategies to obtain higher prices for farmers.

From our research we had identified the importance of price collapses in discouraging farmers from higher input use (Sanders and Shapiro, 2006). The two initial, strategies are to encourage farmers to sell later after the recovery from the post harvest price collapse, to produce clean grain, and to encourage food and feed processors to pay farmers for this clean grain. A secondary component of the project is to work with food and feed processors in the four countries.

There have been two major research activities in our INTSORMIL research project. First we evaluate the farm impacts of new technologies being introduced into sorghum and millet production zones in semiarid Sub Saharan African agriculture. For example we evaluated the diffusion of and estimated the potential impact of new *Striga* resistant sorghum cultivars and associated technologies (fertilizers and water harvesting techniques) being introduced into two major states of Ethiopia, Tigray and Amhara. .

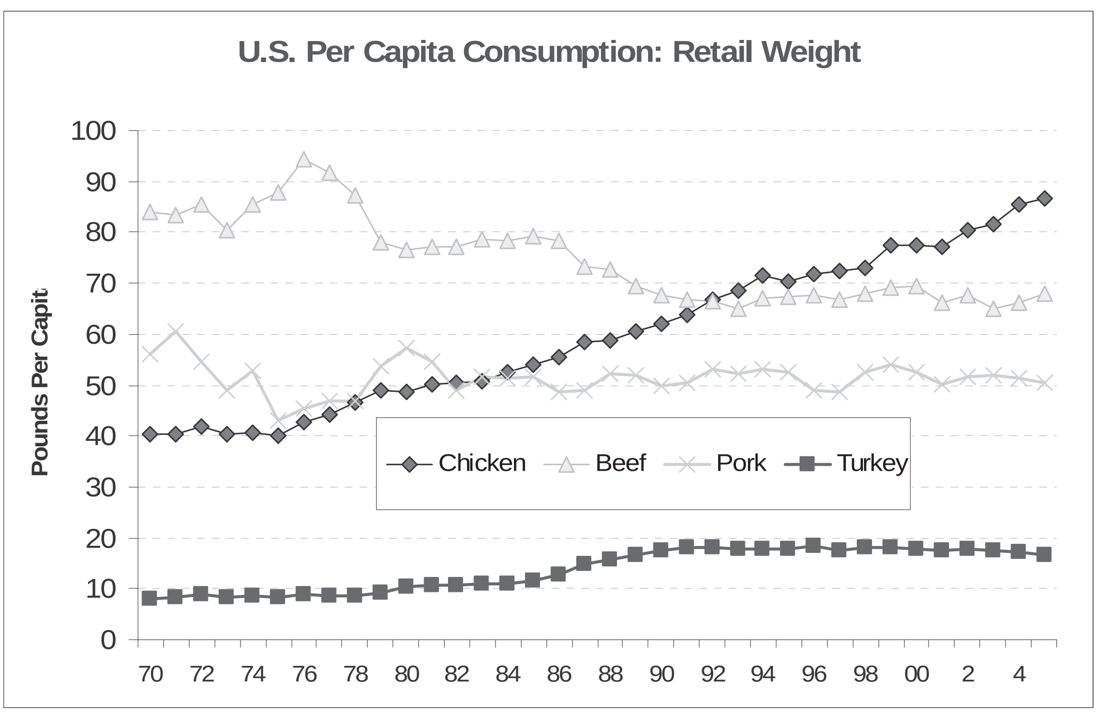
Another major activity is the research support for the Marketing-Processing Project. As part of this activity we estimate the farm level gains to new technologies and to the new marketing strategies. We also look in depth at specific policy alternatives such as evaluating Inventory Credit ("warrantage") programs.

Research Findings and Project Output

Botorou Ouendeba and John Sanders developed the Marketing-Processing Project for farmers' groups and food and feed processors of millet and sorghum. This program combines new technologies with improved marketing strategies (J. Sanders and B. Shapiro, 2006). In the first two years (2003 and 2004) this project relied on other agencies to extend sorghum and millet technologies to farmers. The contribution of the Marketing-Processing Project then was on developing new marketing strategies for farmers to increase their incentives to adopt new technologies. In 2003 and 2004 this activity was supported by INTSORMIL. Over the three years 2005- 2007 this Marketing-Processing Project has been financed by the Regional West African office of USAID. The AID funding has enabled us to support our own farmers' groups in their introduction of the new technologies of sorghum and millet.

The market focus of this program is on the rapidly expanding millet food processing sector in urban Sahel[2] and the substitution of sorghum for maize in the ration for intensive broiler and egg production. With increasing incomes there is a structural change in diets in developing countries to more meat, milk, cheese, fruits and vegetables. One of the main beneficiaries of this process across countries is broilers. A long run process of falling broiler prices relative to other meats converts chicken from a luxury food to a middle class and then even lower class principal meat source. These falling costs result from intensive poultry producers learning how to reduce their costs by gaining experience and on the consumption side from increasing vertical integration and economies of size. This process of the shift in consumption to chicken is

Figure 1. Source: USDA data provided by Chris Hurt, Department of Agricultural Economics, Purdue University.



2. Even though millet is the preferred grain for the food processors they have bought sorghum from our project farmers in all three countries to mix with the millet flour.

Table 1. Farmers and areas in new sorghum and millet technologies in Mali, Niger and Senegal, summer of 2006

Country and locations	Sorghum area	Sorghum farmers	Millet area	Millet farmers
Mali				
Koutiala	50	41	-	-
Kafara	62.5	48	-	-
Tingoni	-	-	50	50
Niger				
Gabi	60	118	-	-
Maraka	40	134	-	-
Doutchi	-	-	50	50
Senegal				
Diobene Talene	25	25	-	-
Mbodiene	20	20	-	-
Ndianda	20	20	-	-
Thiare	-	-	50	50
Dianke Souf	20	9		
Nganda	5	4		
TOTAL:	**302.5**	**399**	**150**	**150**

Source: J. H. Sanders and B. Ouendeba, Annual Report 2006: Marketing-Processing Project, preliminary draft., 8 pages.

illustrated in Figure 1 for the U.S. experience. But this same process of the substitution of chicken for other meats is accelerating in a number of African countries including Senegal.

What is the potential of sorghum to substitute for maize in the cereal component of the ration? According to nutritional evidence non-tannin sorghum[3] has approximately 95 to 97% (J. Hancock, correspondence) of the feed value of maize. So sorghum yields need to increase sufficiently so that it can be profitably sold for less than 95% of the maize price. Sorghum has an advantage in the Sahel over maize from being less susceptible to drought and low soil fertility. Moreover, unlike maize sorghum does not allow mico-toxin development in the field.

In Table 1 we report the number of farmers and cultivated area adopting technologies in the Marketing-Processing project. The summer of 2006 was the second year of intensive on-farm activities. The outstanding success story is in Gabi and Maraka, Niger. There farmers doubled to tripled yields of sorghum for the second year by following program recommendations. The new cultivar Sepon 82 has been very popular with Nigerien farmers. Many farmers in the surrounding region and even from Nigeria have been buying the grain for seed. The principal buyer from these sorghum producers has been Harouna Labo, the largest egg producer in Niger. Mme Cisse, a millet food processor, has historically been the most important buyer of millet from our farmer producer groups and she has been purchasing sorghum from the program farmers in 2006.

The program successes in doubling to tripling sorghum yields have been encouraging us to rapidly expand the program. In Senegal, Mali, and Niger we are expanding the number of farmers and the cultivated areas in the regions where farmers are following the technology and marketing recommendations as well as developing their own farmer organizations. These more successful zones are Thiare (millet) in Senegal, Kafara (sorghum) and Tingoni (millet) in Mali, Gabi, Maraka, and Doutchi in Niger. In other regions the inorganic fertilizer ended up on other crops besides the sorghum and/or the new technologies were planted late and on the poorer soils.

There has been useful feedback to the breeders in both Mali and Senegal from the program. In Mali a shorter, sturdier cultivar is being demanded by farmers. Farmers appreciate one of the new cultivars with these characteristics observed in regional trials of Aboubacar Toure of IER in Mali. In Senegal the lack of sorghum improvement programs in the last two decades means that there are not many non-tannin sorghum cultivars available. The Senegalese sorghum breeder of ISRA, Ndiaga Cisse, is presently trying to remedy this situation. More advance work needs to be done to convince farmers that with higher yields and prices sorghum can be competitive with cotton and maize in profitability terms.

Marketing recommendations have been critical in increasing the profitability of these technology innovations especially by encouraging farmers to sell later than at the post harvest price collapse. Secondly, the program provides “baches” (tarps) to keep the threshing off the ground. Clean grain not only saves processors a cleaning cost but also provides 10% to 20% more grain by eliminating the dirt, sand and rocks from doing threshing on the ground. A second marketing strategy is to press food and feed processors to pay a quality premium for both the savings in cleaning costs but also the increased quantity of grain. Table 2 summarizes the price gains obtained by farmers in the different regions, which can be principally attributed to the two marketing strategies above. These price gains make a substantial difference in raising the profitability of the new technology components. These technology components

3. In a recent bulletin of the Marketing-Processing project (Abdoulaye et al, 2006) it was demonstrated that it is now a myth that all sorghum cultivars have tannin. In all four countries of the Sahel there are now many non and low tannin cultivars of sorghum available.

Table 3. Household incomes (in dollars) for different technology and marketing strategy for the different states of nature (model results), Niger.

	Without New Technologies	With New Technologies	New technologies and inventory credit	New technologies with less government intervention in bad years	New technologies and only moderate price collapse in good and very good years
Adverse	459 (159)	529 (244)	528 (246)	775 (478)	530 (249)
Normal	583 (278)	794 (504)	827 (543)	849 (574)	792 (511)
Good	647 (334)	914 (623)	955 (670)	1018 (736)	11146 (865)
Very good	640 (322)	977 (684)	1016 (731)	1107 (826)	1559 (1278)
Expected income	587 (279)	805 (515)	835 (550)	914 (633)	939 (657)

Source: Abdoulaye, T. and J.H. Sanders, 2006. "New technologies, marketing strategies and public policy for traditional food crops: Millet in Niger," Agricultural Systems, 90: p. 288.
Numbers in parentheses are crop incomes and outside of the parenthesis are whole farm incomes. Both are in dollars.

include improved cultivars, moderate levels of inorganic fertilizer, and improved agronomy.

Then in our research we complement the extension activity by evaluating the income effects of different marketing strategies. In the US and other developed countries there are both insurance programs (federally subsidized for drought regions) and disaster assistance to aid farmers in drought regions during adverse rainfall years. In West Africa there are public programs for the worst years, the major drought years, which occur approximately once a decade. However, for poor rainfall years governments often intervene to drive down consumer prices of the basic staples. This public sector behavior makes it more difficult for farmers to make money and then invest in annual inputs and in fixed investments. Table 3 demonstrates that a public policy program to convince governments not to intervene in bad rainfall years could result in substantial benefits to farmers waiting to sell after harvest. This type of non-intervention by government in bad years[4] by allowing the food staple prices to go up then would serve some of the same purposes as risk insurance and disaster assistance in the US of raising farmers' incomes in adverse rainfall years.

One major problem with the principal food staples is that in normal and good rainfall years there is an abundant supply but consumers can only eat so much. Once consumers with income have their food requirements, there are few other uses hence prices of food staples collapse. To moderate this good weather price collapse one strategy is to facilitate the evolution of the food and feed processing sector. This provides an alternative market thus setting a floor on prices primarily for good rainfall years. In the last column of table 3 the impact of this market evolution in moderating the price decline in good and very good years is estimated. With this development of the food and feed sector farmers' incomes are increased by 16%.

Another study, also a spin-off from the Marketing-Processing Project, was an examination of Inventory Credit Programs. These programs enable farmers to obtain cash at harvest for the many pressing expenditures incurred at this time. In improved Inventory Credit programs farmers retain ownership of their grains so they can then sell them later in the season. Farmers repay the credit plus interest and storage costs once they have sold their grain. The farmers' group holds the grain as an assurance of repayment but the farmers make the decisions on when and where to sell. As presently implemented in the Sahel these Inventory Credit programs tend to make profits for the producers' groups but give few incentives to farmers. Farmers turn their grains over to the farmers' groups and receive the harvest time prices. The farmers' groups make the profits from the seasonal price increase and use the profits to purchase fertilizers for the group for next season with quantity discounts from larger purchases. Returning the control of the grain to the farmers rather than the producers' groups increases farmers' expected income by 8% (Baquedano and Sanders, 2006, p. 307).

Description of Methods of Work Used

In the Marketing-Processing Project there is an extension approach to getting technology and marketing strategies used by farmers. We are also engaged with food and feed processors in developing better ties and higher prices for the farmers' groups. We provide feedback to the plant breeders researchers on how the technologies are functioning. Moreover, this project helps identify many research issues. Some of these applied issues are handled within the project such as surveys on the importance of tannin in West African sorghum cultivars. We have also been interviewing millet processors about the purchasing decisions especially the premium for higher quality millet. We interview poultry producers about their decision to mix their own feeds and to substitute sorghum for maize in the ration. This extension project helps us identify issues for further in depth analysis in our INTSORMIL funded research program.

In our research we rely on survey data of farmers and do modeling from that to answer a series of policy related questions about technology introduction and marketing. For example with Tahirou Abdoulaye we have estimated the income effects of four of the marketing strategies being introduced. With Felix Baquedano we

4. Prices for sorghum and millet are in the 90 to 110 FCFA/ kg range in normal years. As the prices go to 200 FCFA/kg governments normally intervene with food aid or imports to drive down these prices. If the national governments waited until the price were 240 FCFA before intervening to drive down prices, farmers would be substantially benefited as indicated in Table 3.

have investigated the effects of improvements in the types of Inventory Credit Programs being introduced in West Africa. A major activity has always been estimating the impacts of new technology introduction. This research is based upon farmer surveys though in Mali a sector model was developed by Vitale to more accurately predict national effects.

Networking Activity

With the Marketing-Processing Project there are a large number of systematic ties to other agencies. The most important of these are to the national agricultural research organizations (IER in Mali, INRAN in Niger, INERA in Burkina Faso, and ISRA in Senegal) and to the extension agencies, either the national extension service, (ANCAR in Senegal) or to NGOs working at the village level (Catholic Relief Services in Niger, Global 2000 and AHMED in Mali). With the national agricultural research agencies we identify the technologies and obtain the seed of the new cultivars. Then the extension groups work with us in getting the technologies to farmers' groups and in providing technical services to these farmers to support the introduction of the technologies and the marketing strategies. We also involve the millet processors, intensive poultry producers and feed mixers in our activities tying them where possible to the farmers' groups. As part of this networking we hold an annual workshop to explain what we are doing and to get feedback from the agencies, firms and farmers involved.

Publications and Presentations

Journal Articles

Baquedano, F. and J.H.Sanders. 2006. "Introducing Inventory Credit into Nigerien Agriculture: Improving Technology Diffusion." Agricultural Finance Review, Vol. 66, No. 2 Special Issue, (297-314).

Nega Gebreselassie and J. H. Sanders. 2006. "Farm-level Adoption of Sorghum Technologies in Tigray, Ethiopia." Agricultural Systems, 91 (122-134).

Abdoulaye, Tahirou and John H. Sanders, 2006. "New Technologies, Marketing Strategies and Public Food Policy for Traditional Food Crops: Millet in Niger," Agricultural Systems, 90 (279-292)

Book Chapters

Winslow M., Shapiro S. and Sanders J., 2007 "Policies, Institutions and Market Development to Accelerate Technological Change in the Semiarid Zones of Sub-Saharan Africa" in Andre Bationo, Boaz Waswa, Job Kihara and Joseph Kimetu, (ed), Advances in integrated soil fertility management in sub Saharan Africa: challenges and opportunities. Forthcoming.

Sanders, John H., and Barry Shapiro. 2006. "Policies and Market Development to Accelerate Technological Change in the Semiarid Zones: A Focus on Sub-Saharan Africa." In Gary A. Peterson, Paul W. Unger, and William A. Payne, (ed), Dryland Agriculture, Agronomy Monograph No. 23, Second Edition. American Society of Agronomy, Inc. Crop Science Society of America, Inc. Soil Science Society of America, Inc. 677 South Segoe Raod Madison, Wisconsin 53711. (879-900)

Extension Bulletins

Abdoulaye, Tahirou, John H. Sanders, and Botorou Ouendeba, 2006. Quelle Cereale pour les Aliments de Volaille en Afrique de l'Ouest: Sorgho ou Mais ?, INTSORMIL Bulletin No 4, Projet Marketing-Processing, University of Nebraska, Lincoln, NE, 24 pages.

Abdoulaye, Tahirou, John H. Sanders, and Botorou Ouendeba, 2007. Revenue des Producteurs: Effets des Technologies et des Strategias de Marketing,Campagne Agricola 2005-2006, INTSORMIL Bulletin No 5, Projet Marketing-Processing, University of Nebraska, Lincoln, NE, 17 pages.

Cropping Systems to Optimize Yield, Water and Nutrient Use Efficiency of Pearl Millet and Grain Sorghum

Project UNL 213
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Summary

INTSORMIL Project UNL-213 continues with international research efforts related to nutrient management and use efficiency in West Africa and Central America. Microdose fertilizer application increased average pearl millet and sorghum grain yield across four years and three West African countries by 372 kg ha^{-1} (67%) and stover yield by 838 kg ha^{-1} (51%). Microdose application resulted in similar net nutrient removal as the zero fertilizer control. Over 30 kg N ha^{-1} and approximately 10 kg P ha^{-1} were required to eliminate mining of nutrients from the soil. The highest grain and stover yields required 20 kg P ha^{-1} and 30 kg N ha^{-1}. Studies focused on grain sorghum production practices for traditional beer (dolo) production and poultry manure use for pearl millet production were initiated, while continuing on-farm research and technology transfer of animal traction zaï in Burkina Faso.

In El Salvador, the photoperiod sensitive varieties 85SCP805 with 47 kg N ha^{-1} application increased grain yield by approximately 800 kg ha^{-1} (26%) over the local check without N application. These results were validated on-farm, and transfer has occurred in the Department of Cabañas in El Salvador with economic benefits of several miilion dollars. Transfer activities are starting in the Department of Chalatenango and in Honduras In studies on N use

efficiency (NUE), yields of photoperiod insensitive lines ranged from 1.8 to 3.0 Mg ha^{-1} in El Salvador, but only ICSVLM-90520 produced a higher yield than the best control variety of Soberano and had high NUE. In Nicaragua, the local check variety Pinolero along with the line ICSCVLM-93076 produced approximately 3.7 Mg ha^{-1} grain surpassing the yields of rest of the varieties by 0.5 to 1.1 Mg ha^{-1}. With N application, ICSCVLM-93076 produced the highest grain yield of 5.1 Mg ha^{-1} compared to 4.2 Mg ha^{-1} for the check variety Pinolero. ICSCVM-93076 was N responsive while still producing high yields without N application. These lines have been incorporated into public plant breeding programs.

In El Salvador, average grain yield of photoperiod insensitive varieties without N fertilizer was 2002 kg ha^{-1} while with 21 kg N ha^{-1} average yield was 2920 kg ha^{-1}, and increase in yield of 46% with a marginal return of 44 kg ha^{-1} grain production for each kg N ha^{-1}. In Nicaragua, N fertilizer application increased the average grain yield from 3.1 to 3.9 Mg ha^{-1} (26%), documenting the importance of N fertilizer use to increase grain sorghum yields.

Research in the United States determined that rotation with non-nodulating soybean without soil amendment increased sorghum grain yield by 2.6 to 3.0 Mg ha^{-1} , stover yields by 1.5 to 1.8 Mg ha^{-1}, and soil NO3-N at the vegetative growth stage. Rotation with nodulating soybean further increased grain yields by 1.7 to 1.8 Mg ha^{-1} and stover yield by 0.6 to 0.9 Mg ha^{-1}. On average, grain N concentrations and hardness were increased for sorghum rotated with non-nodulating and nodulating soybean. This study along with research on environment influence on grain quality of food-grade sorghum have shown that production practices have a large impact on grain quality, and should be considered in production of value-added grain for human food, livestock feed and industrial uses.

Project principal investigators have incorporated research results into extension bulletins (production guides) in El Salvador and Nicaragua.

INTSORMIL Project UNL-213 has emphasized capacity development through graduate education and short-term training, Graduate degrees have been earned by students from Burkina Faso, Chad, Niger and the U.S.

Objectives

Production and Utilization Constraints

Pearl millet and grain sorghum are usually grown in stressful environments with high temperatures, lack of predictable water supply, fragile soils with low nutrient status, and limited growing season length. Lack of water is usually considered to be the most critical environmental factor controlling growth and limiting yield in Africa and Central America, but a source of N and/or P often is more critical. Nutrient and water use efficiencies are closely interwoven with higher yields possible with improved cropping systems utilizing improved cultivars. Another important constraint to production and utilization of pearl millet and grain sorghum is the limited human capital for research and extension activities.

Objectives

Conduct multi-year research on microdose, N and P fertilizer application on pearl millet grain yield, nutrient removal, and changes in soil nutrient levels in Burkina Faso, Mali and Niger.

Conduct research on mechanized (i.e., animal traction) zaï production system for pearl millet and crop/soil management for traditional sorghum beer production in Burkina Faso, weed control interactions with fertilizer in Mali, and poultry manure use for pearl millet production in Niger.

Conduct research to better understand N and non-N influences of crop rotation on grain and stover yield, growth, grain quality and N nutrition of sorghum plants.

Determine environment interactions with food-grade sorghum hybrids for grain yield and quality.

Conduct N rate and N use efficiency studies for grain sorghum production in El Salvador and Nicaragua to identify N use efficient varieties and determine N rate recommendations.

Increase research human capital in West African and Central American countries where pearl millet and grain sorghum are important crops through graduate education, short-term training and through mentoring former students upon return to their home country.

Collaborate with national extension services, farmers' organizations and NGO/PVOs in transferring improved pearl millet and grain sorghum agronomy practices.

Domestic (Nebraska) Research Activities

Nodulating and Non-Nodulating Soybean Rotation Effect on Sorghum Grain Yield and Quality (Nanga Mady Kaye, M.S. Thesis)

Research Methods

A long-term crop rotation experiment with continuous sorghum, sorghum rotated with nodulating soybeans, sorghum rotated with non-nodulating soybeans, continuous nodulating soybean and continuous non-noduating soybean with different fertilizer applications (zero, 90 kg ha^{-1} N to sorghum and 45 kg ha^{-1} N to soybean, and annual feedlot manure) was studied to separate N and non-N effects of crop rotation.

Research Results

Cropping sequence x soil amendment effects were present for most parameters measured. Rotation with non-nodulating soybean without soil amendment increased grain yield by 2.6 to 3.0 Mg ha^{-1}, stover yields by 1.5 to 1.8 Mg ha^{-1}, and soil NO3-N at vegetative growth stage. Rotation with nodulating soybean further increased grain yields by 1.7 to 1.8 Mg ha^{-1}, stover yield by 0.6

to 0.9 Mg ha^{-1}, and soil NO3-N at vegetative growth stage. Biologically fixed N accounted for only 35 to 41% of enhanced sorghum yield due to crop rotation with soybean. On average grain N concentrations were increased by 0.5 to 1.0, 2.5 to 5.0 and 3.3 to 4.7 g kg^{-1} for N application to continuous sorghum and sorghum rotated with non-nodulating and nodulating soybean, respectively. Cropping sequences influenced grain hardness to a lesser extent. Irregardless of cropping sequence, manured plots produced the highest grain and stover yields, grain N concentration, and grain hardness. TADD removal indicated that continuous sorghum without manure or N application produced the softest grain with 43 to 44% TADD removal, and sorghum rotated with nodulating soybean with manure application produced the hardest grain with 22 to 27% TADD removal. Cropping sequence and soil amendment choices are important to assure optimal sorghum grain yield and quality important for food and livestock feed uses.

Environment effect on White Sorghum Hybrid Grain Yield and Quality (Joni Griess, M.S. Thesis)

Research Methods

Eight commercial food-grade commercial grain sorghum hybrids, one food-grade variety check (Macia), three experimental food-grade hybrids along with six commercial check hybrids were planted in randomized complete block designed experiments in six environments in 2004 (east central and central Nebraska locations with and without irrigation) and seven environments in 2005.

Research Results

Grain yields and kernel weights varied greatly across environments. Harder kernels were produced in 2005 environments than in 2004 environments, with Orleans 2005 having the lowest TADD removal. Low N environments had the lowest protein concentrations in both years and the highest starch concentration in 2005. Dryland environments in 2005 with hard kernels had high starch setback viscosities as a result fo high final viscosities and moderate holding viscosities, indicating that products made from grain produced in these environments would have similar qualities. Commercial check hybrids produced higher yields and heavier kernel weights than food-grade hybrids. Hybrid differences for bulk and true density were small, while TADD removal differences were larger. The food-grade check Macia had the lowest TADD removal of 21% which was similar to Asgrow Orbit and UNL N252AX1038R. Starch cooking properties of NC+7W92, Kelly Green Seed KG6902, Asgrow Eclipse and Fontanelle W^{-1}000 had high peak viscosities, dispersed starch molecules during shear thinning, and high final and setback viscosities. The opposite was true for Macia, UNL 03H21203, UNL N252AX1038R, Asgrow Orbit and NK1486 desirable for many food uses. Kelly Green Seed KG6902, Fontanelle W^{-1}000 and NC+7W92 had lower protein and higher starch concentrations and softer kernels, indicating likely usefulness for brewing and ethanol production.

Water Supply on Pearl Millet and Sorghum Yield and Water Use Efficiency (Nouri Maman, Ph.D. Thesis)

Research Methods

The experiment was conducted on a Keith silt loam under a linear move irrigation system with drop nozzles in western Nebraska (semi-arid environment) in 2000 and 2001. The experiment was conducted using a randomized complete block design with a factorial (2 x 4) treatment arrangement and three replications. Factor 1 was the pearl millet hybrid (68Ax 086R) and one grain sorghum hybrid (DK 28E). Factor 2 was composed of four different water regimes. The water regimes consisted of; (i) Control, rainfed; (ii) Full water supply at all growth stages; (iii) water supply at boot stage, and (iv) water supply at grain fill stage. Environments were considered to by year, location and water regime combinations.

Research Results

Pearl millet grain yields were 60 to 80% that of grain sorghum. Average grain yields in eastern Nebraska were 5.1 Mg ha^{-1} for pearl millet and 6.1 Mg ha^{-1} for grain sorghum. In western Nebraska, average pearl millet yields were 1.9 to 3.9 Mg ha^{-1} for pearl millet, and 4.1 to 5.0 Mg ha^{-1} for grain sorghum. Both crops used similar amounts of water and responded to irrigation with a linear increase in grain yield as water use increased. Sorghum had a greater water use efficiency than pearl millet (12.4 to 13.4 vs 5.1 to 10.4 kg grain ha^{-1} mm-1). Correlation and path analysis direct effects indicated that the number of kernels per panicle and kernel weight were associated with grain for both crops. However for sorghum, kernel weight was more highly associated with grain yield than kernels per panicle. Pearl millet had lower and less stable yields than sorghum, thus is not a viable substitute for sorghum in Nebraska.

Nitrogen Response of Pearl Millet (Nouri Maman, Ph.D. Thesis)

Research Methods

The pearl millet hybrids 68Ax086R and 293x086R were planted in randomized complete block experiments with N fertilizer rates of zero, 45, 90 and 135 kg ha^{-1} and four replications in 2000 to 2002. The study was conducted in Sidney, NE on a silt loam soil and in Mead, NE on a silty clay loam soil.

Research Results

Hybrids had similar yield, N uptake and nitrogen use efficiencies (NUE) responses. In western Nebraska in 2000, pearl millet yield response to N rate was linear, but the yield increase was on 354 kg ha^{-1} to 135 kg N ha^{-1}. In eastern Nebraska, pearl millet response to N rate was quadratic with maximum grain yields of 4040 Mg ha^{-1} in 2001 and 4890 Mg ha^{-1} in 2002 attained with 90 kg N ha^{-1}. The optimum N rate for pearl millet was 90 kg N ha^{-1} for eastern Nebraska. For western Nebraska, drought may often limit pearl millet response to N fertilizer.

Planting Date and Row Spacing of Pearl Millet (Siébou Palé, M.S. Thesis)

Research Methods

Studies were conducted between 1995 and 2001 to determine recommended planting date and row spacing for pearl millet hybrids was conducted on a silty clay loam and sandy soil site in Mead, NE (east), a loam soil in Sidney, NE (west), and a sandy soil site in Ogallala, NE (west-central). Sidney has low rainfall, short growing season. and efforts are being made to intensify wheat-fallow production systems by incorporating pearl millet as a summer annual crop in this region. The pearl millet hybrids 68A X 086R responses to planting date, and narrow (38 to 50 cm) and wide (76 cm) row spacing were compared to the grain sorghum check DK28.

Research Results

Optimum pearl millet planting times were 399 air heat unites or 410 soil heat units after April 1 for the silty clay loam soil, and 406 soil heat units for the sandy soil. The optimal sorghum planting time was 308 air heat units or 307 soil heat units after April 1 for the silty clay loam soil and 402 air heat units after April 1 for the sandy soil. Both crops had large planting time windows, allowing flexibility in planting time. Sorghum outyielded pearl millet for May and early June planting dates by 0.57 to 2.32 Mg ha^{-1}while pearl millet had higher yields by 0.95 to 1.20 Mg ha^{-1} for late June and July planting times. Sorghum produced greater yields than pearl millet for most planting times while pearl millet produced greater yields for very late planting times.

Row spacing response was similar across locations, planting dates and the two crops. Narrowing rows from 76 to 38 cm increased the yield of both crops by 8 to 14%. Pearl millet and early-season sorghum producers should plant these crops in narrow rows to optimize grain yield production.

Grain Sorghum - Maize Hybrid Comparisons in Dryland and Irrigated Environments

Research Methods

A three-year study was conducted to determine the basis for shift in dryland sorghum to maize production in eastern Nebraska. Best hybrids were identified from the 1950s, 1970s and 1990s as the best performing hybrids in the University of Nebraska Performance Tests and they were produced in three environments each year. The environments were sandy loam and silty clay loam soil types, and irrigated and dryland water regimes on the silty clay loam soil. Regression analysis was conducted to relate year of hybrid release to yield with the objective to determine if a difference in rate of yield increase was present between maize and grain sorghum for different production environments.

Research Results

Maize yields were higher than grain sorghum for all production environments and hybrids. On the high water holding capacity silty clay loam soil, irrigation increased maize grain yield but not for grain sorghum. The rate of yield increase was similar for maize in the sandy loam soils, and grain sorghum in all production environments with the rate of increase being 0.05 ± 0.004 Mg ha^{-1} yr^{-1}. The rate of increase for irrigated maize was 0.0282 Mg ha^{-1} (28 kg ha^{-1}) and 0.0501 Mg ha^{-1} (50 kg ha^{-1}) for dryland maize produced in the high water holding capacity silty clay loam soil. These rates of maize yield increase, except for the dryland, high soil water holding capacity soil, are considerably lower than the 57 to 89 kg ha^{-1} yr-1 reported in the literature for dryland production in central Iowa (Duvick and Cassman. 1999. Crop Sci.39:1622 - 1630). This suggests that the ability to tolerate intermediate stress likely to occur in dryland production on high water holding capacity soils has been the major contribution of plant breeding to maize yield improvement in eastern Nebraska during the past 50 years. These rates of sorghum yield increase due to hybrid improvement are also less than the 23 kg ha^{-1} yr-1 reported in the literature for Bushland, Texas (Unger and Baumhardt. 1999. Agron. J. 91: 870-875). The higher yields and higher rate of yield improvement of maize on dryland, high soil water holding capacity soils partially explain the replacement of dryland grain sorghum with dryland maize in the western corn belt during the last 10 years.

International Research Activities

Microdose Fertilizer Study (Taonda Jean-Baptiste and Siébou Palé - Burkina Faso, Minamba Bagayoko and Samba Traoré -Mali, and Seyni Sirifi - Niger)

Research Methods

Four-year studies were initiated on-station in Burkina Faso (pearl millet), Mali (pearl millet on sandy soil and grain sorghum on heavy soil) and Niger (pearl millet) in 2001. A randomized complete designed study was used with four replications. Treatments consisted of zero, microdose (cap-full of complete fertilizer in the seed hill at planting), Microdose + 20 kg P ha^{-1}, microdose + 40 kg P ha^{-1}, microdose + 30 kg N ha^{-1}, microdose + 60 kg N ha^{-1}, microdose + 20 kg P ha^{-1} + 30 kg N ha^{-1}, and microdose + 40 kg P ha^{-1} + 60 kg N ha^{-1}. Satellite studies were conducted on farms using zero and microdose; zero, microdose, and 20 kg ha^{-1} P; zero, microdose and microdose + 20 kg P ha^{-1} + 30 kg N ha^{-1} treatments depending upon location.

Research Results

Analysis of variance indicated that grain and stover yields responses to fertilizer treatments varied by country and year. On average, microdose fertilizer application increased on-station pearl millet grain yield by 113% (225 to 479 kg ha^{-1}) in Niger, by 81% (351 to 637 kg ha^{-1}) in Burkina Faso, by 30% (764 to 1046 kg ha^{-1}) on sandy soil in Mali, and by 33% (1069 to 1417 kg ha^{-1}) on a heavy soil in Mali. Sorghum yield increase was 117% 885 to 1924 kg ha^{-1}) greater on the heavy soil in Mali. Grain yields were further increased by 20 to 83% with application of N and P fertilizer on sandy soils, and by 10 to 13% on heavy soils in Mali. On-farm pearl millet yield responses were similar, with grain yield increases of 76% (328 to 577 kg ha^{-1}) in Niger, by 180% (197 to 552 kg ha^{-1}) in Burkina Faso, and 27% (1108 to 1448 kg ha^{-1}) in Mali. Stover is important as a livestock feed, construction material and for soil maintenance/improvement. Stover yields increased 61% (1566 to 2626 kg ha^{-1}) in Niger, by 72% (929 to 1597 kg ha^{-1}) in Burkina Faso, and 66% (1545 to 2561 kg ha^{-1}) on a sandy soil in Mali, and by 50% (2500 to 3750 kg ha^{-1}) on a heavy soil in Mali. Additional N and P fertilizer further increased stover yield by 20 to 50%. Microdose application is a low cost investment that has a high probability to increase grain and stover yields across the West Africa pearl millet (and sorghum) production area, but estimated N and P removals are negative and similar to zero application and thus does not alleviate soil nutrient mining concerns. Blank tests to determine the residual benefits of different fertilizer treatments indicated no differences in Niger and Mali, while all fertilizer treatments led to increased yield over the zero treatment in Burkina Faso. Applications of microdose plus 30 kg N ha^{-1} and 10 kg P ha^{-1} are required to reverse soil mining in production systems with both grain and stover removed from the field.

Mechanized Zaï (animal traction) and Other Tillage/Fertilizer Treatments Influence on Grain Sorghum Yield (Taonda Jean Baptiste - Burkina Faso)

Research Methods

The traditional zaï system composed of planting pearl millet seed in a small hole with a small amount of manure application which increases water infiltration in some soils and results in increased yield, but requires much hand labor. Scientists have developed a mechanized zaï using animal traction. The objective of this study was to determine the effectiveness of the mechanized zaï (with 300 g compost per hill) to the traditional zaï (with 300 g compost per hill) and a flat-planted control (without compost) across six different soil types in Burkina Faso. The study was conducted on 12 farms in a 800 mm yr-1 rainfall zone. The soil types present on the farms were sandy (2 farms), sandy loam (5 farms), sandy clay (5 farms), clay (2 farms), gravelly clay (4 farms) and gravelly (6 farms). On-farm research was conducted as a followup to studies on 5 farms with diverse soils in 2004. Treatments were no fertilizer, no tillage (farmer practice), zaï with compost 300 g compost hill-1, and animal traction zaï with 300 g compost hill-1.

Research Results

Pearl millet grain yields varied across soil types with control yields ranging from 246 to 686 kg ha^{-1}. The use of the manual or mechanized zaï consistently increased yields, with the yield increase being greatest on the gravelly soil. Pearl millet stover yield was increased by a similar magnitude. The combination of tillage, creation of a micro-catchment to increase water infiltration, and compost application increased crop yield, and the human labor savings of approximately 278 man-hours ha^{-1} indicated that this is an improved technology for Burkina Faso production situations. On-farm studies indicated that the manual zaï treatment with compost application increased yields from approximately 180 kg ha^{-1} to 480 kg ha^{-1} on silty to silty clay soils (167%) compared to farmer practice, while the animal traction zaï further increased yield to over 600 kg ha^{-1} (233% greater than farmer practice) on silty soils and to nearly 800 kg ha^{-1} (360% greater than farmer practice) on silty clay soils. This is a component of a concerted effort by INERA to promote adoption of animal traction zaï combined with compost application.

Sorghum Production Practices for Dolo (Beer) Production in Burkina Faso (Siébou Palé)

Research Methods

Previous research has shown that the sorghum varieties IRAT 9 and ICSV 1001(Framida) to be superior for dolo (traditional beer) production. Studies were initiated in 2003 to develop production practice recommendations for grain yield and dolo quality. These included studies on production practices to optimize grain production, crop/soil management influence on grain composition and biochemical parameters relevant to malting and brewing (grain protein, tannin, total sugar and reducing sugar), surveys of malt producers, dolo producers, dolo and malt marketers, and dolo consumers, and economic analysis. The crop/soil management study was conducted in a randomized complete block design with split plot treatment arrangement. The whole plot is water management (shallow cultivation control, tied ridges, manual zaï, mechanized (animal traction zaï, and dry soil tillage) and split plots of fertilizer levels (zero, micodose with 4g of 15-15-15 per hill, recommended rate of 75 kg ha^{-1} of 15-15-15 plus 50 kg ha^{-1} urea, and microdose plus 20 kg P ha^{-1} and 30 kg N ha^{-1}). The grain yield study is completed and laboratory quality tests associated with dolo production are being conducted. Surveys are completed and being analyzed, and economic analysis will be completed following completion of the other studies.

Research Results

For Framida (ICSV1001), averaged over three years, tied ridges increased yield over the control by 241 kg ha^{-1}. All fertilizer treatments except for microdose application produced higher grain yields in 2003, but the largest grain yield increases of 420 to 756 kg ha^{-1} occurred when applying microdose + 20 kg P ha^{-1} + 30 kg N ha^{-1}. For IRAT9, all water treatments produced higher grain yield in 2005. All fertilizer treatments except the control produced higher grain yields in 2005. Microdose + P + N increased grain yield by 812 to 1346 kg ha^{-1}. Combination of microdose + P + N with tied ridges increased grain yield by 1462 kg ha^{-1} . The best cropping system to optimize grain yield of Framida and IRAT9 was combining tied ridges and microdose + P + N application.

Weed Control X Fertilizer Study (Samba Traoré - Mali)

Research Methods

A randomized complete block designed experiment to evaluate the interactive effects of hand weeding method and fertilizer application on pearl millet grain and stover yield was conducted at the Cinzana Research Station in 2001 to 2004. Pearl millet was planted on ridges after fertilizer application. Fertilizer treatments consisted of microdose (2 grams diammonium phosphate per hill), 6 grams of 15-15-15 per hill, and 4 T ha^{-1} manure incorporated during soil preparation plus 50 kg ha^{-1} of diamonium phosphate broadcast applied after emergence. Mechanical weed control treatments consisted of complete control, weeding of ridges only, and no weeding.

Research Results

Analysis of variance indicated that yield differences were due to year X weed control and year X fertilizer treatments. In all years, rainfall was limited late in the growing season resulting in average grain yields of 630 to 900 kg ha^{-1} , and average stover yields of 3344 kg ha^{-1} in 2001, 1635 kg ha^{-1} in 2002, and 1366 kg ha^{-1} in 2004. Weed competition was much greater in 2002 than 2001, and rainfall lower in 2004 at least partially accounting for the lower stover production in 2002 and 2004. In 2001 with low weed pressure present, mechanical weeding treatments had little effect on grain and stover yield. In 2002, weeding of ridges increased grain yield by 470 kg ha^{-1} (93%) and complete weed control increased grain yield by 736 kg ha^{-1} (146%) while in 2004 weeding of ridges increased grain yield by 333 kg ha^{-1} (93%) and complete weeding increased grain yields by 481 kg ha^{-1} (134%). The application of 6 gram diammonium phosphate did not increase grain or stover yield due to salt injury reducing emergence. The manure + 50 kg ha^{-1} diamonium phosphate treatment did not increase grain yields greatly in 2001, but in 2002 increased grain yields by 912 kg ha^{-1} (150%) over the microdose treatment, and in 2004 by 303 kg ha^{-1} (57%). Complete and timely weeding combined with application of animal manure and N and P produced the highest grain and stover yields, except in the dry 2001 season.

Pearl Millet Grain Yield Improvement Using Poultry Manure and Fertilizer (Nouri Maman, Niger)

Research Methods

In 2004, a three-pronged research effort on use of poultry manure generated by the expanding poultry industry was initiated. First, a survey of farmer practices presently using this manure source was conducted. Second, an on-farm study was conducted on 9 farms with treatments being zero, 2 t ha^{-1} poultry manure and 2 t ha^{-1} poultry manure + 40 kg ha^{-1} of 15-15-15 fertilizer. Third, on-station studies were initiated to determine the best rate of poultry manure application (zero, 2, 4 and 6 t ha^{-1}) with and without supplemental P application (zero, 10, 20 and 30 kg P ha^{-1}).

Research Results

Survey results of the 10 local producers using poultry manure found that poultry manure contains 10 times more P and K (17 and 2.2 g kg^{-1}) than local cattle manure, and more total N (11.9 to 13.0 g kg^{-1}). The average rate of application by farmer was 1 t ha^{-1}. All farmers agreed that the manure increased yield and improved soil fertility, and only one producer indicated that application labor was a major constraint to use of poultry manure.

Three-year on-farm research found that poultry manure increased pearl millet grain and stover yield by 57% (461 to 721 kg ha^{-1}) and stover yield by 54% (1466 to 2250 kg ha^{-1}). When 40 kg ha^{-1} 15-15-15 fertilizer was applied, grain yield further increased to 999 kg ha^{-1} and stover yield to 2834 kg ha^{-1}. The on-station study showed that maximum pearl millet grain yield 2 t ha^{-1} poultry manure combined with 10 kg P ha^{-1}. Variable cost ratios indicated that more than a five-fold increase in economic income was associated with the use of poultry manure alone (5.63) or in combination with 10 kg P ha^{-1} (5.47).

Nitrogen Use Efficiency (NUE) of Photoperiod Insensitive Sorghum Germplasm (Maximo Hernández, Leonardo García and Orlando Téllez - El Salvador and Nicaragua)

Research Methods

Studies were conducted in El Salvador and Nicaragua between 2001 and 2004 with the objective to determine if NUE differences exist among photoperiod insensitive sorghum varieties and response of these grain sorghum lines to low N fertilizer rates, and to identify high NUE varieties. At each location, 24 lines from breeding programs were initially grown with and without N in a randomized complete block design with four replications, and only the 16 superior lines being carried forward to the following years study.

Research Results

In El Salvador, no line X N interaction was found, suggesting that variety selection and N rate should be independent management decisions. The El Salvador location in 2003 provided little useful information due to site selection of a soil with relatively high nutrient level, but in 2004 the range in yields of lines ranged from 1.8 to 3.0 Mg ha^{-1}, but only ICSVLM-90520 produced a higher yield than the best control variety of Soberano. ICSVLM-90520 had the best grain yield, was in the top 5 for stover yield, and within the top 6 for grain NUE. It was recommended that the Plant Breeding program utilize this line, and that the other lines be dropped. Average grain yield without N fertilizer was 2002 kg ha^{-1} while with 21 kg N ha^{-1} average yield was 2920 kg ha^{-1}, and increase in yield of 46% with a marginal return of 44 kg ha^{-1} grain production for each kg N ha^{-1}.

In Nicaragua, large differences among environments, lines and N rates were present. However, the local check variety Pinolero along with the line ICSCVLM-93076 produced approximately 3.7 Mg ha^{-1} grain surpassing the yields of rest of the varieties by 0.5 to 1.1 Mg ha^{-1}. With N application, ICSCVLM-93076 produced the highest grain yield of 5.1 Mg ha^{-1} compared to 4.2 Mg ha^{-1} for Pinolero. ICSCVM-93076 was N responsive while still producing high yields without N application. This line has been submitted to the CNIA/INTA sorghum breeding program for evaluation and use in the breeding program. Application of N fertilizer increased the average grain yield from 3.1 to 3.9 Mg ha^{-1} (26%).

Nitrogen Use Efficiency (NUE) of Photoperiod Sensitive (Maicillo Criollos) Sorghum Varieties for Relay Intercropping with Maize (Maximo Hernández - El Salvador)

Research Methods

In 2003, validation and transfer trials were conducted on 40 farms in collaborations with the extension service and the NGOs Ramírez Consultores, ESBESA, CONSORCIO and PRODESO. Validation trials with local variety with and without 47 kg ha^{-1} N, the new improved nitrogen use efficient variety 85SCP805 without N and with 47 kg ha^{-1} N were tested on hillside locations with poor soils. In addition, the improved varieties 85-SCP-805, SOBERANO, CENTA S-3 and RCV were planted on 430 farms in the department of Cabañas to facilitate transfer to farmers fields. In 2004, variety validation trials were conducted for 85-SCP-805, ES-790, CENTA S-3, and 86-EO-226 on 635 farm fields totally 162 ha.

Results

In 2003, the improved variety 85SCP805 produced 130 kg ha^{-1} more grain than the local check without N application. Nitrogen application increased grain yield of 85SCP805 by approximately 700 kg ha^{-1}, and of the local check by approximately 300 kg ha^{-1}. In 2004, the yield increase over the local check was 0.5 Mg ha^{-1} for 85-SCP-805, 0.6 Mg ha^{-1} for ES-790, 0.4 Mg ha^{-1} for CENTA S-3 and 86-EO-226. Widespread transfer of the 85-SCP-805 and 86-EO-226 varieties has occurred in collaboration with extension services and NGOs in 2004 through 2007.

Simulation Modeling of Growth and Yield of Pearl Millet in Nebraska and Niger (Dr. Gerit Hoogenboom, SANREM CRSP, University of Georgia, Griffin, GA)

Methods

The CSM-CERES-Millet model of the DSSAT Version 4.0 was calibrated for conditions in Nebraska, USA and Sadoré, Niger. The observed data for calibration were obtained from two experiments conducted at the University of Nebraska under rainfall conditions on a silty clay loam in 1995 and 1996. Daily weather records were obtained from an automated weather station located at Mead, Nebraska (latitude 41.25; longitude 96.58; elevation 366 m). The experiment included three pearl millet hybrids, i.e., 59022A x 89-083, 1011A x 086R and 1361M x 6Rm and two nitrogen fertilizer levels, i.e., a control with no N and 78 kg ha^{-1} of N. For Sadoré, Niger, two experiments were conducted in 1995 and 1996. The soil was sandy and the daily weather records were obtained from ICRISAT, Sadoré, Niger (latitude 13.23; longitude 2.28; elevation 210 m). These two experiments consisted of three varieties, i.e., Heini Kirey, Zatib and 3/4HK and two N fertilizer levels (zero N and 23 kg N ha^{-1}).

The CSM-CERES-Millet model includes seven cultivar-specific coefficients that require modification for new cultivars that have not been previously used with the crop model. The specific cultivar coefficients adjusted for millet were for phenological development followed by crop growth parameters during the calibration process. The cultivar coefficients were determined in sequence, starting with the phenological development parameters, followed by the crop growth parameters. Emergence, flowering, and maturity dates, growth analysis data and yield were used to calibrate the performance of the CSM-CERES-Millet model. The combination of coefficients that resulted in the smallest RMSE and the highest d value were selected as final cultivar coefficients.

Results

The CSM-CERES-Millet model was able to accurately simulate crop phenology for millet grown in 1995 and 1996 in Nebraska. The average number of days observed from planting to anthesis was 62, while the simulated value was 63, with relative low values for RMSE and high d values. In general, pearl millet yield for the conditions in Nebraska was accurately simulated for 1995 and was underestimated for 1996. In 1996, abundant rainfall resulted in an increase in observed and simulated yield when compared to 1995.

The CSM-CERES-Millet model was able to accurately simulate growth, development and yield for pearl millet grown in two contrasting environments, e.g., Nebraska, USA and Sadoré, Niger, and under different management practices that included various hybrids/varieties and N fertilizer treatments.

Networking Activities (2006 - 2007)

Workshops: American Society of Agronomy Annual Meetings, Nov. 2006, Indianapolis, IN.

Research Investigator Exchange: Visited INTSORMIL research efforts in El Salvador and Nicaragua in March and May 2007.

Research Information Exchange: Funds passed through to Burkina Faso, Mali and Niger to assist with collaborative research.

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Soil and Water Management for Improving Sorghum Production in Eastern Africa

Project UNL 219
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Summary

This project focused on soil and water management for improving sorghum production in eastern Africa, with some activities in southern Africa. Enhancement of research and extension capacity in host countries was of high priority and included partial or full support enabling six graduate students from Ethiopia, Mozambique, Latin America, and the U.S. to earn M.Sc. or Ph.D. degrees. A researcher from Ghana is continuing with Ph.D. studies at UNL. Four collaborators from Africa attended an IFDC-organized short course on integrated soil fertility management. On-going technical support to collaborators was an important part of enhancing institutional capacity.

Increasing yield as a means to promote economic growth and improve human nutrition in semi-arid areas has been the objective of research and extension activities. In Ethiopia, tie-ridging resulted in 45% more available water; grain yield with traditional practices was 45 and 62% of the yield with the best tie-ridging practice. In another study, sorghum yield with tie-ridge tillage was the same as flat planting where 3 Mg ha^{-1} of crop residue had been applied as ground cover and 75% more than flat planting with no ground cover. In a third study, highland pulse yield was increased by a mean of 70% with tie-ridging compared with flat planting. Oxen drawn implements for tie-ridging and row planting were verified with farmers as suitable for tie-ridge systems. Extension efforts to promote tie-ridging were enhanced. Evaluation of skip-row planting as a means to improve water availability during grain-fill is underway. In Uganda, several soil fertility management and tillage practices were found to be economical for resource poor farmers through a process of farmer participatory research; extension efforts to promote soil fertility management options were established while evaluation of sustainability issues associated with these management practices continues. In Mozambique, research on integrated soil fertility management was initiated. In central Tanzania, research addresses tillage options to conserve water and enable more timely planting. Information was compiled for five countries in eastern and southern Africa (ESA) and published "The Atlas of Sorghum Production in Five Countries of Eastern Africa". An analysis of sorghum production constraints was done.

In Nebraska, several studies addressed opportunities to improve the profitability of grain sorghum production. The use of starter fertilizer and row cleaning under no-till conditions was not profitable. An N use recommendation for the sorghum-soybean rotation was developed that considers expected yield and the prices for N and grain. One-time tillage of no-till reduced nutrient stratification and the potential for dissolved P runoff with no negative effect on soil organic C content, soil physical properties, microbial communities, or yield. Skip-row planting of sorghum was found to have a yield advantage at 2 of 4 western Nebraska sites and no yield disadvantage at the other 2 sites.

Objectives, Production and Utilization Constraints

Each of the four major objectives of INTSORMIL have been addressed, i.e., promote economic growth, improve nutrition, increase yield, and improve institutional capacity. The main sorghum production constraints addressed were soil water deficits, nutrient deficiencies, and *Striga*.

Ethiopia

- Fine-tune tie-ridge tillage technology for sorghum production systems.
- Partially support M.Sc. education of two EIAR researchers at

Alemaya University and host them to UNL as visiting scientists.
- Conduct training for field extension staff and support their promotion of tie-ridging.
- Evaluate skip-row planting as a means to increase water availability during grain-fill.

Uganda

- Develop soil fertility management and reduced tillage practices for small scale farmers in eastern Uganda, using participatory research approaches.
- Evaluate sustainability of some soil fertility management practices over eight seasons.
- Facilitate extension activities to promote soil fertility management practices.
- Evaluate *Striga* tolerant varieties in eastern Uganda.

Mozambique

- Develop integrated soil fertility options for sorghum production systems.

Tanzania

- Evaluate reduced and water conserving tillage options in Central Tanzania

U.S.

- Develop an N response function for sorghum following soybeans.
- Evaluate the use of starter fertilizer and row-cleaning for no-till sorghum.
- Mentor five students for graduate degrees at UNL with at least partial INTSORMIL support.
- Evaluate occasional one-time tillage of no-till systems as a means for improving productivity, C sequestration, and soil aggregation while reducing potential for P runoff.
- Evaluate skip-row planting as a means for conserving water for the reproductive stage of sorghum in western Nebraska.

Africa and U.S.

- Collect sorghum yield response and nutrient uptake data for evaluation of the QUEFTS concepts in estimation of nutrient needs.
- Compile a geo-referenced data base and publish an atlas of sorghum production in eastern and southern Africa (ESA).
- Determine soil properties affecting P sorption for soils of ESA.
- Strengthen research and extension capacity by technical support to collaborating researchers.

Research Findings and Project Output

Ethiopia. The effectiveness of tie-ridge tillage was evaluated as a means to improve soil water availability through reduced runoff for increased grain and stover yield. Tied-ridging before or at planting resulted in the best soil water status throughout the season and the best crop performance, especially when planting was in-furrow (Table 1; Brhane et al., 2006). Mean soil water content with the most effective tie-ridge treatment was 45% more than with traditional practices. Grain yield with traditional practices was 45% and 62% of the yield with the best tie-ridging practice. In a study of tillage and ground cover interactions, yield with tie-ridge tillage was the same as flat planting with the ground covered with 3 Mg ha^{-1} of crop residues and 75% more than flat planting with no ground cover (Mesfin, 2004). In subsequent research, highland pulse grain yield and nodulation were greatest with tie-ridging at the first weeding after planting with grain yield increases of 79, 31, and 96% for faba bean, lentil, and field pea, respectively, compared with flat planting. Oxen-drawn implements developed at Melkassa ARC for tie-ridging and row planting were evaluated with farmers in Wolencheti and Miesso. Responses were favorable with opportunities, problems and likely improvements identified (Mesfin et al., 2004). Extension staff were trained at Melkassa ARC and Mekele ARC on water conserving technology, use of row planting and tie-ridging equipment, and extension methods to promote tie-ridging. A decision guide to selection of fields appropriate for

Table 1. Grain yield as affected by tillage treatments in northern Ethiopia†

Treatments	Grain yield Mg ha^{-1} 2003	2004
Flat plant‡	1.48	0.79
TR–4WAPIF	2.87	2.50
TR–4WAPOR	2.38	2.00
TR0WAPIF	2.52	2.16
TR0WAPOR	2.16	1.70
Shilshalo	1.78	1.30
TR4WAP	2.12	1.70
LSD 0.05	0.725	0.056

† Adapted from Brhane et al. (2006).
‡ Flat plant = planting with a flat soil surface, a traditional practice. TR = tied-ridging; WAP = weeks after planting; IF and OR = in-furrow and on-ridge planting, respectively. Shilshalo = a traditional ridging practice conducted four weeks after planting.

tie-ridging was developed and provided to extension (Brhane et al., 2005). Researchers have worked with extension to demonstrate tie-ridge technology.

Uganda. Researchers worked with farmers to evaluate alternative low-input practices for soil fertility management in sorghum-based cropping systems. Four studies, comprised of 148 on-farm trials, were conducted at three locations over three years in semi-arid areas of eastern Uganda. The mean mucuna dry biomass yield was 7 Mg ha^{-1} containing 160 kg N ha-1 (Kaizzi et al., 2007; this publication was singled out for special recognition and promotion by the American Society of Agronomy). Application of fertilizer N and P, and of manure, was found to be profitable, even for the most resource-poor farmers (Table 2). The increase in sorghum grain yield in response to 30 kg N ha-1 alone, to a mucuna fallow, and to a rotation with cowpea was 1.15, 1.55 and 0.82 Mg ha^{-1}, respectively. Extension activities are underway and expanding including participatory extension with farmers who participated in the research and collaboration with USAID-APEP and TEDDO and their extension field staff.

Mozambique. Adoption of no-till farming was assessed in Manica province where it had been promoted and subsidized for >5 years after which support was discontinued. The results showed negligible adoption largely due to the cost and/or unavailability of herbicides. Concurrent with the survey, field trials were conducted at three locations to determine main and interaction effects of tillage and soil fertility management practices. Results of the adoption study caused a re-thinking of priorities with a decision to focus on integrated soil fertility management.

African regional activities. Soil properties have been related to P sorption for diverse soils of Ethiopia, Uganda and Mozambique (Mamo et al., 2004). Soil clay content was a major determinant of P sorption with increased sorption due to termite impact on sandy soils.

The importance of 43 biotic and abiotic constraints to sorghum yield were evaluated for Ethiopia, Kenya, Uganda, Tanzania and Mozambique (Wortmann et al., 2006). Total potential production losses for these five countries due to major constraints were 1.8, 1.0, 1.0, and 0.9 million Mg ha^{-1} due to soil water deficits, N deficiency, the stalk borer complex, other weeds, and Striga, respectively (Table 3). Quelea, shoot fly and P deficiency were each found to cause losses of >500,000 Mg yr-1. Approximately 30% of sorghum production area is intercropped (Fig.1).

Nebraska. Twelve trials on the use of starter fertilizer, and another six trials on starter fertilizer and row-cleaning, were conducted for no-till sorghum (Soares et al., 2004; Soares, 2005; Wortmann et al., 2006). Starter fertilizer use and row cleaning resulted in increased early growth but no gain in grain yield. Similar research was conducted for maize using other funding (Wortmann et al., 2006). An extension publication was updated (Hergert et al., 2006). These results were used to develop a lesson for certified crop advisors (Crops and Soils 40:20-24).

Twenty five trials were conducted and an alternative recommendation for N use was developed that considers expected yield and the prices for N and grain; when the value of one bushel of corn is less than the cost of 9 lb of N, the recommendation results in less fertilizer application than the previous recommendation

Table 2. Increase in sorghum grain yield (Mg ha-1) compared with the traditional practice of no input application, and net returns and benefit:cost ratios for minimum acceptable rate of returns of money of 25, 50, and 75% due to application of fertilizer or manure in eastern Uganda.†

Treatment kg ha^{-1}	Increase in grain yield Mg ha^{-1}	Net returns to input use‡ '000 UgSh ha^{-1}			Benefit/cost ratio UgSh $UgSh^{-1}$		
		25%	50%	75%	25%	50%	75%
30 N + 10 P	1.30	88.2	63.7	39.2	1.72	1.43	1.23
30 N + 2500 manure§	1.47	65.7	41.2	16.7	1.38	1.21	1.08
30 N	0.77	53.0	38.6	24.3	1.73	1.45	1.24
2500 manure	1.06	121.7	121.7	121.7	3.43	3.43	3.43

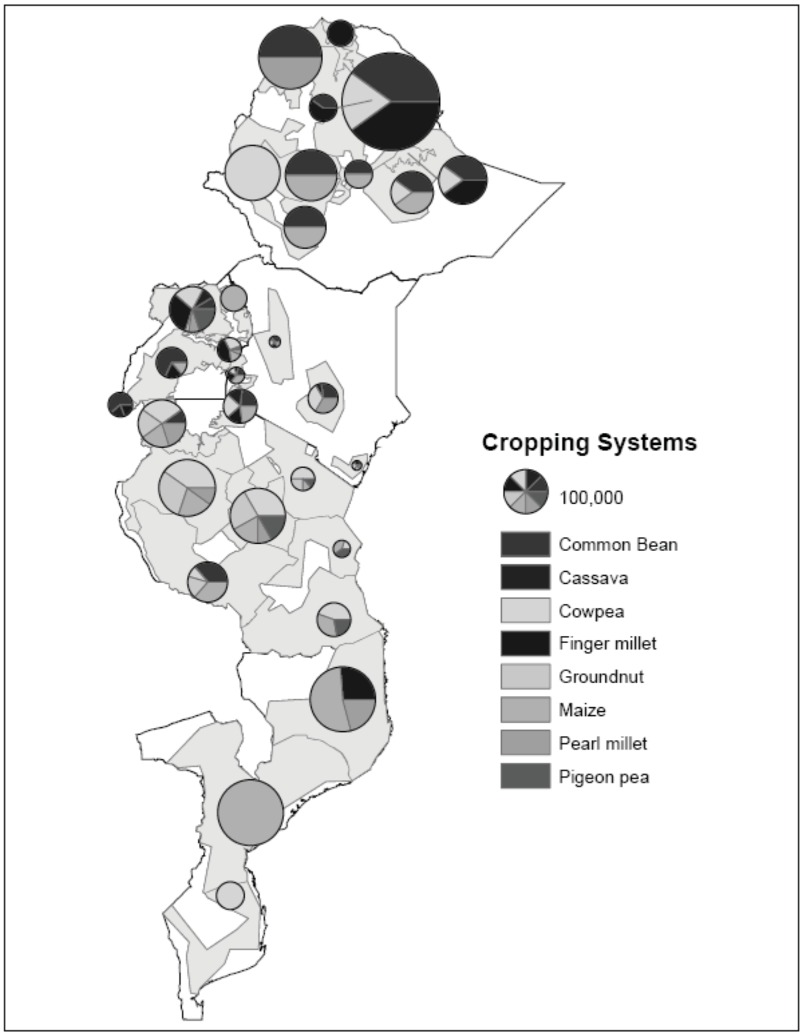
† Adapted from Kaizzi et al., 2007.
‡ Conversion rate of 1800 Uganda shillings (UgSh) per US dollar.
§ The cost of obtaining and applying the manure was estimated to be UgSh 20,000 Mg-1.

Table 3. Estimated losses of grain sorghum production due to the 10 most important constraints in five countries of eastern Africa ('000 Mg yr-1).†

Constraint	Overall	Ethiopia	Kenya	Uganda	Tanzania	Mozambique
Water deficits	1831	718	38	126	283	666
Stem borers	1181	749	46	130	170	86
N deficiency	1025	338	44	81	288	274
Weeds	957	412	24	100	243	178
Striga	927	560	40	118	205	4
Quelea	840	526	47	61	202	4
Shootfly	553	361	31	76	41	44
P deficiency	535	126	25	45	159	180

† Adapted from Wortmann et al., 2006.

Figure 1. The relative importance of associated crops in intercrop production of grain sorghum in eastern Africa. Pie chart diameter varies according to the number of sorghum hectares annually in each production area. Approximately 30% of sorghum area is in intercrop association.



(Wortmann et al., 2006; Wortmann et al, 2007).

In a study of one-time tillage of no-till, nutrient stratification and P runoff potential were reduced with a tendency to higher yield. There was no effect on soil C and an inconsistent effect on rate of water infiltration (Quincke et al, 2007; Quincke, 2006; Quincke et al., 2007). Mycorrhyzal colonization of the roots was reduced by tillage with delayed recovery, probably due to increased root P concentration with tillage (Garcia, 2005; Garcia et al., 2007). The longer-term effects of one-time tillage on C sequestration, yield, and soil properties are being assessed.

Skip-row planting is being evaluated as a means of improving soil water availability during grainfill in a rainfall transect across southern Nebraska. There was not a yield advantage with skip-row planting in the higher rainfall part of the transect, but yield was increased in 2 of 4 trials in the drier western part of the transect with no yield change in the remaining trials (Akwasi et al., 2006). Crops matured earlier with skip-row planting, reducing the risk of frost damage, an important consideration for high plains sorghum production.

Improved institutional capacity. Mr. Brhane and Mr. Mesfin completed their M.S. degrees at Alemaya University with partial funding and advisory support from this project; they visited UNL and presented research findings at ASA annual meeting. Mr. Xerinda from Mozambique completed his M.S. degree at UNL with full INTSORMIL support. A. Quincke (Ph.D.) from Uruguay, J.P. Garcia (M.S.) from Columbia, and G. Miller (M.S.) for the U.S. completed their graduate degrees with INTSORMIL support for their research. A. Abunyewa continues Ph.D. studies at UNL. S. Xerinda, G. Brhane, T. Mesfin and E. Letayo were sponsored to an IFDC-conducted short-course on integrated soil fertility management. Dr. Kaizzi was hosted to UNL as a visiting scientist and presented two papers at an ASA annual meeting. The atlas of sorghum production (Wortmann et al., 2006) and a GIS-referenced database were created to facilitate regional networking. Advisory support was provided to collaborators in Ethiopia, Uganda, Tanzania, and Mozambique.

Description of Methods of Work Used

Most field research was conducted on-station or on-farm over years and/or locations. In Uganda, Dr. Kaizzi used a farmer participatory research approach where farmers were involved in identification of problems and possible solutions, managing on-farm trials, and interpretation of the results. A participatory approach was used in Ethiopia to evaluate oxen-drawn implements. Adoption of no-till technology in Mozambique was assessed using survey results. Data collection, analysis and interpretation for the sorghum atlas was have been described in “The Atlas of Sorghum Production in Five Countries of Eastern Africa”.

Networking Activities

Geo-referenced data was compiled and “The Atlas of Sorghum Production in Five Countries of Eastern Africa” was published to meet information needs of researchers, extension and rural development specialists, policy makers, and emergency relief personnel (Wortmann et al., 2006). Numerous researchers and others knowledgeable of sorghum in their respective countries contributed information and expert opinions to develop the Atlas. The Atlas presents information in maps and tables for 30 sorghum production areas in five countries addressing production constraints, cropping systems, management, uses of grain and stover, phenotype preferences, gender roles, and marketing.

Publications And Reports (2006-2007)

Journal Articles

Garcia, J.P., C.S. Wortmann, M. Mamo, R. A. Drijber, J.A. Quincke, and D. Tarkalson. 2007. One-time tillage of no-till: effects on nutrients, mycorrhizae, and phosphorus uptake. Agron. J. In Press.

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Thesis

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Miscellaneous Publications

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