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

Marketing-Processing Project. The importance of improved quality became very obvious this year as some Senegalese producers added salt to their millet to get a higher weight. Moreover in several areas where farmers were making efforts to improve quality there was still a quality complaint. We need to get the tarps (‘bache”) out faster to the farmers’ groups and continue to encourage the purchase of threshers in the villages.

On the food processor side there are high costs of cleaning. Moreover, processors receive 5 to 15% lower millet quantities with the usual range of impurities. Nevertheless, many food processors still resist paying a quality premium. There needs to be an incentive for farmers to produce a higher quality. This is a potential win-win situation rather than a bargaining power contest between farmers and processors.

Introduction of Striga resistant cultivars and associated technologies in Ethiopia. The field studies in Tigray and Amhara have shown the preference of farmers to plant early cultivars in seasons in which the rainfall starts late (about one third of the time). So it is important to incorporate the *Striga* resistance into middle and late season cultivars as well as early ones.

The importance of inorganic fertilizer was demonstrated in the field analysis in Amhara. There soils are being depleted in spite of the conventional wisdom of high fertility. Marginal analysis of yield equations indicated a 600% return. Besides higher yields in low rainfall years other advantages to *Striga* resistance in Amhara were much lower weeding costs and different rotations. The budgeting evaluation of all three of these changes is now being undertaken.

Turning the Ethiopian food crops into orphan crops in which neither the private nor the public seed sectors are involved is a serious continuing problem for introducing higher productivity and thereby higher incomes in the food crop production sector. The public sector needs to become involved again in production of these basic food crops but with an exit strategy of turning their activities over to the private sector as the demand grows with the introduction of new technologies.

Inventory Credit Programs in Karabeji, Niger. The program here is a paternalistic one in which the farmers’ organization gains the benefits from the price recovery and uses the profits to buy fertilizer in bulk and distribute it to members and non-members at a lower price than available at retail. Program impact is then measured by the increase in fertilizer consumption. Unfortunately, this program provides little in-

centive for increased farmer participation. There is horizontal expansion (new members) but little vertical participation or expansion. Members contribute less than 4% of their millet production in recent years and that share is not increasing.

Objectives, Production and Utilization Constraints

The Marketing-Processing Project is a regionally supported West African AID activity to get new production technologies into the hands of sorghum and millet producers in West Africa by implementing new marketing strategies to obtain higher prices for farmers and thereby pay for the inputs involved in technological change including the payment of a risk premium. A secondary component of the project is to work with food and feed processors in the four countries involved in the project (Niger, Mali, Burkina Faso and Senegal).

The farmers then are increasing the quality and quantity of grain received by the food processors. We also want the processors to pay a quality premium and not to insist on buying all their grain at the post harvest price low. Another function of the project is then to provide the processors with better information on the choice between sorghum and maize in the feed ration (see the discussion in V. A of this report). A future activity of the project will be facilitating the franchising activities of one of the food processors of yogurt with millet grits all over the Sahel.

With workshops and continuing interaction we are facilitating the dissemination of information between processors and between processors and the farmer groups. We are constantly trying to get contracts between the two groups and to increase the understanding of the contracting as there is little experience of contract law in the Sahel. One objective of the next year in this project is to increase the service capability of the public food science labs in the four countries. Working with the food scientists in INTSORMIL and the national organizations we will also be helping with technical and management decision making in the food/feed processing sector for the traditional cereals.

There are two major research activities. We continue to monitor the technological change process and estimate the impact of new technologies being introduced. We are presently engaged in this activity in Tigray and Amhara, Ethiopia. There we have been measuring diffusion and estimating the potential impact of new *Striga* resistant sorghum cultivars and associated technologies (fertilizers and water harvesting techniques).

The second major activity is the research support of the Marketing-Processing Project discussed above. Here we seek to measure better for specific cases the gains to farmers from new technologies with and without the new marketing strategies. Last year we reported results for maize in Mozambique. This year we report on millet in Niger.

Research Approach and Project Output

The Marketing-Processing Project Results

This project starts with the basic hypothesis that the main reason for the failure of new technologies to be introduced into sorghum and millet production is that the farmer is receiving too low a price. There are two markets with which we are operating, food and feed processing. First is the rapidly expanding market for food products. This is principally for processed millet products such as couscous. These products are increasing very rapidly in demand since they are now incorporating the labor saving features previously incorporated in developed countries into wheat and rice. With the increasing value of the time of women in urban areas the demand for these products is increasing very rapidly. This is also a female dominated industry.

The project has concentrated on introducing two marketing strategies at the farm level. A principal focus has been inventory credit, so that the farmer can sell his product later in the season. Another focus is to increase the quality of the grain by getting threshing off the ground and obtaining a quality premium for the farmers.

A major objective of this Marketing-Processing Project is a more rapid introduction of Inventory Credit systems. We will need to get the banks involved as has been done in northern Nigeria. The farmers groups are functioning in the four counties and farmers are understanding better the objectives of the inventory credit and other marketing strategies. We also need to show the processors that farmers receiving higher prices is also a winning strategy for them.

One principal requirement in this food processing sector is a rapid expansion of quality and quantity of grain. We are not only attempting to more rapidly introduce technological change but also to remove the high level of impurities (5 to 15%) generally found in millet and sorghum from threshing on the ground. To improve quality not only do farmers need to get the threshing off the ground as by putting tarps beneath the grain but also there needs to be an incentive for farmers so a quality premium needs to be paid.

In this third year of the program there have been substantial successes in Senegal and Niger in introducing new marketing strategies for farmers. Here the objectives were to improve quality of the grain by getting threshing off the ground, obtain a quality premium from the food processors (millet), and facilitate more selling of their millet by farmers after a recovery from the post harvest price collapse. In both countries there was a high quality product food processor, who took the lead in paying a higher price to farmers. Then in Senegal some of the other processors followed in subsequent years after observing this model processor. Niger is the lowest income country of the four Sahelian countries, with whom we work, so there are fewer processors to imitate.

In Mali and Burkina Faso the food processors met as a group and were following collusive behavior. They argued that they did not have to pay a quality premium and wanted to buy the millet and other staples at the slowest post harvest price. Clearly, food processors will need to pay for a quality premium or there will be no incentive for farmers to get the grain off the ground. Moreover, in the absence of a price premium there will be more pressure on farmers to adulterate the product as many farmers in Senegal did in 2004 by adding salt.

In Mali and Burkina Faso we need to start again to convince processors that paying a higher price can encourage a cleaner grain as well as higher quantities and both of these are necessary for the evolution of the sector. Meanwhile, we are getting the farm producer groups to put tarps down when they are threshing and in Senegal one major cooperative is moving towards putting threshers in the village.

The concentration of the food processing has been on millet and there seems to be a processing food preference for millet in the Sahel. The second major market with which we are working is for the use of sorghum as feed. The big potential for sorghum is for its use in feed for broilers and layers. The demand for broilers expands especially fast in the development process. The Sahel can either import feed grains or raise the productivity of sorghum and provide more of their own feed grains. This is a much larger potential market than that for millet as a processed food.

Two principal reservations were consistently stated by feed processors across the Sahel, (a) a concern with the level of tannin in the sorghum and (b) the question of the ability of sorghum to compete with maize with respect to price. Food scientists in the U.S. believe that tannin is a historic problem since breeders have been working to produce high quality white sorghums without a tannin problem and farmers also tend to select for a whiter "to."

During 2005 Tahirou Abdoulaye collected the cultivars of sorghum in the field and the new cultivars, which breeders are introducing. These cultivars have now been analyzed with one or two (depending on the tannin levels) tests for tannin in the food science labs in the four countries. All the cultivars showing tannin in the simple bleach test have also been analyzed with the vanillin test in the laboratory of Lloyd Rooney at Texas A&M.

Simultaneously, with the cultivar collection Tahirou also obtained price data for sorghum and maize in various regions of all four countries for the past five years. Michigan State had initiated this activity as part of their food security project and then this activity was turned over to national groups.

The price and the tannin data will be analyzed and a bulletin prepared for the feed processors and policy makers on the conditions under which processors should substitute sorghum for maize in the rations. We also want to evaluate the aflotoxin risk, which tends to be much more likely with maize than with sorghum. But this will probably be put off until the revision of the bulletin in 2006.

Preliminary results are that tannin is generally not a problem in Mali or Niger. In Burkina where a principal product is the "dolo" beer there are some high tannin sorghums. In Senegal, where sorghum breeding has been minimal in the last three decades, many of the traditional cultivars have high tannin levels.

We also looked at the relative prices of sorghum and maize and found that there were many periods of time in the last five years that sorghum had a substantially lower price than maize in Niger and Senegal.

Impact of *Striga* resistant cultivars and associated technologies in Tigray and Amhara, Ethiopia

There was substantial excitement about *Striga* resistant sorghum cultivars as the scientific methods for identifying the resistance techniques resulted from multi-disciplinary activities at Purdue. Since the 1997 crop year the new *Striga* resistant cultivars were involved in regional trials in northern Ethiopia. The official release of the new cultivars in Ethiopia was in 1999 and 2000.These cultivars have been sporadically promoted in extension activities during the last five years.

In Tigray a diffusion study was undertaken in 2001 and then the researcher returned and re-interviewed many of the same farmers in the summer of 2003. In Amhara a field survey of the potential impact of the *Striga* resistant cultivars and associated technologies was completed in 2004. Together the researchers spent approximately seven months in the field in these two major sorghum producing regions of the country.

The sampling was selective for regions in which there were introduction programs of the new technologies pushed by the local extension services (Shararo in Tigray and the Qobo Valley in Amhara). In Tigray an estimated 8% of the farmers were utilizing the new cultivars. In Amhara selective sampling of the farmers, who had utilized the new technologies was undertaken. Here in Amhara the objective was to estimate potential impact rather than to measure diffusion.

In Tigray farmers preferred the early *Striga* resistant cultivars in seasons with late rainfall, which occur approximately one-third of the time. With normal and good early rainfall the farmers did not plant the *Striga* resistant cultivars. Farmers also reported on the earliness of the *Striga* resistant cultivars in Amhara but we only had observations of the performance over the 2001-2004 period.

The two other technologies being introduced with the *Striga* resistant cultivars were water harvesting and fertilizer. Improved production conditions (more water and higher soil fertility) are also a method of controlling *Striga*. In these better rainfall years (normal and good years, which occur approximately two thirds of the time), there was no yield advantage to the *Striga* resistant cultivars in Amhara according to the econometric analysis.

Besides a yield increase in low rainfall years two other advantages to *Striga* resistance in Amhara were identified. These include considerably lower weeding costs, as farm family members attempt to pull out the *Striga* in heavily infested regions, and a different rotational system. Hand weeding a *Striga* infestation is an extremely labor intensive activity. The economic values of these three advantages to *Striga* resistance factors are presently being estimated.

The field results indicate a potentially much higher return to the cultivars if *Striga* resistance can be incorporated into medium and long season cultivars as well as the short season ones. There is a presently an on-going process of backcrossing the *Striga* resistance into the locally established cultivars.

The yield analysis showed very high returns to fertilizer in spite of the general failure to introduce fertilization on most of the project farms. In the Qobo region the conventional wisdom is that soils are so fertile that fertilization is unnecessary. In the econometric analysis of crop yields in Qobo the marginal return to fertilizer was over 600% soundly refuting the conventional wisdom.

In Tigray there is a general recognition that soils are depleted. To increase fertilizer use improved water harvesting is necessary to reduce the riskiness of this activity. Water harvesting increases the return from fertilization in adequate and good[1] rainfall years and reduces the probability of loss from fertilization in poor rainfall years. So the extension service has been promoting various types of water harvesting over the last five years.

In both regions water harvesting continued to be introduced. In 2004 there was a shift to the Chinese pit technique. The extension system in Ethiopia works with substantial top down direction and changes priorities and principal activities annually. Staying with the one water harvesting technique over time, such as tied ridges, is expected to have a higher long run payoff than the annual shifting process. The repeated changes of extension priority also distract attention from the importance of developing public sector capacity for producing seed of the *Striga* resistant and other new cultivars.

Sorghum and most food crops in Ethiopia are presently orphan crops. They are not yet sufficiently profitable for the private sector to be interested in seed production. The public sector seed production agency has been ordered by the central government to become more profitable so it is imitating Pioneer by focusing on hybrid maize, wheat and other high value crops. The implications of these private and public policy decisions are serious for Ethiopia, whose basic food consumption activities of teff, sorghum, and several edible legumes are now being ignored in the seed sector.

Inventory Credit Programs and Fertilization in Niger

A principal objective of most inventory credit programs is to enable farmers to sell later in the season after the post harvest price collapse. For a series of financial requirements (school fees, pay to family workers for agricultural activities, financing of seasonal migration, ceremonies and in good years investment in human and physical capital) farmers feel substantial pressure to meet income goals immediately after the harvest. As a result there is an abrupt price collapse of basic commodity prices at this time.

With low seasonal prices and other factors depressing the prices, received for staples by farmers, there is a general discouragement from using new technology. New technology involves the purchase of improved seeds and fertilizers. Fertilizer is critical because of the initial low fertility and the fertility depletion of soils over time. New cultivars embody the technological innovations of the breeders. To accelerate technology diffusion new marketing strategies are introduced to increase the prices received by farmers for their staples.

There are two common forms of inventory credit programs. Farmers store their commodities in some form of group storage and receive loans for the value of their commodities at harvest. Then when prices recover, the farmers can sell their staple at the higher prices and pay for the storage and interest costs. Another basic variation is that the farmers' group or cooperative sells the crop at the higher prices after the price recovery. Then the cooperative will pay for the costs of storage and interest and then divide the profits among the members proportionately to the quantity stored. Both systems give clear incentives to farmers to use more of the new technologies because the marketing strategy has increased its profits.

A third system, practiced in our surveyed region in Niger, has the farmers' association selling later after the price has recovered, keeping the profits, and then purchasing in bulk fertilizer. This fertilizer is then made available to participants and non-participants at a lower price than they would be able to obtain.. The incentives for participating in the program are then the availability and reduction in price of the fertilizer.

We then evaluated the determinants of fertilizer use in the region. Both the direct effects of having a program in your village and the indirect effect of having a lower relative price for fertilizer (price of millet divided by the price of fertilizer) were highly significant in farmers' decisions to use fertilizer. The program was highly successful then in encouraging the use of fertilizer. (Table 1)

[1] In very good rainfall years too much water is a possible result from some water harvesting methods. In this case the structures need to be broken down as sorghum only has short term tolerance of flooding.

Table 1. The determinants of fertilizer use in Karabedji, Niger (Probit technique)

	Coefficient	T-Stat	Marginal
Relative Price	2.63	2.51***	0.969
Program	0.79	2.30**	0.278
Income	-0.0002	-0.63	-7.0E-05
Manure	0.51	1.60*	0.512
Migration	0.18	0.642	0.179
Constant	-2.21	-2.76***	-0.817
Chi-Square	15.94***		
McFadden R-Sqd	0.10		
Log likelihood	-72.4		

Source: Authors estimation from survey data in forthcoming M.S. thesis of Felix Baquedano. *: Significant at 10 percent; **: Significant at 5 percent; and ***: Significant at 1 percent.

The downside is that the incentive effect of higher prices for the farmers' staple is achieved only indirectly through the availability and reduced price of fertilizers. This is a paternalistic system as the farmers are not believed to be able to utilize their increased prices appropriately so the farmers' organization needs to do it for them by buying the fertilizer. With the incentives diluted we would not expect participating farmers to be increasing their very small quantities of millet being sold (less than 4%) to the farmers' organizations. The data is sketchy but even though the number of farmers is increasing, the participation rate (quantity of millet harvested put into the program per farmer) appears not to be increasing.

Networking Activities

West Africa

A principal activity throughout the year has been the Marketing-Processing Project funded by the WARP (West African Regional Program of USAID). To undertake the development activities of this project requires networks between the agricultural and food science research agencies plus farmers' organizations, NGOs, and the food/feed processing sector. Substantial activity of all three principal personnel is put into maintaining these networks and collaboration.

In November 2004 this project sponsored a workshop with participants from all these sectors plus USAID and INTSORMIL in Bamako. Ouendeba Botorou did most of the organizational activity and Joan Frederick provided the financial organization and support.

We are also sponsoring the field level transfer of new sorghum technologies in Mali, Niger and Senegal in the summer of 2005. Another on-going activity is to make available in the region all our program documents in french.

As part of this activity Dr. Sanders made five trips to west Africa and will make another one in June. This Marketing-Processing Project is extremely time demanding as we are trying to implement a development program. Most of the NARS and NGOs we deal with are more used to working with a foreign aid program rather than focusing on low cost delivery of services.

Central America

This workshop evolved out of the previous visit to El Salvador and Nicaragua in the summer of 2003 by Dr. Sanders, Dr. Rooney and Felix Baquedano. There the importance of the tannin problem in the utilization of domestic sorghum or imported maize became an important issue. Since then Drs. Lloyd Rooney and Joe Hancock have given workshops on the subject and this workshop was a continuation of these activities. Sanders presented a paper in this workshop.

Publications and Presentations

Journal Articles

Abdoulaye, Tahirou, and John H. Sanders, 2005. "Stages and Determinants of Fertilizer Use in Semiarid African Agriculture: The Niger Experience," *Agricultural Economics*, 32(167-179).

Vitale, Jeffrey D., and John H. Sanders, 2005. "New Markets and Technological Change for the Traditional Cereals in Semiarid Sub-Saharan Africa: The Malian Case," *Agricultural Economics*, 32(111-129).

M.S. Thesis

R.N. Uaiene, "Maize and Sorghum Technologies and the Effect of Marketing Strategies on Farmers Incomes in Mozambique," Department of Agricultural Economics, Purdue University, 2004.

Presentations

Sanders, John H., "Marketing Strategies and Technology Adoption in Sorghum/Millet Production in West Africa," presented at the Marketing-Processing Project Workshop in Bamako, Mali, Nov. 15, 2004

Sanders, John H. "Demand Factors and New Technology in Sorghum Systems in Central America," presented at the Workshop on uses of Sorghum, Managua, Nicaragua, May 19, 2005.

Miscellaneous Publications

Ouendeba, Botorou, "Six Month Report: Marketing-Processing Project," mimeo, Niamey, Niger, 13 pages.

Ouendeba, Botorou (edited), *Amelorations des Marches et Nouvelles Technologies pour les Cultures Vivrieres au Sahel*, , INTSORMIL, Lincoln, Nebraska, bulletin included three papers translated into French and republished in 2005.

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

Project UNL 213

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Summary

Principal investigators in 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 pearl millet grain yield across three years and three West African countries by 249 kg ha^{-1} (49%) and stover yield by 612 kg ha^{-1} (38%), but results were variable as indicated by interaction effects. Microdose application resulted in similar net nutrient removal as the zero fertilizer control. Over 30 kg ha^{-1} N and approximately 10 kg ha^{-1} P were required to eliminate mining of nutrients from the soil. The highest grain and stover yields required 20 kg ha^{-1} P and 30 kg ha^{-1} N. 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 ha^{-1} N application increased grain yield by approximately 800 kg ha^{-1} (26%) over the local check without N application. In 2004 the range in yields of photoperiod insensitive 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 nitrogen use efficiency. It is recommended that the Plant Breeding program introduce this line into its crossing program and evaluate it further, and that the other lines be dropped from breeding and evaluation efforts. 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.

In El Salvador 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, N fertilizer application increased the average grain yield from 3.1 to 3.9 Mg ha-1 (26%), emphasizing the importance of promoting N fertilizer use to increase grain sorghum grain yields. Increased technology transfer efforts in collaboration with fertilizer input suppliers, extension service and NGOs is merited.

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 were increased by 0.5, 5.0 and 4.7 g kg^{-1} for continuous sorghum and sorghum rotated with non-nodulating and nodulating soybean, respectively. Cropping sequences influenced grain hardness to a lesser extent. Non-biological N fixation effect accounted for 67 to 83% of enhanced sorghum yield due to crop rotation with soybean.

INTSORMIL Project UNL-213 emphasizes capacity development through graduate education, short-term training, and coordination of the Central America Regional Program. Graduate students from Chad and the U.S. are working on M.S. degrees.

Objectives, Production and Utilization Constraints

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) zai production system for pearl millet in Burkina Faso, production practices for traditional beer production in Burkina Faso, weed control interactions with fertilizer rates in Mali, fertilizer rate by plant population for hybrid grain sorghum seed production in Niger, and use of poultry manure as nutrient and soil improvement for pearl millet production in Niger.

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

Initiate research on environment interactions with white, food-grade sorghum hybrids for grain yield and quality.

Determine recommended production practices for double-crop pearl millet production following winter wheat in Nebraska.

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 is an important crop through graduate education, short-term training and through mentoring former students upon return to their home country.

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

Constraints

This project has focused primarily on crop production systems which increase the probability of obtaining higher pearl millet and sorghum grain and stover yields. This involves systems which increase nutrient and water availability to growing crops, and produces desired uniform stands. Present efforts emphasize inorganic and organic fertilizer management, developing varieties and cropping systems to improve nitrogen use efficiency of sorghum, water management of traditional and improved cultivars, and weed control strategies.

Cropping system research efforts require long-term investments of well-trained, interested scientists and stable funding. Education of additional scientists in crop management and continued support of their work after return to their home countries is needed to improve productivity of cropping systems and to maintain the soil/land resource.

Research Approach and Project Output

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, but a source of nitrogen and/or phosphorus often is more critical. This is especially true for intensive cropping systems using improved cultivars on degraded land. Nutrient use and water use efficiencies are closely interwoven with higher yields possible with improved cropping systems utilizing improved cultivars. Since human capital for research and extension activities are very limited for pearl millet producing areas in West Africa, project activities are generally conducted as either as graduate education programs for scientists from this region and as mentored collaborative activities upon return of former graduate students. Studies have been initiated with collaborators in Central America on nitrogen fertilizer management and identification of nitrogen use efficient genotypes for grain sorghum production which is also a critical issue in the region. In the United States Great Plains, production practice recommendations for planting date, nitrogen rate and water supply for high yielding, dwarf pearl millet hybrids are being determined to help adoption as an alternate grain crop. Due to pearl millet having relatively higher rain yields than other crops with late planting, double cropping research with winter wheat was initiated. Research is on-going to better understand the basis for yield enhancement and N credit for grain sorghum rotated with soybean. This complex interaction of water, nitrogen, phosphorus, cultivars and yield enhancing production practices is the focus of Project UNL-213's research efforts.

Domestic (Nebraska)

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-nodulating 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 with the objective to separate N and non-N effects of crop rotation. Data collection done in 2003 and 2004, and included grain and stover yield, soil water, soil NO_3-N, relative greenness using a SPAD chlorophyll meter, yield components and grain quality assessment (kernel weight, test weight, true density, and tangential abrasive dehulling device removal). Data were analyzed using analysis of variance and correlation procedures.

Research Results

In 2003 and 2004, 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} (Tables 1 and 2), stover yields by 1.5 to 1.8 Mg ha^{-1} (Tables 3 and 4), and soil NO_3-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 NO_3-N at vegetative growth stage. On average grain N concentrations were increased by 0.5, 5.0 and 4.7 g kg^{-1} for continuous sorghum and sorghum rotated with non-nodulating and nodulating soybean, respectively. Cropping sequences influenced grain hardness to a lesser extent. Non-nodulating soybean accounted for 67 to 83% of enhanced sorghum yield due to crop rotation with soybean. Irregardless of cropping sequence, manured plots produced the highest grain and stover yields, grain N concentration, and grain hardness. Grain yield and N supply influenced grain N to a greater extent than grain hardness. Cropping sequence and soil amendment choices are important to assure optimal sorghum grain yield and physical quality.

Environment Interaction with White, Food-Grade Sorghum Hybrid for Grain Yield and Quality (Joni Griess, M.S. Study)

Research Methods

Twelve white or cream colored commercial grain sorghum hybrids with tan plants along with eight checks with either red grain or white grain/purple plant checks were planted in randomized complete block designed experiments in six environments in 2004 (east central and central Nebraska locations with and without irrigation) and will be planted in seven environments in 2005 (Same as 2004 with additional western Nebraska location without irrigation). Plant and glume color, plant height, flowering date, lodging, grain yield and water content data was collected. Grain samples were collected from each plot to be analyzed for kernel weight and color; hardness using bulk and true density, decortication properties using the Tangential Abrasive Dehulling Device (TADD), starch, oil and protein concentrations; and starch viscosity. Field and grain quality data will be used for economic analysis of food-grade grain sorghum production for export contracts and domestic consumption.

Table 1. Influence of cropping sequence and soil amendment on grain yield and quality in 2003, Mead, NE.

Cropping sequence	Soil amendment	Grain yield	Panicles m^{-2}	100-kernel weight	Grain N	Test weight	True density	Tangential abrasive dehulling device
		$Mg\ ha^{-1}$	Number	g	$g\ kg^{-1}$	$kg\ l^{-1}$	$g\ cm^{-3}$	% removal
Continuous sorghum	Zero	2.1	10.3	2.32	10.4	0.73	1.333	43
	Nitrogen	5.8	11.5	2.40	10.9	0.78	1.348	33
	Manure	6.2	11.5	2.42	10.9	0.79	1.358	33
	Mean	4.7	11.1	2.71	10.7	0.77	1.346	37
Sorghum following non-nodulating soybean	Zero	5.1	11.0	2.34	8.3	0.77	1.340	39
	Nitrogen	7.5	12.0	2.34	10.2	0.78	1.360	30
	Manure	7.9	12.5	2.45	13.0	0.78	1.355	28
	Mean	6.8	11.8	2.38	10.5	0.78	1.352	32
Sorghum following nodulating soybean	Zero	6.7	12.5	2.32	8.9	0.77	1.348	34
	Nitrogen	7.2	12.0	2.05	13.8	0.78	1.340	31
	Manure	7.3	12.0	2.35	14.8	0.78	1.350	27
	Mean	7.1	12.2	2.24	12.5	0.78	1.346	31
	F test and contrast probabilities (F > F							
Replication (REP)		0.41	0.02	0.71	0.24	0.77	0.71	0.08
Cropping sequence (CS)		<0.01	0.01	0.39	0.16	0.10	0.35	0.02
Rotation vs continuous		<0.01	0.00	0.50	0.33	0.04	0.50	0.01
Nodulating vs non-nodulating rotation		0.60	0.15	0.30	0.10	0.74	0.22	0.43
Soil amendment (FERT)		<0.01	0.01	0.02	<0.01	<0.01	<0.01	<0.01
Manure vs nomanure		<0.01	0.03	<0.01	<0.01	<0.01	<0.01	<0.01
N vs zero		<0.01	0.02	0.17	<0.01	<0.01	0.01	<0.01
CS*FERT		<0.01	0.01	0.04	<0.01	0.00	0.01	0.06
Rotation-continuous vs manure-nomanure		0.02	0.57	0.36	0.01	0.04	0.07	0.57
Rotation-continuous vs N-zero		<0.01	0.06	0.04	0.03	<0.01	0.23	0.07
Rotation nodulating-rotation nonnodulating vs manure-nomanure		0.06	0.02	0.52	0.97	0.91	0.86	0.43
Rotation nodulating-rotation nonnodulating vs nitrogen-zero		0.01	0.01	0.03	0.02	0.85	<0.01	0.02
MSE (CS)		0.90	0.25	0.10	5.04	0.0001	0.0001	15.00
MSE (Residual)		0.49	0.32	0.01	1.77	0.0002	0.00007	5.50

Research Results

To date, grain yield, bulk, true density, kernel weights and tangential abrasive dehulling device removal have been determined for 2004 plots. Environment influenced grain yield and kernel hardness, with lowest yields and softest kernels in the dryland, low N environment, second softest kernels in the eastern Nebraska dryland environment, and highest yields and hardest kernels in the eastern Nebraska irrigated and central Nebraska dryland and irrigated environments. Preliminary analysis of hybrid data indicates that hybrid differences for grain yield across environments was variable; true density differences were small; that the hybrids Asgrow Orbit, NK8828, Macia (African line) and the experimental hybrid UNL N252X1038R had the lowest TADD removal; and that DK42-20 consistently had the best test weight. IN 2005, this same experiment is planted in seven environments in eastern, central and west-central Nebraska.

International

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

Research Methods

Four-year central 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 ha^{-1} P, microdose + 40 kg ha^{-1} P, microdose + 30 kg ha^{-1} N, microdose + 60 kg ha^{-1}, microdose + 20 kg ha^{-1} P + 30 kg ha^{-1} N, and microdose + 40 kg ha^{-1} P + 60 kg ha^{-}

Table 2. Influence of cropping sequence and soil amendment on grain yield and quality in 2004, Mead, NE.

Cropping sequence	Soil amendment	Grain yield	Panicles m^{-2}	100-kernel weight	Grain N	Test weight	True density	Tangential abrasive dehulling device
		$Mg\ ha^{-1}$	Number	g	$g\ kg^{-1}$	$kg\ l^{-1}$	$g\ cm^{-3}$	% removal
Continuous sorghum	Zero	3.3	15.0	2.52	8.8	0.79	1.340	44
	Nitrogen	8.2	15.0	2.81	9.8	0.82	1.375	28
	Manure	9.0	17.5	2.87	9.4	0.81	1.378	26
	Mean	6.8	15.8	2.70	9.7	0.81	1.364	33
Sorghum following non-nodulating soybean	Zero	5.9	18.5	2.73	8.2	0.81	1.370	35
	Nitrogen	8.9	17.3	2.86	10.7	0.81	1.383	27
	Manure	9.4	21.3	2.87	13.4	0.82	1.378	23
	Mean	8.1	19.0	2.80	10.8	0.81	1.377	28
Sorghum following nodulating soybean	Zero	7.7	19.0	2.68	8.4	0.81	1.370	32
	Nitrogen	9.5	18.5	2.83	11.7	0.81	1.375	22
	Manure	9.6	19.5	2.89	11.9	0.82	1.378	22
	Mean	8.9	19.0	2.80	10.7	0.81	1.374	25
F test and contrast probabilities (F > F)								
Replication (REP)		0.32	0.58	0.58	0.32	0.39	0.71	0.32
Cropping sequence (CS)		<0.01	<0.01	0.44	0.10	0.54	0.08	0.05
Rotation vs continuous		<0.01	<0.01	0.23	0.04	0.29	0.03	0.02
Nodulating vs non-nodulating rotation		<0.01	1.00	0.79	0.81	1.00	0.61	0.26
Soil amendment (FERT)		<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01
Manure vs nomanure		<0.01	<0.01	<0.01	<0.01	0.03	0.01	<0.01
N vs zero		<0.01	0.27	<0.01	<0.01	0.02	<0.01	<0.01
CS*FERT		<0.01	0.19	0.31	<0.01	0.01	0.01	0.07
Rotation-continuous vs manure-nomanure		<0.01	0.65	0.20	<0.01	0.93	0.02	0.12
Rotation-continuous vs N-zero		<0.01	0.44	0.12	0.09	<0.01	<0.01	0.03
Rotation nodulating-rotation nonnodulating vs manure-nomanure		0.02	0.03	0.45	0.01	0.66	0.64	0.17
Rotation nodulating-rotation nonnodulating vs nitrogen-zero		<0.01	0.56	0.86	0.34	0.45	0.42	0.85
MSE (CS)		0.13	1.52	0.03	1.23	0.0001	0.0001	31.00
MSE (Residual)		0.15	1.62	0.01	0.71	0.0001	0.0001	10.08

^{1} N. Each plot was sampled prior to initiating the experiment so that soil nutrient levels after four-years could be determined. In addition, satellite studies were conducted on farms using zero, microdose and microdose + 20 kg ha^{-1} P or 20 kg ha^{-1} P + 40 kg ha^{-1} N treatments. One replication was planted per farm, and in the data analysis farms were considered to be replications.

Research Results

Analysis of variance indicated that grain and stover yields to fertilizer treatments varied by country and year. However, on the average, microdose fertilizer application increased grain yield by 58% and stover yield by 38% (Table 5). Yield increases were greater for P than N application, but the highest yields included microdose combined with P and N application. On-farm studies showed similar yield increases to on-station in Mali and Niger, but grain and stover yields with microdose application were over 100% greater than without fertilizer in Burkina Faso. Microdose application increased yield of sorghum on heavy soils in Mali, but less so than for pearl millet on the sandy soils in the regional study. Clearly the microdose application is a low cost investment that has a high probability to increase grain and stover yields across the West Africa pearl millet production area, but N and P removal is similar to zero application and thus does not alleviate soil nutrient mining concerns.

Zaï and other tillage/fertilizer treatments influence on grain sorghum yield (Taonda Jean Baptiste - Burkina Faso)

Research Methods

On-farm research and demonstration was conducted as a follow-up to studies conducted on-station and on-farm in pre-

Table 3. Influence of cropping sequence and soil amendment effects on stover yield, stover N and plant height in 2003, Mead NE.

Cropping sequence	Soil amendment	Stover yield	Stover N	Plant height
		$Mg\ kg^{-1}$	$g\ kg^{-1}$	cm
Continuous sorghum	Zero	5.0	10	95
	Nitrogen	7.6	15	103
	Manure	8.5	16	102
	Mean	7.0	14	100
Sorghum following non-nodulating soybean	Zero	6.8	10	101
	Nitrogen	8.2	17	109
	Manure	7.9	19	110
	Mean	7.6	15	106
Sorghum following nodulating soybean	Zero	7.4	13	110
	Nitrogen	6.5	19	108
	Manure	7.6	22	107
	Mean	7.2	18	108
	F test and contrast probabilities (P > F)			
Replication (REP)		0.34	0.30	0.11
Cropping sequence (CS)		0.07	<0.01	0.01
Rotation vs continuous		0.08	<0.01	<0.01
Nodulating vs non-nodulating rotation		0.08	<0.01	0.37
Soil amendment (FERT)		0.04	<0.01	0.01
Manure vs nomanure		0.04	<0.01	0.13
N vs zero		0.09	<0.01	<0.01
CS*FERT		0.11	0.13	0.02
Rotation-continuous vs manure-nomanure		0.13	0.04	0.56
Rotation-continuous vs N-zero		0.07	0.10	0.11
Rotation nodulating-rotation nonnodulating vs manure-nomanure		0.83	0.73	0.04
Rotation nodulating-rotation nonnodulating vs nitrogen-zero		0.12	0.59	0.02
MSE (CS)		1.44	3.26	20.23
MSE(Residual)		2.00	2.43	15.22

vious years (see INTSORMIL annual reports for 2001 and 2002). This effort was done on five farms with diverse soils in the zone of Samba in 2004. Treatments were no fertilizer, no tillage check (farmer practice), zaï with compost 300 g $hill^{-1}$ compost application, and animal traction (zaï mécanique) zaï with 300 g $hill^{-1}$ compost application.

Research Results

The 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 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. These results support results previously reported, and are a part of a concerted effort by INERA to promote adoption of the use of the animal traction zaï combined with compost application.

Sorghum Production Practices for Dolo (Traditional Beer) Production in Burkina Faso (Siebou Pale)

Research Methods

Previous research has shown that the red grain sorghum varieties IRAT 9 and ICSV 1001(Framida) to be superior for dolo (traditional beer) production. A study was initiated in 2003 to develop production practice recommendations for grain yield and dolo quality. The study is being conducted with a randomized complete block and 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, microdose with 4g 15-15-15 per hill, recommended rate of 75 kg ha^{-1} 15-15-15 plus 50 kg ha^{-1} urea, and microdose plus 20 kg ha^{-1} P and 30 kg ha^{-1} N). Grain yield and quality tests associated with dolo production are being conducted.

Table 4. Influence of cropping sequence and soil amendment effects on stover yield, stover N and plant height in 2004, Mead, NE.

Cropping sequence	Soil amendment	Stover Yield	Stover N	Plant height
		Mg ha^{-1}	g kg^{-1}	cm
Continuous sorghum	Zero	5.2	11	111
	Nitrogen	8.7	18	129
	Manure	8.6	19	128
	Mean	7.5	16	123
Sorghum following	Zero	6.7	13	123
non-nodulating soybean	Nitrogen	8.9	21	136
	Manure	10.4	28	132
	Mean	8.7	21	130
Sorghum following	Zero	7.8	13	133
nodulating soybean	Nitrogen	8.6	26	136
	Manure	12.6	28	133
	Mean	9.7	22	134
F test and contrast probabilities (F > F)				
Replication (REP)		0.90	0.60	0.49
Cropping sequence (CS)		0.04	<0.01	<0.01
Rotation vs continuous		0.02	<0.01	<0.01
Nodulating vs non-nodulating rotation		0.17	0.15	0.15
Soil amendment (FERT)		<0.01	<0.01	<0.01
Manure vs nomanure		<0.01	<0.01	<0.04
N vs zero		<0.01	<0.01	<0.01
CS*FERT		0.23	0.01	<0.01
Rotation-continuous vs manure-nomanure		0.17	<0.01	0.01
Rotation-continuous vs N-zero		0.18	0.13	0.01
Rotation nodulating-rotation nonnodulating vs manure-nomanure		0.24	0.35	0.23
Rotation nodulating-rotation nonnodulating vs nitrogen-zero		0.43	0.04	0.01
MSE (CS)		2.57	6.84	30.46
MSE (Residual)		2.84	5.10	13.64

Research Results

The two-year results indicated no interaction between water management technique and fertilizer application method/rate, while variety interactions were present with both water management technique and fertilizer application/method rate. The grain yield of the variety IRAT9 was nearly double that of Framida, but stover yields and response to water management technique were similar. Tied ridges and animal traction zaï without compost increased grain yields of Framida from 463 to approximately 650 kg ha^{-1}, and IRAT9 from 787 to 884 to 1014 kg ha^{-1}. Microdose fertilizer application increased grain yield from 359 to 876 kg ha^{-1} (144% greater than zero) and microdose + 20 kg P ha^{-1} and 30 kg N ha^{-1} further increased yield to 1438 kg ha^{-1} (330% greater than zero). A similar response was found for stover yield. Recommended fertilizer rates had lower grain yields than the microdose treatments. Dolo quality tests are presently being conducted.

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, 2002 and 2004. Pearl millet was hill planted on ridges after fertilizer application. Hills were thinned after emergence to two plants per hill. 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} diammonium phosphate broadcast applied after emergence. Mechanical weed control treatments consisted of complete control, weeding of ridges only, and no weeding. Grain and stover yield were determined, and data were analyzed using analysis of variance procedures.

Table 5. Fertilizer treatment influence on pearl millet, grain and stover yield, and relative increase (averaged over 4 years and 3 replications).

	Grain Yield				Stover Yield				Relative Yield Increase	
Fertilizer Treatment	Burkino Faso	Mali	Niger	Mean	Burkino Faso	Mali	Niger	Mean	Grain	Stover
	kg ha^{-1}								%	
Zero	398	772	341	504	1072	1644	3006	1907	------	------
Microdose	646	1091	524	753	1735	2789	3033	2519	58	38
Microdose + 20 kg P ha^{-1}	844	1140	743	909	2039	2974	4121	3045	96	64
Microdose + 40 kg P ha^{-1}	904	1349	624	959	2009	3854	3264	3042	104	65
Microdose + 30 kg N ha^{-1}	657	1050	608	771	1600	2870	3882	2784	61	52
Microdose + 60 kg N ha^{-1}	727	1080	608	805	1716	3090	4113	2973	70	61
Microdose + 20 kg P ha^{-1} + 30 kg N ha^{-1}	941	1216	960	1039	2239	3630	4840	3569	113	95
Microdose + 40 kg Pha^{-1} + 60 kg N ha^{-1}	1108	1274	917	1100	2402	4231	4389	3674	128	101

Research Results

Analysis of variance indicated that yield differences were due to year X weed control and year X fertilizer treatments. No weed control X fertilizer interaction effects were present. 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 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} diammonium 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 combined with N and P produced the highest grain and stover yields, except in the dry 2001 season with low weed pressure.

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 nine 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} or 100, 150 or 200 kg rock phosphate ha^{-1}). Grain and stover yield data were gathered, and analyzed by analysis of variance and with economic value/cost ratios.

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 survey indicated that at present they receive the manure free, and apply to all the major dryland crops (pearl millet, grain sorghum, peanut and cowpea) in the Maradi region of Niger. The average rate of application is 1 t ha^{-1}. All farmers agree that the manure increased production and improved soil fertility, and only one producer indicated that application labor was a major constraint to use of poultry manure.

On-farm research found that poultry manure increased pearl millet grain and stover yield by 264 kg ha^{-1} (42%) and 1697 kg ha^{-1} (37%). Addition of complete fertilizer increased grain yield 612 kg ha^{-1} more (138% more than zero) without influencing stover yield, and this gave the highest value/cost ratio of 5.5. On-station experiments were adversely affected by the dry growing season, thus yield responses were limited. Continuing research is planned to better evaluate the short-term and long-term effects of poultry manure application on pearl millet production.

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

Research Methods

A series of 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 (47 kg ha^{-1}), and to identify high NUE varieties. At each location, 24 lines from breeding programs were initially grown initially with and without N in a randomized complete block design with four replications, and only the 16 superior performing lines being carried forward to the following years study. Grain and stover yield, and N concentration of grain and stover at harvest were collected and agronomic characteristics. Data analysis was done using analysis of variance procedures.

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 five for stover yield, and within the top six for grain nitrogen use efficiency. It is recommended that the plant breeding program introduce this line into its crossing program and evaluate it further, and that the other lines be dropped from breeding and evaluation efforts. Average grain yield without nitrogen 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}. Increased technology transfer efforts in collaboration with fertilizer input suppliers, extension service and NGOs is merited.

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. Nitrogen fertilizer application increased the average grain yield from 3.1 to 3.9 Mg ha-1 (26%), emphasizing the importance of promoting N fertilizer use to increase grain sorghum grain yields.

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 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 Zone 3 to facilitate transfer to farmer's 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.

Research 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. 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.

Validation of the Improved Forage Hybrid HF-275 (Maximo Hernández, El Salvador and José Molina, Nicaragua)

Research Methods

In El Salvador, the improved forage hybrid HF-275 was validated on 15 farms with the commonly used hybrid HF-895 used as a check. The plots were green cut for forage three times, samples dried and yields recorded on dry matter basis. Laboratory analyses for forage quality including protein, fiber and energy were done. In Nicaragua six forage sorghum hybrids were validated on-station.

Research Results

The improved HF-275 hybrid produced more forage dry matter for each harvest date, with total production of 32 Mg ha^{-1} compared to 22 Mg ha^{-1} for HF-895. Fiber contents were similar for the two hybrids, but HF-275 had higher energy content (3% higher total digestible nutrients) and 1% higher crude protein. In El Salvador, HF-275 will be validated with dairy producers in 2005 for potential release in 2006. In Nicaragua, HF-275 had one of the highest forage yields and quality among the six hybrids tested.

Networking Activities

Workshops

Central America Sorghum Utilization Workshop, 19 - 20 May 2005, Managua, NI,

Max Hernández (El Salvador) and Orlando Téllez Obregón, PCCMCA Meeting, 2 - 5 May 2005, Panama City, Panama.

Research Investigator Exchange

Nanga Mady Kaye (Chad) will complete a M.S. degree in Aug 2005.

Assisted in setting up a Ph.D. program for Siebou Pale (Burkina Faso) at the University of Natal, South Africa.

Research Information Exchange

Funds passed through to Burkina Faso, Mali and Niger to assist with collaborative research.

Visited INTSORMIL research efforts in El Salvador, Honduras and Nicaragua in November 2004, and May 2005. Initiated interaction for collaboration with the private seed companies Cristiani Burkard and Prosemillas. USAID missions in El Salvador, Guatemala, Honduras and Nicaragua were visited in November 2004.

Organized Grain Sorghum Utilization Workshop in Managua, Nicaragua 18 - 19 May 2005.

Publications and Presentations

Abstracts

Hernández Valle, M.A. and S.C. Mason. 2005. Ensayos regionales de germoplasma fotoinsensitiva que responda a requerimientos mínimos de fertilizante nitrogenado. PCCMCA Meeting, 2 - 6 May 2005, Panama City, Panama.

Hernández Valle, M.A. and S.C. Mason. 2005. Validacion del hibrido forrajero experimental de sorgo 275. PCCMCA Meeting, 2 - 6 May 2005, Panama City, Panama.

Molina Zamora, J. A. and R. Valdivia Lorente. 2005. Evaluacíon de cinco híbridos de sorgo para forraje. PCCMCA Meeting, 2 - 6 May 2005, Panama City, Panama.

Journal Articles

Maman, Nouri, S.C. Mason and D.J. Lyon. 2004. Yield components of pearl millet and grain sorghum across environments in the Central Great Plains. Crop Sci. 44: 2138 - 2145

Maman, Nouri, S.C. Mason and D.J. Lyon. 2005. Nitrogen rate influence on pearl millet yield, N uptake and N use efficiency in Nebraska. Comm. Soil Sci. Plant Anal. (In Press).

Duarte, A.P., S.C. Mason, D.S. Jackson and J. de C. Kiehl. 2005. Grain quality of Brazilian maize genotypes as influenced by nitrogen level. Crop Sci. 45: (In Press).

Undergraduate Theses

Mario Antonio Gadea Moreno and Ruby Anayensi Altamirano Palacios. 2005. Evaluación agronómica de la variedad de sorgo (*Sorghum bicolor* L. Moench) bajo dos fuentes de fertilización en el municipio de San Ramón, Matagalpa. B.S. thesis, Universidad Nacional Agraria, Managua, Nicaragua.

Mauriel Alberto Gurdian Velazquez. 2005. Evaluación agronómica de la variedad de sorgo (*Sorghum bicolor* L. Moench) bajo dos fuentes de fertilización en el municipio y uso eficiente de nitrogeno por 15 lineas de sorgo (Sorghum bicolor L. Moench) en el municipio d Posoltega, Chinandega. B.S. thesis, Universidad Nacional Agraria, Managua, Nicaragua.

Eliezer de Jesûs Manzanarez Rugama and Francisco Josééalero Romero. 2004. Evaluación de comportamiento agronómico y el uso eficiente del nitrógeno de 12 líneas de sorgo (*Sorghum bicolor* L. Moench) en el municipio de San Ramón, Matagalpa. B.S. thesis, Universidad Nacional Agraria, Managua, Nicaragua.

Yolanda María Herrera Chavarría and Chepita Clementian García Pichardo.2004. Evaluación agronómica y el uso eficiente de nitrogeno en 15 líneas de sorgo (*Sorghum bicolor* L. Moench) con dos niveles de fertilizacion nitrogenada en el municipio de Zambrano. B.S. thesis, Universidad Nacional Agraria, Managua, Nicaragua.

Ramiro Antonio Manzanares Rugama and Roberto Salomón Hernádez Gadea. 2004. Evaluació del efecto de la fuente de nitrógeno y del fraccionamiento de la fertilización en el rendimiento del sorgo para grano (*Sorghum bicolor* (L.) Moench) y uso eficiente del nitrógeno en Tisma, Masaya. B.S. thesis, Universidad Nacional Agraria, Managua, Nicargua.

Soil and Water Management for Improving Sorghum Production in Eastern Africa

Project UNL 219
Charles Wortmann and Martha Mamo
University of Nebraska

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Kaizzi Kayuki, KARI-NARO, P.O. Box 7061, Kampala, Uganda
Soares Xerinda, INIA, Av. das FPLM, P.O. Box 3658, Maputo, Mozambique

Summary

Promote economic growth, improve nutrition, increase yield. Opportunities to increase yield or to reduce production costs have been identified while promising research is continuing and technology dissemination activities have been initiated. Following verification and fine-tuning of the targeting of tied-ridge tillage for semi-arid areas of Ethiopia, extension efforts have been initiated. A decision guide for targeting of tied-ridging is being developed, two papers were presented at the 2004 ASA meeting, and a paper has been submitted to Agronomy Journal. Additional research has been initiated on tied-ridging by soil fertility interactions and on skip-row technology. Four opportunities for low-input management of soil fertility in semi-arid eastern Uganda have been verified as economical using farmer participatory approaches; information dissemination is to begin with the second season of 2005; and more detailed research has been initiated to assess the medium-term sustainability of these practices. Preliminary research was conducted on tillage and soil fertility management alternatives in Mozambique. Results of research on how soil properties relate to P availability for diverse soils of eastern Africa was presented at the 2004 ASA meeting. A paper is under review with Agronomy Journal reporting the results of the first phase of starter fertilizer research for no-till sorghum production in eastern Nebraska and the second phase of this research is to be completed in 2005. Research on occasional tillage to improve the productivity of no-till sorghum production systems continues as the dissertation and thesis research of two graduate students; four papers are to be presented at the 2005 ASA meeting.

Improved institutional capacity. Tewodros Mesfin, who completed his M.S. degrees at Alemaya University with support from UNL 219, came to UNL as a visiting scientist. Gebreyesus Brhane also completed his M.Sc. degree with our support and is now our collaborator in Tigray. Soares Xerinda completed his M.S. degree at UNL and is now our collaborator in Mozambique. The research of a U.S. and two international graduate students is currently supported by this project. Mr. Mesfin, Brhane and Xerinda were sponsored to IFDC training in integrated soil fertility management in Ghana. A study of sorghum production areas in Ethiopia, Uganda and Kenya has revealed stalk borer, water deficits, *Striga*, bird damage, N deficiency, weeds, and shootfly as the greatest causes of yield loss. Additional data has been compiled on sorghum production areas of Ethiopia, Kenya, Mozambique and Uganda; a GIS referenced database is being created that should be valuable to regional networking activities. Drs. Wortmann and Mamo visited their collaborators in Africa in February 2005.

Objectives, Production and Utilization Constraints

Ethiopia

- Conduct on-station and on-farm research at four locations to verify and fine-tune the targeting of tied-ridging and to determine fertilizer interactions with water management.
- Co-supervise soil and water management research projects of two M.Sc. students (Gebreyesus Brhane and Tewodros Mesfin Abebe) at Alemaya University. Host two

of these students to the U.S.
- Conduct training for field extension staff at 2 or 3 locations on aspects of water and nutrient management.

Uganda

- Conduct on-farm research in two counties in eastern Uganda to validate and fine-tune low input approaches to soil fertility management and to develop a reduced tillage system for small scale farmers.

Mozambique

- Conduct tillage and soil fertility in collaboration with Soares Xerinda.
- Collect data for sorghum production areas in Mozambique.

Eritrea and Tanzania

- Explore opportunities for collaboration.
- Invite participation in Ethiopia workshops for extension staff.

U.S.

- Complete research on N response for sorghum following soybeans.
- Complete the first phase of research on starter fertilizer for no-till sorghum and study of other aspects of starter fertilizer for no-till sorghum.
- Mentor an INTSORMIL sponsored graduate student to completion of M.S. degree at UNL.
- Develop recommendations and extension publication on starter-fertilizer application in no-till system and publish results in referred journals.
- Conduct research on occasional tillage in no-till sorghum-soybean systems with support to the research of a Ph.D. student and a M.S. student who are involved in this research.
- Fine-tune the N recommendation for sorghum following soybean.

Africa and U.S.

- Continue to collect sorghum yield response and nutrient uptake data for evaluation of the QUEFTS concepts in estimation of applied nutrient needs.
- Characterize sorghum production areas of Ethiopia, Kenya and Uganda using data collected in 2003-2004.
- Complete research on P sorption for soils of Ethiopia, Uganda, and Mozambique.
- Inadequate nutrient supply and water deficits are the primary production constraints addressed in this water and nutrient management research.

Research Approach and Project Output

Nutrient and water management research in Ethiopia. Research to evaluate tillage and mechanization options continued with trials established in three semi-arid sorghum production locations in 2004 and 2005which vary in elevation from 1300 to 1600 m. The locations include Welench'iti, Miesso, and Mekele at Abergele. Tillage treatments differ according to location but generally include some variation of the following:

- Traditional, e.g., tilled with *maresha*, broadcast sowing, and *shilishalo* for weed control.
- Tie ridging using modified *maresha* (a test implement) with tie ridges made before planting. Plant in the furrow with a row planter (test implement).
- In-furrow row planting with the row planter but tie ridge at first weeding with the modified *maresha*.
- Conservation tillage or reduced tillage.

Nearly all farmers found tie-ridging to be superior to their typical practice of flat cultivation for reducing runoff and improved crop performance. The tie-ridger was seen as culturally appropriate as it is a simple modification of the *maresha* and it was well rated for agronomic effectiveness, usability and affordability. These results were reported at the 2004 ASA meeting.

In his thesis research, Tewodros Mesfin observed improved yield with tie-ridging compared with no-till or conventional tillage in the Central Rift Valley with little or no ground cover by crop residues. Soil water availability was greater throughout the season with tie-ridging as compared to other tillage practices.

Gebreyesus Brhane completed his M.S. degree and evaluated various tie-ridging options for effects on soil water and crop yield in Tigray. Making the tied-ridges either before planting or at planting resulted in better soil water conditions and grain yield than tie-ridging at weeding time or with traditional tillage practices (Table 1). The research results were reported at the 2004 ASA meeting and a paper is under review with *Agronomy Journal*.

Brhane, G., C. Wortmann, M. Mamo, H. Gebrekidan, and A. Belay. 2005. Micro-basin tillage for grain sorghum production in semi-arid areas of northern Ethiopia. *Agronomy J. (in review).*

Training workshops were conducted for extension staff on practices to reduce water loss and to improve efficiency of water and nutrient use; these were in Melkassa in February 2005 and in Mekele in June 2005. An operational plan was developed and resources provided to extension staff for technology dissemination beginning in 2005. Demonstrations were installed on farmers' fields at Miesso, Siraro, Chiro, and Adama areas with follow up by our partners.

Table 1. Mean soil water volume, yield, and harvest index yield sorghum as affected by tillage treatments in 2003 and 2004 at Abergelle in northern Ethiopia.

	2003				2004			
	Soil water	Grain yield	Stover yield	HI	Soil water	Grain yield	Stover yield	HI
Treatments	$m^3\ m^{-3}$	$Mg\ ha^{-1}$		$Mg\ Mg^{-1}$	$m^3\ m^{-3}$	$Mg\ ha^{-1}$		$Mg\ Mg^{-1}$
Flat plant‡	0.26	0.79	3.87	0.17	0.24	0.79	3.87	0.17
$TR_{-4WAP}IF$	0.35	2.50	9.67	0.21	0.35	2.50	9.67	0.21
$TR_{-4WAP}OR$	0.30	2.00	7.53	0.20	0.30	2.00	7.53	0.20
$TR_{0WAP}IF$	0.32	2.16	8.84	0.19	0.32	2.16	8.84	0.19
$TR_{0WAP}OR$	0.29	1.70	6.80	0.20	0.29	1.70	6.80	0.20
Shilshalo	0.27	1.30	5.24	0.19	0.25	1.30	5.24	0.19
TR_{4WAP}	0.29	1.70	6.64	0.20	0.27	1.70	6.64	0.20
LSD 0.05	0.032	0.056	0.258	0.037	0.011	0.056	0.258	0.037

‡Flat plant = planting with a flat soil surface. 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.

Discussions were held with the sorghum research team in Ethiopia and it was agreed to study some aspects of tied-ridging in 2005; this research has been initiated and equipment for monitoring soil water availability has been provided. Research on skip-row planting as a means to improve water availability during grain fill has been initiated. Opportunities for greater utilization of sorghum grain were investigated with beef feeding operations in Nazareth.

Gebreyesus Brhane and Tewodros Mesfin were invited to visit UNL in 2004 but Gebreyesus was not able to obtain a U.S. visa. Gebreyesus Brhane and Tewodros Mesfin participated in the IFDC training in Accra, Ghana on integrated soil fertility management.

Nutrient and water management research in Uganda. The economic and agronomic feasibility of four low input practices for soil fertility management were verified through research conducted with farmers in two communities each of Kumi and Katikwe Districts. Results are to be presented by Dr. Kaizzi at the 2005 ASA meeting. Preparations have been made for technology dissemination to begin with the second season of 2005; including collaboration with the USAID supported Agricultural Enhancement Support Project (APEP). Participatory research is continuing on the development of a reduced tillage system with farmers. Research on the medium and long-term sustainability of the low input practices has been initiated.

Project activities in Mozambique. Soares Xerinda completed his M.S. degree at UNL in August 2004 and returned to Mozambique in September. He did a small survey to assess adoption of reduced tillage and no-till practices by small scale farmers and found very little adoption despite years of promotion by extension, with the support of Sasakawa Global 2000. Preliminary trials to investigate tillage by soil fertility interactions were established at three locations, although quality of the results will be limited due to late planting. Data were collected on sorghum production in Mozambique. Soares Xerinda participated in the IFDC training in Accra Ghana on integrated soil fertility management.

Project activities in Tanzania. A visit in August 2005 is planned to discuss potential activities in 2005-2006 that will complement regional projects.

Phosphorus fixation of soil in Ethiopia, Uganda, and Mozambique. Phosphorus sorption isotherms were determined for 36 soil samples collected from Ethiopia, Uganda, and Mozambique. Clay content accounted for 78% of the variation in P sorption over all soil samples. Oxalate extractable Al accounted for 93% of the variance in P sorption for soils of Uganda and Mozambique. Organic carbon accounted for 31% of the variance in P sorption. The model Y = 28.2 + 0.87*Clay + 11.8*Ca accounted for 90% of the variation in P sorption. Data of this research was presented at the 2004 ASA meeting. Results are being compiled for a journal publication.

Creation of sorghum database for eastern and southern Africa. In addition to the 19 sorghum production areas delineated for Ethiopia, Uganda and Kenya, another five have been determined for Mozambique but only part of the data has been collected. We have not obtained needed information for Tanzania and Eritrea. Collaboration with ASARECA-ECARSAM was explored. For the sorghum production areas in Ethiopia, Uganda and Kenya, the greatest causes of yield loss have been identified as stalk borer, water deficits, *Striga*, bird damage, N deficiency, weeds, and shootfly. The importance of sorghum uses was determined by assigning 100 points to different uses and adjusting for production area; the results are 16 for baked foods, 15 for injera, 10 for cooked foods, 10 for fuel, nine for fodder, seven for non-alcoholic beverages,

Table 2. Starter fertilizer effect on grain sorghum yield under no-till conditions in southeastern Nebraska in 2002 and 2003. Means of three trials per location.

	Beatrice 2002	Pickrell, 2002	Beatrice, 2003	Firth, 2003
	---Mg ha^{-1}---			
Control	6.13	6.17	4.52	6.69
N+P, 50x50 mm	6.61	6.34	4.38	7.19
N+P, over-the-row	6.31	6.46	4.80	6.55
N+P, in-furrow	6.20	6.30	4.75	6.83
N+P+S_{as}†, 50x50 mm	6.40	6.28	4.66	6.55
N+P+S_{as}, over-the-row	6.19	6.28	4.40	6.73
N+P+S_{as}, in-furrow	5.97	6.48	4.86	6.88
N+P+S_{ats}†, in-furrow	6.23	6.26	4.72	6.86
		P>F		
Treatment (Trt)	*	*	NS	NS
Trt x topographic position	*	*	**	NS
		Contrasts and mean differences		
Starter mean vs control	0.15	-0.11	0.13	0.09
N+P vs N+P+S_{as}	0.32	-0.23	0.00	0.14
50x50 vs OR & IF‡	0.26*	-0.06	-0.18	0.12

*, **, NS significant at 0.05, 0.01, and not significant.
† S_{as} and S_{ats} = sulfur with ammonium sulfate and ammonium thio-sulfate as the S source.
‡ Starter fertilizer placement methods: 50x50 = 50 cm to the side and 50 cm deep, OR = over-the-row, and IF = in-furrow.

four for alcoholic beverages, and 29 for other uses. Sole crop production was estimated to be the main cropping system (84%) and corn and bean are the main associated crops in intercropping.

Starter fertilizer for no-till sorghum production in Nebraska. The first phase of this research was completed and a paper submitted to *Agronomy Journal*. Yield response was more frequent in upland environments than in bottomlands where placement at 5 cm to the side and 5 cm deep and in-furrow placement were generally more effective than over-the-row placement. Starter fertilizer reduced grain moisture at harvest by 9 to 28 g kg^{-1} in 25% of the environments. Overall, however, response of no-till grain sorghum to starter fertilizer application was not economical (Table 2).

Wortmann, C., S. Xerinda, and M. Mamo. 2005. No-till row crop response to starter fertilizer in eastern Nebraska: II. rainfed sorghum. *Agronomy J. (in review).*

Fine-tune the N recommendation for sorghum following soybean. **Eleven trials were conducted in 2004 and the field research is to be completed with the nine trials that have been established in 2005. Field work will be completed in 2005.**

Occasional tillage to improve the no-till sorghum-soybean rotation. Research is underway to determine the effects of one time tillage in no-till systems on crop performance, soil C dynamics, and on soil chemical, physical and microbiological properties. Two graduate students, Juan Pablo Garcia and Andres Quincke, are involved in this research. The effects of four tillage practices, conducted in one year only, relative to continuous no-till, and the effects of P management regimes are being evaluated. Andres is investigating the effects of: soil C dynamics and microbial activity; crop yield; and soil physical properties. Juan Pablo is investigating effects on: nutrient redistribution with tillage; mycorrhyzal colonization; and plant nutrient uptake. Juan Pablo found mycorrhyzal colonization to be much reduced with tillage and with manure application, and the effect persisted throughout the season (Fig. 1); P uptake and grain yield, however, were not affected by the tillage treatments. Andres observed a tillage effect on the composition of microbial communities, little effect on total microbial biomass, and a greater effect on mycorrhyzal biomass (Fig. 2), but the agronomic significance of these shifts has not yet been determined. Various aspects of this research, including treatment effects on yield and soil organic matter, will continue for another five years. Four papers are being prepared for 2005 ASA. Presentations are being prepared for two extension field days in July 2005.

Soil pH stratification and localized liming on sandy soils. Research is underway to evaluate the effects of soil pH stratification and localized lime application on sorghum yield, nutrient uptake, root mass and root length per plant, soil and solution chemistry, and soil mycorrhizal. Results indicated that above ground sorghum biomass was not affected by acid treatments. However, root proliferation was very limited in treatments with pH lower than 5.0 in the subsurface soil layer. Soil solution aluminum and manganese levels increased significantly for the unlimed soil 35 days after planting compared to soils limed to 5.5 and 6.3. This decrease was correlated to a significant pH drop in the unlimed soil. M.Sc. graduate student, Greg Miller, is completing his research in 2005.

Networking Activities

Collaboration with extension organizations in Africa increased. Training workshops and extension programming with

Figure 1. The effect of one-time tillage in an otherwise continuous no-till system on mycorrhizal colonization of soybean roots at R6.9 in a sorghum-soybean rotation.

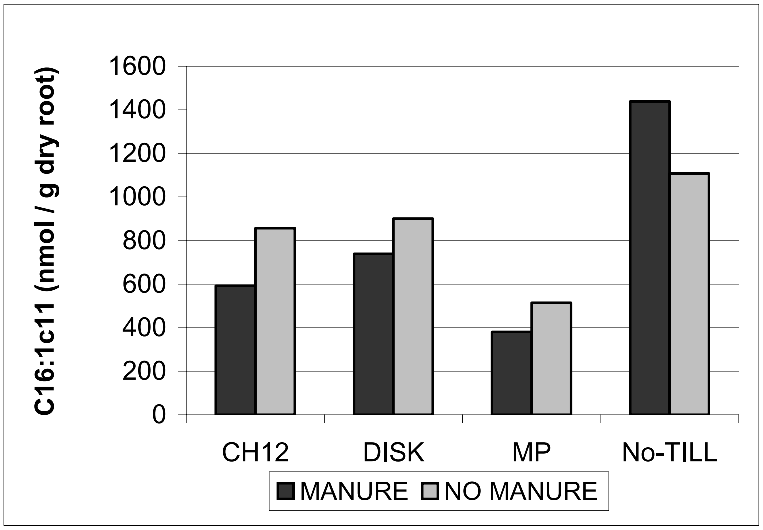
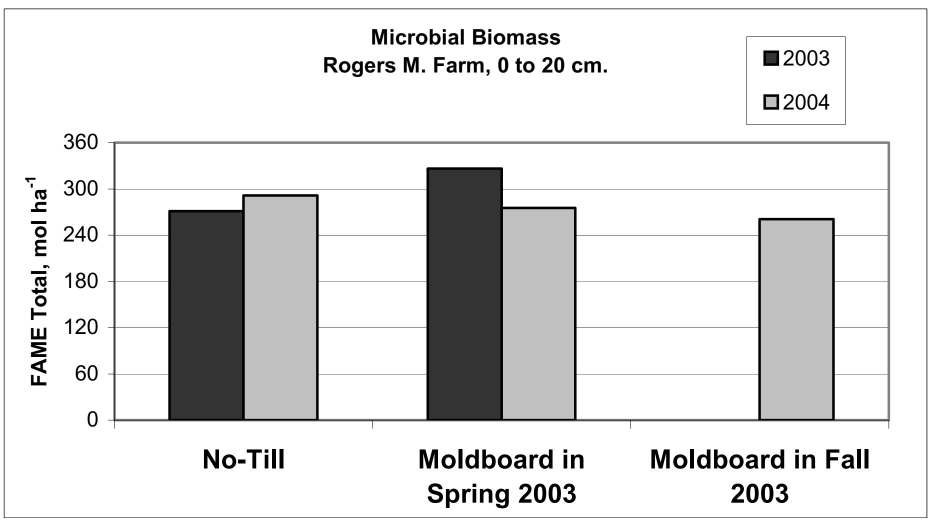


Figure 2. The effect of one-time tillage in an otherwise continuous no-till system on soil microbial and mycorrhizal biomass.



extension staff in Ethiopia are expected to lead to promotion of tillage and soil fertility management options. Arrangements are underway in Uganda to work with a number of extension organizations, with facilitation support from the USAID supported APEP, to promote soil fertility management options; arrangements are also being made to employ farmer-to-farmer and field school approaches. Opportunities for collaboration with the ASARECA-ECARSAM network were explored but we have not identified any opportunity for collaboration. The development of the sorghum production database is expected to be a valuable resource for future networking activities as it will strengthen the basis for germplasm and information exchange, identification of screening environments, constraints prioritization, etc.

Publications and Presentations

Journal Articles

Brhane, G., C. Wortmann, M. Mamo, H. Gebrekidan, and A.Belay. 2005. Micro-basin tillage for grain sorghum production in semi-arid areas of northern Ethiopia. *Agronomy J. (in review).*

Wortmann, C., S. Xerinda, M. Mamo, and C. Shapiro. 2005. No-till row crop response to starter fertilizer in eastern Nebraska: I. Irrigated and rainfed corn. *Agronomy J. (in review).*

Wortmann, C., S. Xerinda, and M. Mamo. 2005. No-till row crop response to starter fertilizer in eastern Nebraska: II. rainfed sorghum. *Agronomy J. (in review).*

Dissertations and Theses

Xerinda, Soares Almeida, 2004. No-till corn and grain sorghum response to starter fertilizer in eastern Nebraska. M.S. thesis. University of Nebraska-Lincoln, Lincoln NE.

Gebreyesus Brhane. 2004. Tied Ridging As *In Situ* Rain Water Harvesting Method For Improving Sorghum (*Sorghum bicolor* L.) Yield at Abergelle area, Tigray Regional State. M.S. thesis. Alemaya University.

Tewodros Mesfin. 2004. Effect of *in-situ* water harvesting on the growth, yield and water use efficiency of sorghum (*Sorghum bicolor* (L.) Moench) under semi-arid conditions of Ethiopia. M.S. thesis. Alemaya University.

Abstracts

Mamo, M., C. Wortmann, R. Renken. 2004. Phosphorus sorption in soils of Ethiopia, Uganda, and Mozambique. *American Society of Agronomy National Meeting,* Seattle, WA, Oct. 31-Nov. 4.

Mesfin, T., M. Mamo, C. Wortmann. 2004. Tillage and Crop Residue Management Effects on Soil Water and Sorghum Yield in the Central Rift Valley of Ethiopia. *American Society of Agronomy National Meeting,* Seattle, WA, Oct. 31-Nov. 4.

Brhane, G., C. Wortmann, M. Mamo. 2004. Water Use Efficiency in Grain Sorghum Production in Northern Ethiopia as Affected by Tillage Practices. *American Society of Agronomy National Meeting,* Seattle, WA, Oct. 31-Nov. 4.