SAHELIAN DROUGHTS:
A Partial Agronomic Solution

by

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Preface

This is a true story about an agricultural development project that was initiated in response to the droughts which occurred in the Sahelian zone of Africa beginning in 1968. These droughts persisted through the 1990s causing catastrophic problems for the people, their livestock and the environment. This project developed and implemented a partial agronomic solution to the droughts enabling many poor hungry people to have more food.

I began preparing this memoir in the late 1980s. I was the Principal Investigator of a collaborative research and training project involving scientists from several U.S. and African institutions. I had initiated collaboration in research between the University of California, Riverside, where I worked, and the Agricultural Research Institute of Senegal several years earlier in 1976. In the late 1980s the collaborative project was being reviewed about every second year. Reviewers would visit for a day and expect me to take only a few minutes to provide them with a history of the project, which by now had been underway for more than ten years. Instead I wrote a description of the history of the project and gave it to them together with other briefing documents when they arrived in the evening prior to the review day. I gained the impression that the reviewers were more interested in the memoir than they were in the extensive scientific reports that I provided.

At that time the memoir was only in a brief summary form. Subsequently, I decided to expand it to provide more detailed background information and a perspective of the effort and collaboration needed to make some progress in agricultural development in Africa. Up to this time, many agricultural development projects in Sub-Saharan Africa had experienced some difficulty making progress. I also wanted to introduce readers to the complexities of conducting research and extension for agricultural development in Africa, and to some more basic research.

Occasionally I have diverged from the main flow of the story to describe past events that have influenced my perspectives, and to give my opinions on issues I consider to be important and some practical matters. I hope that readers find these diversions interesting and not too distracting.

This book is intended for a wide range of people who are interested in agriculture, rural development in poor countries, Africa and science. I have not provided the full set of references required by a more scholarly book. The references I have provided give credit to my many colleagues
for their contributions to the agricultural development project and provide supporting documentation and background information on some important issues. I also have included some references to lead readers to further explanations and ‘new pastures’ of intellectual inquiry that I have found to be intriguing.

A useful overview of the droughts and other problems that confront people in the Sahel, and attempts to overcome them, is available in a book that also can be accessed through the internet. ¹ The superscript one ¹ refers to the place in the Preface section of References where the complete references to this book and the internet site are presented. The book and internet site also describe an agricultural development project that was conducted in Mali. I worked as a consultant evaluating the past performance of this project and developing plans for its future activities during a memorable month-long visit to Mali in 1983.

Further information on some of the crop science terms and concepts that I refer to can be found in a book I wrote on “Crop Responses to Environment”. ² The book is based on advanced undergraduate and graduate courses that I taught at the University of California, Riverside from 1972 through 2001.

I thank my wife Bretta Hall and daughter Gina Hall for their support. I also thank my daughter Kerry Hall and friends Samba Thiaw, Ndiaga Cisse and Bill Luellen for reading earlier drafts of this memoir and providing useful suggestions. I am responsible, however, for any mistakes in the book.

I dedicate this memoir to the many people who contributed to the development and implementation of a partial agronomic solution to the Sahelian droughts: the farm families, extension workers, scientists, staff and students, including some colleagues who died too young: Dr. Kwadjo Owusu Marfo from Ghana, Dr. Mbaye Ndoye from Senegal, Dr. Mubarak ElKhidir Abdalla from Sudan and Dr. Rommel Mesquito de Faria from Brazil.

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When I first went to work in Africa in 1961 it was widely believed that food production should be rapidly increased in all of the developing countries. At this time food supplies were inadequate in most of these countries and rapid increases in human population were occurring that were projected to result in more severe famines than had occurred in the past.

**Human population and food-supply problems are complex**

Solving food-supply problems was not a simple task in that the cause-and-effect relationships between human population and food production systems can be complex. Lloyd Evans¹ examined relationships between human populations and agriculture from ancient times to the late 1900s. He describes two contrasting hypotheses: either that increases in human population have stimulated attempts to increase agricultural production; or that opportunities for increasing food production have encouraged or permitted increases in human population.

Distinguishing between these two possibilities is important. In many parts of Africa, projects should not be initiated that encourage increases in human birth rates because this could not only result in worse famines for more people in future years, it also will accelerate the destruction of the biosphere. New technologies and other developments that make possible the exploitation of new lands for use by agriculture could tend to stimulate increases in human population, especially if they only provide poor living conditions for farm families. In contrast, new technologies that enable farmers to make more efficient use of their current arable land and provide improved living opportunities for farm families might indirectly result in decreases in human birth rates as will be discussed later in this chapter.

Increases in food production did not keep up with increases in human population for most of Africa during the 20th Century leading to greater shortages of food per person for people who already had insufficient food and often were hungry. A pragmatic approach to solve this problem was that two objectives should be pursued aggressively: enhance the efficiency of food production systems; and encourage reductions in human birth rates through humane methods.
Increased efficiency is defined as where the outputs of a food production system are increased per unit of inputs such as land area, labor or fertilizer. The more efficient agricultural systems also needed to be more sustainable than existing systems from both economic and environmental standpoints. This is difficult to achieve due to the inevitable trade-offs involved in balancing opportunities and innovations with their inherent costs and risks. One of the major dilemmas confronting agronomists was how to increase the production of food and other agricultural and non-agricultural products needed by a growing population without destroying the natural resource base on which the future of people, their agriculture and the biosphere depends.

By the 1960s many agronomists had recognized that the key to solving hunger in many parts of Africa and other continents was to develop cropping systems that produce more yield per unit land area, i.e. systems that are both more productive and more efficient. This approach contrasted with what often had been happening prior to the 1960s, a continuing expansion of the area of land under cultivation. Unfortunately, that earlier approach had become less and less effective or efficient because the best land already had been taken. Usually the new land that became available for farming was not as fertile as existing arable land or had other problems such as acid soils, steep slopes, flooding, or limiting supplies of water. Consequently the new land usually provided poor living conditions for farm families. Also, the expansion of the area under cultivation had destroyed natural lands that previously had provided vital contributions to the biosphere as watersheds, marshes and habitats for wild species.

Besides increasing food production, another major advantage that may accrue from the development of more efficient cropping systems is increases in farmer profits and thus reductions in poverty. When poverty is reduced birth rates have decreased, in some cases, resulting in slower increases in human population. This association has been explained by William Murdock as follows. “Poor parents have many children because the economic benefits of the children outweigh their economic costs. The benefits come in the form of labor, income, and security for parents in their old age. As parents’ incomes rise, and inevitably also their level of education, and as the economic structure of society changes, the benefit/cost ratio of children declines. as income increases, the balance will favor small families.”
Consequently, improved agricultural systems have the potential to solve not just one, but two major components of the hunger problem. They do it directly by enhancing food production and indirectly by reducing birth rates, and thus the number of people that will need to be fed in the future. For this to occur, however, the improved agricultural systems must be adopted by many poor farmers and be of benefit to them. Decrease in birth rates also can bring about another critical benefit, it provides women with more time and opportunities to contribute to societal development. The emancipation and empowerment of women are keys to development in many parts of Africa.*

Since 1961 substantial increases in productivity and food production have been achieved in Asia and parts of Latin America due to the ‘Green Revolution’ and other agricultural innovations.\textsuperscript{1} The main driving forces behind the Green Revolution involved breeding new semi-dwarf varieties of wheat (\textit{Triticum} sps.) and rice (\textit{Oryza sativa}) that are highly productive in fertile soils \textsuperscript{1,3}, and encouraging and helping farmers to provide the new varieties with substantial applications of nitrogenous and other fertilizers. In addition, increased productivity was achieved in other cereals, such as maize (\textit{Zea mays}), sorghum (\textit{Sorghum bicolor}) and pearl millet (\textit{Pennisetum glaucum}) through the development of hybrid varieties that also respond well to large applications of fertilizer.\textsuperscript{3}

During the 1970s the Green Revolution was criticized by many social scientists. A major criticism concerned the case of agrarian societies where landholding patterns are highly stratified. Since the technology requires increased inputs of fertilizer per unit of land area, larger landowners who are wealthier can be the first to benefit from the new technology. Then, if the large landowners have the ability to impose political or economical control, they can prevent poorer farmers from benefiting from the new technology by either buying their land or through other means. The bottom line, however, is that the technology developed by the agricultural scientists that made possible the Green Revolution is sound within the context of a rapidly increasing human population, and that more effective work is needed by social scientists and others to achieve the necessary social reform to insure that the technology benefits many people.

* Refer to reference one in the preface, and chapter 6 on “On-Farm Experiments and Progress for Women in Africa” for further discussion of this important point.
Green Revolution technology has not helped people in the many parts of Sub-Saharan Africa that do not have large areas of wheat and rice because the staple foods in this region mainly are maize, sorghum and pearl millet. Few improved hybrid varieties have been developed for these crop species that also are well adapted to the conditions of Sub-Saharan Africa. Also, many farmers in these countries either cannot obtain or cannot afford to buy the seed of hybrid varieties, which is needed every year, and the necessary fertilizer. Due to relatively high transportation costs in the African interior the purchase cost of a unit of fertilizer nitrogen (per unit value of grain sold) usually is more expensive than in most other parts of the world. The high price of fertilizer in relation to the returns from grain sold on local markets results in large fertilizer applications being less economic in many parts of Africa than other investments available to farmers.

Increases in food production in much of Africa, therefore, have been only moderate and less than the increases in human population. Consequently, the amount of food available per person has decreased, and severe famines have occurred. In addition, the environment has deteriorated due to reductions in soil fertility, loss of trees, loss of top soil and, in the Sahel, desertification. There are many other reasons why the increases in food production in Sub-Saharan Africa only have been moderate including: disruptive effects of wars and human diseases, continuation of inappropriate colonial policies that gave too much emphasis to export crops and too little emphasis to staple food crops, inadequate political leadership following independence and corruption. In some cases agricultural research and extension were not effective, and droughts have occurred that seriously disrupted agriculture.

**Our contributions to solving the problem**

This memoir is about droughts in the Sahelian zone of Africa and a project that developed and implemented an agronomic solution to the problems caused by these droughts. Solving these problems was extremely difficult and the solution is only partial with much remaining to be done.

In recent years while working on committees of the United Nations I have had disagreements with some African colleagues concerning rural development in Africa. They indicated a belief that I was being too pessimistic in emphasizing the problems confronting development in Africa and the
difficulties in solving them. In contrast, I believed they were being too optimistic about the opportunities for development there. These differences of opinion may reflect our differences in perceptions. They had experienced, first-hand, some of the improvements that have occurred in living conditions in Africa. In contrast, looking at Africa from European and North American perspectives, I saw a wide gulf between the way things are in much of Africa and my perception of the way things could be. I suspect that my African colleagues were concerned that my views would discourage donors from investing in rural development in Africa. I believed, however, that a realistic appraisal was necessary if projects were to be developed that had a chance of being successful. Many development projects in Africa have had limited success which already has discouraged donors.

**Focus of the project**

The Sahel is a band of land on the southern fringe of the Sahara that is a semiarid transition zone between the desert and the wetter Savanna zone to the south. This band has been defined based on average annual rainfall. However, published definitions have varied and the climate in this zone has changed substantially during the 20th Century. Consequently, I see little value in using definitions based on average rainfall or attempting to provide a precise description of the location of the Sahel. My approximate definition is that the Sahel stretches across Africa from northern and central Senegal and southern Mauritania in the west to central Sudan in the east, passing through central Mali, northern Burkina Faso, southern Niger and central Chad (Figure 1).

The Sahel is a harsh place for people to live in. It has a short highly variable 1- to 3-month rainy season during July, August and September. This is followed by a long dry season that becomes very hot with strong harmattan winds and sand storms blowing from the Sahara desert in May and June. Through the years the vegetation of the Sahel has been strongly influenced by burning during the dry season and other activities of people. In the sandy plains of the northern drier part of the Sahel there are very few trees due to the short rainy season and fires. Grasses flourish during the rainy season but at the end of the dry season the vegetation consists of hardy shrubs, some of which even goats will not eat. In contrast there are more trees and diverse species of grasses and shrubs in the southern wetter part of the Sahel.
Figure 1. The Sahel stretches across Africa from northern and central Senegal and southern Mauritania in the west to central Sudan in the east, passing through central Mali, northern Burkina Faso, southern Niger and central Chad.
Dangers of outsider perspectives

During a visit I made to Dakar, Senegal in 1976, an agronomist who worked for an international development agency, but mainly had experience in other continents, suggested that it might be a good idea to remove the trees in the Sahel to facilitate the use of tractors in cultivation. I explained that it would be a terrible mistake because the trees and their products are critical for the lives of the people, complement the types of agriculture that they practice and act as wind breaks reducing the extent of soil erosion and sand storms.

At that time, and especially in earlier years, development agencies had a tendency to try to introduce developed-country agricultural methods into Africa. While working in Tanzania during the early 1960s I had the opportunity to examine failed mechanization schemes. Farmers had bought tractors on credit but they were soon repossessed because the farmers could not make their loan payments. The costs of European tractors, fuel, oil, filters, tires, spare parts etc. were relatively large because they had to be imported over large distances. The returns to the farmers from cultivating their own land and the land of their neighbors who were poor were relatively small. Consequently, the use of tractors was not profitable.

In the Sahelian zone of Senegal virtually all of the farmers were very poor and buying a horse and cultivator represented a major life-time expenditure for them. There were virtually no tractors being used for cultivation in this zone in 1976 and there has been little change in this by 2006. Farmers in the Peanut Basin of Senegal still mainly used horse-drawn planters, cultivators and carts, many of which were very old.

Removing the Acacia albida trees in the Sahel would be particularly detrimental due to their many contributions to the integration of cultivation and herding, as was discussed by Paul Pélissier. These trees are spatially distributed as in a park. They have no superficial roots near the soil surface and therefore only slightly constrain the animal-draft mechanization used by many Senegalese farmers. These farmers cultivate close to the base of the tree trunks, and plant annual crops around and in-between the trees.

These specific acacia trees also have an unusual inverse growth cycle that benefits agroforestry. They have no leaves during the rainy season, so they do not shade crops grown close
to their trunks. Just after the rainy season has ended and the annual crops are approaching harvest, the trees produce leaves and then pods.

The roots of these trees grow deeply and the water that the leaves obtain for transpiration comes from deep zones in the soil where it is not available to the annual crop species. The leaves and pods of the trees provide browse for livestock, which is particularly valuable during the dry season because once crop residues have been consumed there is little other food available for the animals. The leafy trees also provide some protection to the soil surface from the strongly erosive harmattan winds.

At the end of the dry season, with the beginning of the rains, all remaining leaves fall from the trees. Farmers can incorporate these leaves into the soil by raking while preparing the land for sowing. The leaves are rich in plant nutrients and improve soil fertility because these acacia trees, in association with bacteria, fix atmospheric nitrogen. In addition, they recycle nutrients that have been leached below the root zones of the annual crops. Further, the soil is enriched by the feces of animals that have grazed on the pods and leaves.

The enhanced fertility in the area around the trees is of critical importance for crop production because the sandy Sahelian soils typically are infertile due to low levels of organic matter, nitrogen and phosphate. Cereal crops growing close to the trees usually are much bigger and greener and produce more grain than cereals growing a few paces away from the trees.

*Acacia albida* is not native to this area but probably came from the south due to the activities of people. The trees are very popular and people propagate them. Due to natural dormancy mechanisms, however, the seeds of *Acacia albida* do not readily germinate. When the fruits are eaten by livestock, though, any seeds that pass through into the feces will more readily germinate. This results from the strong digestive juices in the stomachs of the animals breaking down the chemicals responsible for the dormancy. In some cases local ordinances have been enacted to protect the trees against those who would chop them down or remove large branches for firewood. Any project that removed significant numbers of *Acacia albida* trees to facilitate mechanization using large tractors likely would break these local ordinances and annoy many indigenous people.
**Major limitations to crop production in the Sahel**

Insufficient water from rain and limited plant nutrients in the soil are both major problems in the Sahel. In the northern part drought is the main constraint to plant growth, while deficiencies of nitrogen and phosphate are the major constraints to cereal production in the southern Sahel. With a small amount of water and nutrients, cereal crops often only have enough resources to produce roots, stems and leaves, and do not grow long enough or big enough to produce much of the grain that provides a staple food for people in the Sahel.

Some parts of the Sahel are slightly more favorable for people to live in due to concentration of the soil and water from rain into small areas. For example, large areas of the land surface in northern Burkina Faso have been severely eroded leaving hilly outcrops with a hard surface that the rain does not penetrate. Casual observers might consider this as only being a catastrophic problem. A major international project was conducted in the Yatenga area of Burkina Faso in the late 1950s and early 1960s by the Groupement Europeen pour le Restauration des Sols to try to solve this problem. At this time the country was called Upper Volta. This project tried to reduce soil erosion by constructing infiltration ditches and bunds on the contour using heavy earth-moving equipment. Unfortunately, as I observed while working there in 1976, the ditches and bunds were not being maintained, and the project does not appear to have had any major long-lasting beneficial effects.

Despite the fact that soil erosion is a major problem in the Sahel, some of the soil erosion in Yatenga appears to have been beneficial. In these cases, soil erosion created more favorable deep-soil environments for annual crops and trees on the lower parts of the land area. In addition, the eroded outcrops act as watersheds providing run-off water that augments the rain falling on the low areas. Some water collects in ponds in the lowest depressions providing a source of drinking water for people and livestock. In addition, water from the ponds is used to irrigate small gardens where vegetables are grown during much of the year. These more-favorable areas for cultivation must now be protected from further erosion.

In more recent times, small-scale erosion control projects have been undertaken in Burkina Faso by local people with assistance from the private voluntary development and relief organization Oxfam. In these projects, rock bunds have been constructed by hand and have achieved some success.
in protecting fields from excessive soil erosion. The people who did the hard work of constructing these rock bunds and observed their beneficial effects will have some incentive to maintain them.

**Droughts in the Sahel in the 20th century**

In the 19th Century there were a relatively small number of people in the Sahel who mainly were semi-nomadic herders. The Peul and Fulani peoples are semi-nomadic in that the men often leave their families in settlements while they move with their herds. Due to increases in the population of semi-nomadic herders, and migration from the south of sedentary farmers there now are many more people who depend on the Sahel for their livelihood. Just prior to 1968 there were several million people in the Sahel, some were sedentary farmers while others were semi-nomadic herders with many cattle, sheep, and goats. Water for people and livestock came from wells, ponds, and river valleys. But after the droughts that began in 1968, water became scarce in the dry season and conditions for the people and their animals became very difficult due to extreme shortages of food and forage.

Rainfall data from northern Senegal are similar to those of much of the Sahelian zone. A map is provided (Fig. 2) with lines to denote places with similar average annual rainfall for the period from 1931 through 1975. You can see that the average annual rainfall decreases progressively from south to north. There is a major area of crop cultivation in the drier northern part of the Sahel around the town of Louga where the average annual rainfall between 1918 and 1968 had been 442 mm (Fig. 2). Traditional systems of agriculture that had evolved through hundreds of years were adapted to these conditions and proved adequately productive in most years.

In an average year the rainfall provided enough water for local varieties of drought-resistant annual crops of: pearl millet, sorghum, peanut (*Arachis hypogaea*) and cowpea (*Vigna unguiculata*). The major crops grown on the largest areas were pearl millet and peanut.

Local varieties of crops grown in the Sahelian zone of Senegal in the 1960s and 1970s had durations from sowing to harvest of 75 to 105 days with cowpea varieties having the shortest cycle length. Some annual grasses would emerge during the rainy season and provide high-quality forage for the livestock of the semi-nomadic herders, while water would be available year-round from wells.
to quench the thirst of people and animals.

In 1968 the annual rainfall at Louga only was 212 mm which is less than half the average value for the previous fifty years (Fig. 3). The growing season was very short with droughts occurring within the rainy season. Crops of pearl millet, sorghum and peanut failed, producing only a small amount of grain and food for people and only a modest amount of forage for livestock.

This was not a major disaster because many people knew how to cope with the occasional drought. They had enough granaries to store sufficient pearl millet grain or sorghum grain to provide food for 2 to 3 years. The rains returned in 1969, provided abundant water with 599 mm at Louga (Fig. 3), and hope was restored.
Figure 3. Annual rainfall from 1918 through 1999 (solid lines) and averages for 1918 to 1967 and 1968 to 1998 (dotted lines) for Louga in the Sahelian zone of Senegal (location 15°37'N 16°15'W elevation 38 m).
But it proved to be a false hope. Since 1969 there have been 29 years of a virtually continuous drought in the Sahel, with an average annual rainfall at Louga of only 276 mm from 1968 through 1998 (Figure 3). During most of these dry years the rainy season started so late that the duration of the growing season was very short, often less than 60 days at Louga. Even the southern wetter part of the Sahelian zone in Senegal at Bambey had an average rainfall of only 466 mm from 1968 through 1998, compared with an average rainfall of 670 mm from 1947 to 1968. In only one of the 29 dry years since 1969 did the rainfall at Louga exceed the long-term average of 442 mm, and in 23 of the 29 years the rainfall was less than 300 mm (Figure 3).

**Consequences of the droughts**

Many people in the outside world were aware of and horrified by the effects of the droughts occurring in the Sahel from 1968 through 1973, and many countries responded by providing assistance. But as the droughts continued during the 1970s, 1980s, and 1990s there was a progressive decrease in the outside world’s awareness of the tragedy that was occurring in the Sahel. Yet, this may have been the longest and most severe series of droughts, with respect to effects on agriculture, that has ever been recorded.

A comprehensive analysis by social scientists Richard Franke and Barbara Chasin points out that poorly conceived policies and projects conducted during the colonial period prior to 1968 had made the Sahelian peoples less resilient to the affects of drought. Their analysis is valuable but in my view tends to put too much blame on colonialism and capitalism, and gives too little emphasis to the contributions to the problems that occurred of the rapid increases in populations of people and livestock and the change in climate.

During the first series of droughts between 1968 and 1973, millions of people in the Sahel suffered from famine and hundreds of thousands of people died. A graphic description of the terrible effects of the drought on the indigenous people is provided in the book of Richard Franke and Barbara Chasin. Also many shallow wells dried up and many livestock died. As of 1974, it was estimated that the livestock population in the Sahel and Savanna zones had decreased by about 80%. This temporarily solved the over-grazing problem but also destroyed the livelihoods of many...
herders who lost all of their livestock and thus were not able to rebuild their herds. In some cases, farm families ate the grain they normally would have saved for use as seed, which was highly unusual and severely compromised their chances of recovery by cultivating land in future years. By 1974 about 2 million people, mainly families of herders but also some families who had been settled cultivators were living in refugee camps depending on international relief programs for their food.  

The progressive deterioration of natural resources occurring prior to 1968 had been accelerated with many trees, including valuable acacia trees, being chopped down for use as firewood or dying due to the drought. Many people migrated south and to other regions and countries seeking a better livelihood. In northern Senegal, however, where conditions due to the droughts were extremely difficult, fewer people have suffered from famine than in many other parts of the Sahel as a consequence of an agronomic project we conducted.

The difficulty of developing agricultural solutions to the problems caused by the droughts.

Our project developed improved methods for rain-fed crop production and crop storage that have been adopted by many farmers in Senegal and Sudan, and are spreading to other Sahelian countries. The importance of the project should not be underestimated in that, due to the difficult circumstances, many of the development projects that were initiated in the Sahel in the 1970s were not successful. There has been a tendency for large-scale projects imposed from outside to fail, whereas some ‘grass-roots’ projects of modest scale have been successful. Our project was intermediate scale with contributions by outside agencies, and African-government, non-government and ‘grass roots’ organizations.

While planning this project I considered various alternative solutions to the problems caused by the Sahelian droughts. Developing improved rain-fed crop production systems for the Sahelian zone that could be adopted by farmers would be difficult and might not be possible. When I first began evaluating this problem there was no assurance that agronomic solutions to the droughts could be developed.

Consequently, I wondered if one should attempt to improve conditions for semi-nomadic herding, the traditional use of this zone. The herds of the nomads grazed the nutritious grasses
present in the northern Sahel during the rainy season. As the Sahel became dry they progressively moved south to the wetter Savanna zones or to the banks of the Niger and Senegal rivers and Lake Chad eating residues of crops grown by sedentary farmers and coarse grasses. At the end of the dry season and after the rainy season had begun, the herds and herders returned to the northern Sahel continuing their annual cycle of migration.

Prior to the 1970s, complex interactions were occurring between semi-nomadic herders and sedentary farmers in many parts of the Sahel that often were mutually beneficial. Under the political, demographic, and social conditions of the twentieth century, however, semi-nomadic herding was becoming a difficult way to make a living. The natural rangeland can support only relatively small herds in a sustainable manner, and annual migrations to the south and the banks of the rivers and lakes had become constrained by increased populations of sedentary farmers in these areas.

Given these conditions, the most sustainable use of this land might involve a system whereby sedentary farmers collaborate with a small number of semi-nomadic herders, and combine livestock husbandry with the cultivation of cereals and legumes, such as cowpea and peanut, to provide food and hay. Use of animal wastes for manure, and biological fixation of nitrogen by the leguminous crops and Acacia albida trees could maintain the fertility of the soil and contribute to the sustainability of the system. Legume hay produced by the farmers could be used to improve the conditions of the livestock during the dry season, especially those that are to be used as draft animals during the rainy season and those destined for breeding or slaughter to provide food and cash. But, could agronomic improvements be made to this cereal-legume-livestock farming system?

Of particular importance in this system is the fact that livestock provide an opportunity for investment by farmers and herders. The main problem with this investment method occurs when there are too many livestock. Herds become so large that they begin to over-graze and destroy the rangelands. The herders do not own the grazing land so they have no incentive to preserve it. This can become a major problem in areas around wells and other sources of drinking water for livestock. With over-grazing the animals starve thus smaller herds are needed with fewer animals that are in better condition. Livestock that are in better condition would have greater individual value.
Can irrigation solve the problems due to droughts in the Sahel?

While irrigation is a potential solution to droughts in many parts of the world, it only appeared to have a moderate opportunity for enhancing food production in the Sahel. This was in the basins of the Senegal and Niger rivers. Traditionally, a practice called recession cultivation was used on the banks of these rivers. Crops were planted in the deep moist alluvial soil that was exposed as the level of the river water receded. These crops were able to grow even in the absence of rain because their roots progressively extended into the soil profile accessing more water. The recession crops produced significant food grain even though little rain occurred during the cropping season.

Various projects have been conducted to permit irrigation of crops in these river basins. In these projects, the flow of water in the rivers has been controlled by dams, and heavy equipment has been used to make level basins in which crops were grown and irrigated using pumps typically driven by diesel engines.

In my view, the main opportunity from these irrigation schemes is the production of vegetables such as onions, peppers and tomatoes that have high value on West African markets. Use of these schemes to produce staple food crops such as rice and maize is problematic from an economic standpoint. The relatively low value of these crops coupled with the relatively high costs of pumping water and providing fertilizer make irrigated production of grain crops not very competitive in the Sahel. The problem is exacerbated by the subsidies paid by governments of other nations to their farmers who are growing the same crop species. Grains from these countries have been placed on world markets at relatively low prices. These grains have been bought by some African governments and provided at relatively low cost to their urban and other non-agricultural residents. These groups of people tended to be politically active and have been favored more by these African governments than the rural communities that were producing local grain crops.

In the extensive crop-production areas away from river basins the only water, other than rain, is in underground aquifers. During the period from 1986 through the early 1990s a humanitarian relief and development organization, World Vision International, installed individual wells in about 400 villages in the Sahelian zone of Senegal. The boreholes were deep averaging 62 m (about 203 feet) depth, which necessitated the use of mechanized drilling equipment. The aquifers that these
wells tapped into were mainly able to provide enough water in a sustainable manner to meet the drinking and other domestic requirements of people and their livestock. In some cases well water also was used for irrigating small dry-season gardens to produce high-value vegetable crops. In general, though, these aquifers were unable to sustainably supply sufficient water to irrigate the large fields of pearl millet grown around these villages.

It should also be noted that even if substantial water had been available, irrigated production of pearl millet or sorghum usually was not economically viable in the Sahel during the 20th Century. Also some of the deep aquifers in the Sahel only contain ‘fossil’ water that is not being replenished and therefore can only be used once. Apparently, the main value of these aquifers is to provide drinking water for people and livestock.

The personnel at World Vision International appreciated this limitation and installed mainly hand pumps in the wells they drilled, even though they could have used motorized pumps. One of their reasons for that was to try to ensure that the aquifers will not be rapidly overdrawn, which could result in a substantial decrease in the water table and a progressive loss of effectiveness of the wells. World Vision International also trained local people as blacksmiths, thus providing the villages with the ability to maintain and repair their hand pumps so that the technology would be sustainable. Motorized- pump technology would have been much less sustainable.

Clearly, there only was modest opportunity in the Sahel for using irrigation to increase the production of staple food crops. The main opportunities for increasing food supplies and improving the livelihoods of the indigenous people appeared to be by enhancing the rainfed production of pearl millet, sorghum, peanut and cowpea, and increasing the effectiveness of herding.

What about human migration is it a solution or another problem?

Another potential solution to the droughts involved encouraging more people to leave the Sahel. But there are many semi-nomadic herders and many sedentary farmers who have considered this zone their home for several generations. These herders and farmers are conservative, and opportunities for whole families to permanently move to wetter regions or emigrate to other countries were not good. By the 1980s, however, there were many villages in northern Senegal where
the young men had departed, leaving behind the old men, women and young children. Those people who remained needed methods for producing food and cash.

Permanent migration also has caused problems for those who left. Many young men from the villages moved to local cities, while others emigrated to neighboring countries in Africa and even to Europe and the United States. Unfortunately, there are too few legitimate job opportunities in cities or developed countries for men who have the skills needed for living in the African countryside but lack formal education. Many of these emigrants have experienced difficulty achieving productive lives in cities and developed countries.

There have been some benefits from the human migration, however. Some emigrants leave the villages only during the dry season, then return during the wet season to cultivate their crops. Others emigrated more permanently but have sent back money, which has been a major factor contributing to the survival of the people who remain in the villages. The excessive migration of poor rural people to cities, however, is one of the major tragedies of Africa. The people leave the rural ways of living and value systems that in the past had been effective. They are attracted by the hope of a better way of life in the cities but have little chance to achieve their dreams.
Chapter 2. Search for an Agronomic Solution to Drought: research in Senegal and California from 1974 - 1980

USAID-funded institutional development grant to the University of California, Riverside

In the 1970s the United States Agency for International Development (USAID) provided a few U.S. universities with institutional development grants. The agency wanted to strengthen the involvement of US universities in the development of solutions to world food production problems. Importantly, USAID had recognized that agricultural scientists in the United States needed to gain an improved understanding of developing countries if they were to be most effective in generating these solutions and supporting the technical assistance projects of USAID.

In 1974 the University of California at Riverside (UCR) obtained one of these grants for a 5-year project titled Moisture Utilization in the Semi-arid Tropics (MUSAT). The goal of the project was to help UCR solve problems of rain-fed agriculture in areas of developing countries affected by drought, such as the Sahel. The agency wanted to know if any of the dryland farming methods used in the United States and elsewhere could be effective in Sub-Saharan Africa. Officials at the agency recognized that in the 1970s most scientists in the United States did not know enough about African countries and peoples to work effectively in developing solutions to their problems. Thus the USAID provided funds to enable scientists at UCR to learn more about the Sahel and how we could contribute to solving its problems.

I have the impression that the USAID did not devote as much funding to institutional-development projects in the United States during the 1980s and 1990s as it did in the 1970s. I do not know whether this was due to a shortage of funds, a belief that this type of project was no longer needed, or a loss of faith in the value of this type of project. MUSAT did lose its way on some occasions but overall it made some useful contributions to the solution of world food production problems due to an unusual set of circumstances.

MUSAT was directed by Professor Glen H. Cannell, a UCR soil physicist with much practical experience. I assisted Glen with the project, contributing my complementary skills as a
plant scientist with some experience working in Africa. My scientific contributions to MUSAT during the first year consisted mainly of reading and thinking about scientific literature on agriculture in the Sahel using materials from a special library that was being developed at UCR by the project.

At that time I was an assistant professor striving to become a tenured professor. Thus I also needed to devote considerable effort to conducting original research, writing technical journal articles and teaching or I would not be able to stay at UCR. In the fall of 1975, I decided to try to get an accelerated promotion. My personal file was evaluated by external peers, Departmental faculty, the Dean of the College, various committees and the UCR Chancellor. Fortunately, I gained the promotion to associate professorial rank thereby achieving tenure. This gave me the freedom to devote considerable effort to the UCR-Africa project while not totally jeopardizing my career as a scientist and professor.

**MUSAT gives interdisciplinary emphasis to one crop species**

In 1975, I decided that my research contributions to both MUSAT and the California Agricultural Experiment Station would place major emphasis on one specific crop species. This decision may have been one of my major administrative contributions in that it influenced the direction taken by MUSAT. Some other professors at UCR also decided to conduct research on this crop as part of their contributions to the project, but they did not continue to work on it when the institutional development grant from USAID ended in 1979. In contrast, my research continued to place major emphasis on this crop until my retirement from UCR in June 2003.

The reasons behind my decision to focus on one specific crop were not profound but they resulted in my taking a different approach to research from many other professors at major universities. Most professors focus their studies on a specific scientific sub-discipline and work on either basic questions of fundamental importance, which many scientists are studying, or continue to work on the topic that they studied for their dissertation. These approaches can provide the easiest ways to gain stature as a scientist, which can be very difficult in that only a small proportion of scientists become widely recognized for their research contributions.

In contrast, I decided to move away from the fundamental research areas that had enabled me
to gain tenure and instead conduct research on a specific crop. My main reason for doing this was that this crop species was important to many poor farmers and herders but had been neglected by science. Research on this crop was needed to make possible the development of improved cropping systems. I knew very little about this crop but I did know it was suited to the environment of Riverside, the location of the UCR main campus, because in earlier years it had been a major crop in this area. I also decided to broaden my research program and include many of the disciplines that are relevant to plant breeding and agronomy, including genetics, plant sciences, soil sciences, atmospheric sciences, plant pathology, nematology, and entomology. The development of improved crop production systems required that I take this broad approach. This represented a radical departure from my Ph.D. research, which emphasized the physiological responses of plants to a viral infection, and my subsequent research on photorespiration, photosynthesis and plant adaptation to drought including plant water relations and stomatal responses to environment.

I felt the need to focus on plant breeding, since by itself plant physiology did not seem to offer direct opportunities for increasing the production efficiency of an annual crop species. Also I predicted that by combining plant physiology with plant breeding and Mendelian genetics I might discover some basic insights into plant adaptation to abiotic stresses. This prediction came true. While mainly conducting plant breeding with some agronomy we also made some fundamental discoveries about plant stress tolerance. We did this by breeding pairs of near isogenic lines with and without traits conferring tolerance to heat or chilling or adaptation to drought. We then compared the lines and discovered some mechanisms of plant stress tolerance and adaptation. Many other plant physiologists were taking a contrasting approach, which has been popular up to now, a reductionist progression downwards in a vertical direction ultimately using molecular methods.

My ‘new’ broadly horizontal approach was similar to the approach used by some plant breeders of the California Agricultural Experiment Station in the early 1900s, and has its roots in ecology. For this reason, I decided to call myself a ‘Crop Ecologist’ and subsequently, had my business cards changed to reflect this fact. They described me as being a “Professor of Plant Physiology and Crop Ecologist in the Experiment Station.”

This career strategy caused a few professional difficulties for me. I eventually achieved the
undesirable status of being recognized by some plant physiologists as being a good plant breeder, and by some plant breeders as being a good plant physiologist, without being recognized by main-line scientists in either discipline as doing significant research. The interdisciplinary strategy that I adopted did, however, enable my research team to make some unique progress with respect to improving understanding of heat and chilling tolerance and adaptation to drought.

Since the 1970s few individual scientists have had research programs as broad as the one I conducted, because the various disciplines have become very complex. Major plant breeding and agronomy programs now have large teams of scientists with each scientist specializing in a different discipline representing only a small part of the entire program.

From 1982 to 2003, my small team at UCR consisted of a deputy scientist with expertise that was complementary to mine (initially Dr. P. N. Patel, a plant pathologist who specialized in plant resistance to diseases and subsequently Dr. J. D. Ehlers, a plant breeder who specialized in plant resistance to insect pests), a research assistant who mainly looked after our germ plasm collection and equipment, a variable number of graduate students and postdoctoral fellows, and some part-time assistants who helped with sowing, weeding, harvesting etc.

Through these years we conducted field experiments on nine experimental farms of the California Agricultural Experiment Station and with collaborating growers throughout the Central Valley of California from Davis in the north to Shafter in the south, and in the Desert Valleys of southern California from Riverside in the north to El Centro in the south near the border with Mexico. The straight-line distance between Davis and El Centro is about 520 miles (ca 840 km) and we traveled by road from our home base at Riverside while conducting these field experiments covering several hundred miles on a typical day. This provided us with many opportunities to visit farmers’ fields, which proved to be extremely valuable both in diagnosing field problems in California and making friends. In addition, we conducted collaborative field experiments with scientists in several parts of Africa and in the high plains of Texas, which provided us with a broad perspective of crop production problems.
Most important crops in the Sahel

Pearl millet is the main staple food, grown for thousands of years under rain-fed conditions in the extensive sandy soil areas of the Sahel. Sorghum also is an important crop in smaller areas where the soil has significant amounts of clay and for recession cultivation in river basins. In addition, sorghum is favored in many parts of the Sudan where people prefer it as their staple food.

Peanut is an important cash crop in the Sahel. It is grown on a large scale for production of vegetable oil for export and domestic use. Peanut kernels also are an important food for people. In addition, the residue from kernels, after extracting the oil, is a valuable feed for livestock, as is peanut hay.

Cowpea was a minor crop in the Sahel grown for human food and as hay for livestock. Much of the plant is eaten by people including the dry beans, fresh peas, immature pods and leaves, which taste similar to spinach. Cowpea is called blackeye beans or southern peas in the United States. In the Francophone countries of Africa, scientists and government officials call cowpea niébé. Many local names are used: in Senegal the Serere people call it niao, and the Wolof call it seub. In some parts of the Sudan cowpea has the local name luba hilu.

Cowpea evolved together with pearl millet in the African Savannas’ where both crop species were domesticated and adopted by early cultivators. In many cases, farmers in the Savanna zones still grow them as a mixture or intercrop. The term intercrop is used when there is a systematic rather than a random arrangement of plants as is the case with mixtures. In many cases, pearl millet seeds are sown at wide spacing into dry soil just before the beginning of the rainy season, and then a few days or weeks after the commencement of the rainy season, when the pearl millet plants are growing vigorously, cowpea seeds are sown in between them and in places where the pearl millet plants have died. In other cases, pearl millet seeds are sown into moist soil after the first major rainfall event of the season and cowpea seeds are sown in between them a few days or weeks later, such as after the first weeding is completed.

Value of cowpea

Pearl millet is grown on a large area in the Sahel where its grains provide much of the food
energy in the diets of the people. Cowpea also is valuable as food because in addition to carbohydrate its grains are rich in proteins with amino acid profiles that complement those present in grains of pear millet and other cereals. The remainder of the cowpea plant shoot produces a nutritious hay for livestock that can be very valuable to farmers and herders in the Sahel.

In addition, cowpea has the ability to enhance the fertility of the soil by fixing atmospheric nitrogen in symbiosis with soil bacteria and by taking up soil phosphate at low concentrations in symbiosis with soil fungi. These traits are particularly important in the extensive areas of the Sahel and other Savanna zones where the soils are very infertile.

I came to the conclusion that improved cowpea varieties might produce more grain than traditional cowpea landraces without requiring additional inputs of fertilizer, and that they might also enhance the fertility of the soil thereby increasing the grain yields of cereal crops grown on the same land. If this was the case, the new cowpea varieties could be adopted by the poorest farmers and produce several important benefits for them. All the farmers would need would be a one-time access to the new seed, and advice on the best ways to manage the new varieties, incorporate them into their cropping systems, and produce more seed. They also would need new methods for storing the seeds and grains that were more effective than those currently being used.

Cowpea was not considered to be an important crop in the Sahel in the 1970s. For example, a book written in 1980 that discusses the Sahel and possible solutions to the recurring famines does not even explicitly mention cowpea.\(^7\) Chap. 1

I decided, however, that our project should focus on cowpea and not directly on the staple food crops.

Considerable research already was being conducted on pearl millet and sorghum, especially in India and subsequently in the Sahel.\(^1\) Preface Also, I anticipated that we would have had difficulty studying pearl millet under field conditions at Riverside because its grain is highly attractive to birds. We would not have been able to determine the potential grain yield without resorting to the use of poisons that would have disturbed people who appreciate birds and other wild creatures. The bird problem is not unique to California either. Farmers in the Sahel also must compete with birds for the pearl millet at harvest time.
As of 1974, cowpea had not attracted the attention of many scientists in technically advanced countries, was not a major crop in the United States, and was grown only on a very small scale in Europe, mainly in a few small gardens around the Mediterranean sea. In contrast, cowpea was an important crop for poor farmers in the large drought-prone areas of Sub-Saharan Africa and northeastern Brazil, and in Asia.3

Cowpea grew well in the area around Riverside where it had been a significant crop until urban sprawl from Los Angeles forced the growers to sell their farms. Some of the local farmers I had worked with in the 1970s subsequently moved to the San Joaquin Valley, where the main part of California cowpea production occurred during the major period of my research program. At this time cowpea was grown on a modest area in California producing about 40,000 tons per year of dry cowpea grain that were sold as blackeye beans.4

In the 1970s California was the world’s leading organized international exporter of cowpea grain, if one excludes the cross-border marketing of cowpea that occurs in Africa, such as the major exports from Niger to Nigeria. California blackeye beans have been exported to as many as 30 countries. During my travels I have encountered blackeye beans from California in markets in Ghana and Trinidad. Conducting research on cowpea enabled me to simultaneously pursue my responsibilities to my employers—UCR and the California Agricultural Experiment Station—and to USAID, which subsequently provided a significant proportion of the funds required to support my research program until my retirement. The availability of large quantities of cowpea seed in California also proved to be important for the project, as will be shown in chapter 4 on “‘Operation Cowpea’ in Senegal: 1984–1986.”

**Difficulties encountered when working with a ‘minor’ crop species**

The difficulties of conducting research on a crop species that is perceived to be of ‘minor’ importance on either a regional or a global scale should not be underestimated. I will discuss two of those difficulties here.

First, its agricultural industries are small or poor, which means these industries are able to provide researchers with only limited financial support. Nevertheless, the blackeye dry bean growers
of California were able to provide a small grant to fund my research program on an annual basis every year from 1980 until my retirement. I appreciated their support because I enjoyed working with the farmers. My research program responded to their support by developing a new variety, ‘California Blackeye 27’ (‘CB27’) and improved cowpea production systems for California.

The fact that I had been able to gain funding support from California growers gave my program a degree of legitimacy that I exploited while seeking the major grants from the federal government that I needed to fully operate my research program. Unfortunately, this proved to be difficult because federal agencies tended to support the more fundamental research expected of scientific programs at major universities, which address basic rather than applied questions. In the plant sciences, the widely researched major crop species and the model plant species *Arabidopsis thaliana* usually provide the most effective systems for this type of research. Most federal agencies have shown little interest in funding research conducted with cowpea except for the USAID, and the United States Department of Agriculture (USDA), which provided me with small grants for enhancing the US cowpea germ plasm collection. I was only able to obtain other sources of federal funding for research with cowpea that was perceived by reviewers as addressing scientific questions that also were relevant to major crop species viewed as being more important than cowpea for the United States.

The second problem involved with working on minor crops is that the advent of genetic engineering in the 1980s brought with it a tendency for research organizations to ignore ‘minor’ crop species, such as cowpea. Genetic-engineering research is expensive and requires more extensive basic knowledge of the studied species than usually is available for minor crop species. Public and private plant research organizations began focusing their research efforts on a small number of major crop species, for which there already was a substantial amount of knowledge, and where profits from the new technology could be very large.

It should be recognized, however, that there are many ‘minor’ crop species, e.g. more than 200 of them are grown in California, and collectively they are extremely important for mankind. The future for research and cultivation of minor crop species is dismal if society does not begin to recognize the importance of using a diverse set of plant species in agriculture, and supporting their
enhancement and maintenance.

Maintenance research is important for the sustainability of cropping systems. Plant pests and diseases continue to evolve, producing more destructive strains. Also, with the current extensive travel of people and transportation of goods, exotic species and strains of pests and diseases often inadvertently move from other countries or regions into new areas. Consequently, continuous breeding of varieties is needed to incorporate resistance to new strains and species of pests and diseases together with research on other approaches to pest and disease management. Without this maintenance research, agricultural enterprises will not retain their effectiveness in being profitable and providing the agricultural products needed by people.

Gaining experience in West Africa

During the initial phases of the MUSAT project in 1974 I used my annual vacation to work as an agricultural consultant for an oil company that was planning an agricultural development project in Guinea-Conakry. I wanted to learn more about West Africa, which I had not visited. While working in Guinea, I examined potential agricultural development projects involving pineapple, banana, and rice production in coastal areas, and N’Dama cattle breeding and ranching in the Fouta Djalon highlands near Mamou.

N’Dama cattle are important for the parts of Africa inhabited by tsetse flies because they are one of the few cattle breeds that have resistance to the trypanosome parasites that can be transmitted by the tsetse flies. Cattle breeds used in the Sahel, such as Zebu, are highly susceptible to the trypanosoma protozoa. Fortunately, tsetse flies only occur at the southern boundary of the Sahel and in the wetter Savanna zones.

People also have to be careful in the presence of tsetse flies because in addition to having a probe that is very piercing, some species of tsetse flies can transmit the protozoa responsible for ‘sleeping sickness’ in humans, a disease that often has been lethal. I had experienced bites of tsetse flies while working as an extension officer in the bush country of East Africa and have carefully avoided them ever since.

The time I spent in Guinea-Conakry in 1974 was interesting but difficult due to the repressive
nature of the government of President Sekou Touré. Most of the government officials I met were very nervous as if their lives depended upon what they said. And it was not just government officials who exhibited this trait. A scientist I had known as a student at the University of California, Davis, was just as nervous as the others. He was the head of the National Institute of Research at Foulaya near Kindia. Ten years later, after the death of President Sekou Touré, I read in a newspaper that in the 1970s the Government of Guinea had a detention camp near Kindia where many people had been tortured and murdered.

The only man I met in Guinea who had any assurance was Moussa Diakité, the Minister of the Interior and Security, who was the Chairman of the State Committee for Cooperation with the American Countries. He was in-charge of our ‘negotiations’ with the Government and had a serious demeanor. The atmosphere of the meetings we participated in was always tense and the other government officials who were present said little. The Minister began the first meeting by referring to a list of projects proposed by the President. The first possible project on the list involved producing rice in the coastal marshes of Guinea using the mechanized methods of California.

I had visited a rice farm in the Sacramento Valley of California in the 1960s and had been amazed by the high level of mechanization. The farmer had taken war surplus equipment and modified them for use in rice production. He had taken a tank that could cross the wet rice fields, removed the turret and guns and welded on top a combine harvester. Half-tracks had been modified so that they could follow the harvester and catch the rice grain in a bulk container for transportation out of the field. For sowing, the farmer flooded the field, moistened the grain to make it heavy and commence germination, and then flew it onto the flooded field using a small plane. With this equipment a few people could grow large areas of rice without even touching a single grain.

I suggested to the Minister that Chinese methods for growing rice would be more effective in Guinea than California methods. Rice production in Guinea should take advantage of the local labor supply, many people needed jobs, and should make minimum use of mechanization which was very expensive in Guinea. The Minister didn’t appreciate our negative responses to his strong recommendations and terminated the meeting at lunch time. Following lunch we remained in a government rest house while elements of the Guinean army conducted maneuvers around the house.
The same procedure was used on subsequent days after we had disagreements with the Minister. I assume that the maneuvers were intended to be a softening-up process and two members of our four-person team did become very nervous. One member of the team used a pretext to visit a government official who had an office near the Conakry airport and took the first plane leaving Guinea.

Eventually, the Minister proposed some projects that we agreed to evaluate including N’Dama cattle breeding and ranching in the Fouta Djalon highlands. Other people probably had strong confrontations with the Minister. After the death of President Sekou Touré in 1984 a new government was formed. The new Government of Guinea arrested Moussa Diakité and executed him in 1985 in Kindia.

My visit to Guinea did have some pleasant moments, including the opportunity to hear some outstanding singing and music. One evening while listening to the sounds of Africa from the veranda of a government rest house in Conakry, I was surprised to hear some beautiful singing. I first thought someone was playing one of my favorite LP records, but then realized it was a real person singing, not a recording. It occurred to me that Miriam Makeba and Stokely Carmichael were living in Guinea at this time. I assumed that she had been invited to a function in an embassy that was some 50 paces away from the rest house and was giving an impromptu performance. I was not able to move closer to the embassy to confirm this assumption because the armed guards who surrounded our government rest house were not particularly communicative.

During our stay in Conakry we had not been allowed to leave the rest house without permission from the Ministry of the Interior and Security. Subsequently, after leaving Conakry and traveling up country, the Government invited me to attend, as a special guest, an evening of entertainment with a brass band and dancing at Mamou in the Fouta Djalon highlands. The band played in the style of the Bembeya Jazz National, which had been a very popular band in Guinea and elsewhere in West Africa. Several local women asked me to dance with them in the ‘Highlife’ style, including an intriguing and charming woman who was in charge of a local women’s brigade. At that time, the organization of Guinea had some elements of the Soviet system. One of the few good things that I observed the Government of Guinea was doing at that time was promoting the empowerment of women.
While working in Guinea, I learned that West Africa can be uncomfortable for someone who grew up in Europe, East Africa, and California. The high night temperatures, high humidity, and insects can make it difficult to sleep when there are no air conditioners or mosquito nets. I began to think about the possibility that the performance of crop plants might be constrained by high night temperature, which is discussed in chapter 7 on "Improved Cowpea Production Systems for the Sahel and California.”

In colonial times the highland areas of East Africa were considered to be a paradise, and I enjoyed living there; in contrast West Africa has been described as the ‘white mans grave.’ The bad reputation of West Africa, at least for Caucasians, arose from the prevalence of various life-threatening diseases. I have been extremely ill on many occasions when working in West Africa. In contrast, except for attacks of malaria, I rarely have been sick when traveling and working in many other parts of the world including countries in East Africa, Asia and Central and South America.

In 1975 Dr. Cannell, the director of MUSAT, and a team of UC scientists visited the Sahel to study potential projects. I wanted to participate in this work but I decided not to go to Africa with the team because I thought it would be more beneficial for other UC scientists who had not had the chance to visit Africa. I wanted to encourage them to get involved in the project. I already had some African experience. In addition to my work in Guinea-Conakry, I had worked in Tanzania as a field-level agricultural extension officer (a ‘bwana shamba’) during the periods just before and just after independence from 1961 through 1963.

**California field studies of the drought adaptation of cowpea**

During the summer of 1975, I stayed at Riverside and began studying the responses of cowpea to drought. Kenneth J. Turk* worked with me on this project while studying for his Ph.D. In 1975 we conducted a preliminary field experiment, which indicated that cowpea is a hardy crop.

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* In later years Dr. Turk continued to contribute to agricultural development by working for the Peace Corps and USAID-funded development projects in Belize.
We planned a major experiment for the following summer to study the responses of cowpea to drought under field conditions. The climate of southern California is ideal for field research on drought responses of warm-season crops because it doesn't usually rain in the summer. In this environment, plants can be subjected to different types of soil drought by controlling the timing and amounts of water that are available to the crop using irrigation.

In the late spring of 1976, we planted cowpea seed into a soil profile that we had dried the previous fall and winter by growing a cool-season cereal to maturity with no irrigation and little rain. We used sprinklers to apply a small amount of water to germinate the cowpea crop, then imposed a range of irrigation treatments to simulate several Sahelian rainfall regimes.

We obtained interesting results from one treatment where we had imposed a severe drought consisting of no irrigation after germination for 43 days during a time of very hot weather and no rain. Remember that the soil contained very little water. Typical irrigation experiments for improving California agriculture would not have imposed this severe a treatment because it would have killed virtually all annual crop species. The cowpea plants were badly stunted but most plants survived and, after irrigation was resumed on the 44th day, they rapidly recovered. To our surprise, these plants, though subjected to an extreme drought for most of their vegetative period, produced very high yields of cowpea grain (about 4,000 kg/ha = 3,600 lbs/acre) by 107 days after sowing. A control treatment that had been irrigated every week with an abundant supply of water produced only a similar yield during the same period.

These results demonstrated, for the first time, the tremendous ability of cowpea to recover from a severe vegetative-stage drought. We also learned that cowpea plants subjected to moderate soil drought throughout the growing season could produce as much as 1,000 kg/ha of grain while using only 150 mm of water. In contrast, average yields of cowpea in the Sahelian zone of Senegal during the 1960s with 410 mm of rain had been only 289 kg/ha (Table 1 in Chapter 4).

We now had evidence that new cowpea varieties might provide a partial solution to the Sahelian droughts where rainfall was averaging about 270 mm per cropping season (Figure 3 in Chapter 1). But, our studies also showed that cowpea can be badly damaged by severe droughts if it occurs during either flowering or pod-filling. This meant that developing improved cowpea
production systems for the Sahel would require careful attention to both varietal design and crop management methods.

In the summer of 1977 we repeated the field experiment on cowpea responses to drought at UCR. Field systems are complex with the weather changing from year-to-year, and repeating experiments enables one to test the reliability of any conclusions that are reached. Repeating the experiment was particularly necessary, in this case, because some earlier studies conducted by scientists in England had produced contrasting results. They had studied cowpea grown in pots in a greenhouse and had concluded that cowpea is very sensitive to drought during the vegetative stage. I did not know at that time whether these contrasting results were caused by the different environments or the different cowpea varieties that were used in the research. Subsequent research by other scientists showed that some cowpea varieties are indeed sensitive to vegetative-stage drought.

The cowpea resistance to vegetative-stage drought we observed in 1977 was not as strong as the previous year. Although the cowpea plants survived the extreme drought again during the vegetative stage they produced smaller yields than the control plants that were irrigated weekly. We suspected that higher temperatures and therefore higher evaporative demands during pod-set in 1977, compared with 1976, prevented the plants from completely recovering from the vegetative-stage drought. We also observed that vegetative-stage drought can kill some cowpea plants if the organism causing the ashy stem blight disease or the insect pest lesser corn stalk borer are present in the soil.

However, our subsequent research under field conditions in both California and Senegal has shown that there are many circumstances where our cowpea varieties can survive extreme drought during the vegetative stage and then recover and produce high grain yields.

The use of potted plants probably was responsible for the contrasting cowpea responses to drought observed in England. Through the years I have learned that much of the earlier research on plant responses to drought that had been conducted in greenhouses and other artificial environments did not provide reliable predictions of plant responses in real-world field environments. A major reason for the difference is that plants in artificial environments usually are grown in pots and even
relatively large pots result in a confined root system. Cowpea roots can grow as deep as 2 meters (6 feet) in field conditions. Simulating this condition in a greenhouse would require extremely large pots that would be too heavy to lift by hand.

When plants with a confined root system are subjected to drought they are stressed so rapidly that they have insufficient time to acclimate, meaning their responses can be completely different from plants growing in most natural field environments. For example, I have rarely seen leaves of cowpea wilt under field conditions, instead the leaves become more erect when they experience a slowly imposed but intense drought. Yet, the leaves of cowpea plants grown in small pots readily wilt and hang downward in a limp manner if the plants have not been watered for a few days. Graduate student Kenneth A. Shackel * demonstrated that when cowpea plants are slowly subjected to drought, such as occurs in most field conditions, the leaves not only become more erect but they also move such that they remain perpendicular to the direct beams of solar radiation. The diurnal movement of the leaves minimizes their absorption of solar radiation and thus reduces their tendency to heat up and lose water. This is one of the mechanisms whereby cowpea resists drought during the vegetative stage.

Communication within the plant

There is another reason for the differences in response to drought that can occur between plants in pots and plants in natural soil environments that are stressed more slowly. Plant root systems have mechanisms that sense changes in their root environment and send signals to the shoot system that influence leaf functioning. This process can take a few days, though, which is the reason why plants in pots that have been subjected to rapid changes have been known to respond differently from plants in the soil that have been subjected to slower changes.

* Subsequently, Dr. Shackel became a Professor and member of the Agricultural Experiment Station at the University of California at Davis. He has developed improved methods for irrigating tree crops based on plant-water-relations measurements.
The surfaces of plant leaves have many small valves called stomata that regulate the loss of water vapor from those leaves. It was known for many decades that these stomata can close when plants are subjected to drought. In earlier years, it was thought that this closure resulted from the loss in turgor and wilting of the leaves. Graduate student Loretta M. Bates demonstrated that stomata closed when cowpea plants were subjected to soil drought; even when the leaves neither wilted nor exhibited any detectable changes in bulk leaf water status. We hypothesized that the stomata were closing in response to changes in root water status and the flow of information from roots to leaves which thereby prevented the wilting of the leaves.

More detailed research by other scientists supported this hypothesis and indicated that the changes in information involve changes in amounts of hormones flowing from the roots to the leaves and changes in pH of the xylem sap. The extremely sensitive responses of cowpea stomata to conditions in the root zone provides another mechanism to explain the ability of cowpea to avoid dehydration and thereby resist drought during the vegetative stage.

The new concept that was introduced by this research involving sensitive and sophisticated communications between root systems and shoot systems has general relevance to plant adaptation to various stresses in the root zone because adaptation requires that the responses of the roots and shoot are coordinated. This concept also has led to the development of irrigation systems involving partial root-zone drying that result in more efficient use of irrigation water.

In classes for students, I have taught how plant function may differ from that of humans. While we may be considered as an organism with only one control center, the brain, plants probably have at least two control centers, one at the shoot apex and another in the roots. In well-adapted plants, root and shoot activities and development must be coordinated because root function determines the uptake of water and nutrients by the plant; whereas shoot function determines the rates at which water is lost by transpiration and nutrients are used in the acquisition of carbohydrate, which in turn influences root growth and function. Coordination of root and shoot function and thus plant adaptation would appear to require that there is a sophisticated and effective communication system operating between the different control centers in the shoot and root systems.
Weaknesses in research on tropical crops

Our knowledge of many tropical crops is limited because much earlier research was conducted in technically advanced institutions, which usually are in temperate climates where it is too cold to conduct field research on these crops. Consequently, many studies with tropical crops have been conducted with plants in pots in greenhouses or growth chambers with artificial lighting and have produced results that, in some cases, are not relevant to the natural world.

In addition, many of today’s research institutions show an unfortunate tendency to neglect field research and chase more fashionable avenues of molecular research in laboratories that attract much funding. While molecular research can produce results that are useful for agriculture, a continuum of research is required from the molecular to the field level if reliable useful technology is to be produced.

Many of the younger plant scientists in technologically advanced countries have little experience or appreciation of agriculture and either do not understand the need for field studies or do not have the skills needed to conduct them well. Young plant scientists in technologically advanced countries who are interested in field studies often specialize in working on either natural ecosystems or environmental problems. Many crop science students from developing countries continue to seek advanced degrees in institutions in technologically advanced countries but many of these institutions now are emphasizing molecular research. These developing-country students are not gaining much expertise in agronomic field research. Consequently, the future for field research on crop production is bleak for both technologically advanced and developing countries. Much of the modern genetic engineering of crop plants only will produce useful practical results if it is combined with effective collaborative field research.

Relevance of the research to the Sahel

My subsequent observations of cowpea growing in the Sahel confirmed that some varieties of this crop have similar tremendous resistance to vegetative-stage drought in these tropical conditions as we had observed in subtropical conditions in California. In Senegal there have been several years when droughts occurred just after the beginning of the growing season and had
sufficient severity to kill pearl millet plants. In contrast, cowpea plants growing in the same fields survived these droughts, recovered when the rains returned, and produced substantial yields of grain.

While studying for her Ph.D. degree Claudia L. Petrie conducted basic research to try to explain this difference between cowpea and pearl millet. Based upon her observations, she hypothesized that under prolonged drought pearl millet develops drier tissue than cowpea due to a root system that is less effective at taking up water.\textsuperscript{10,11} This hypothesis may explain why the pearl millet dies. But the surprising feature is that pearl millet has more roots than cowpea, so how could it be less effective at taking up water? In one series of experiments she demonstrated that a severe drought could kill a pearl millet plant even when it was growing in the same pot as a cowpea plant that survived the drought.\textsuperscript{10}

How could one explain these strange results? Based upon theory and computer simulations, Claudia hypothesized that pearl millet is less effective because its roots have a more clumped distribution and these clumps become surrounded by dry soil such that water is taken up only at the root tips.\textsuperscript{12} Cowpea, in contrast, has roots that are more uniformly distributed in the soil. Her simulations predicted that virtually all of its root surface contributes to the uptake of water.

These are the only hypotheses I am aware of for explaining the survival of cowpea under droughts that kill pearl millet, and the hypotheses have not been evaluated by direct experimental tests. In principle, the hypothesis concerning the effectiveness of the different root systems could be tested by comparing the drought resistance of genetic lines of the same species that have different degrees of root zone clumping. But, genetic lines of this type are not yet available. Also, there may be a fundamental flaw in current understanding of plant water relations, such that there also may be another explanation for the enhanced vegetative-stage drought resistance of cowpea compared with pearl millet that involves the shoot not the root system.

Research results of Dr. Bir B. Singh and his colleagues at the International Institute of Tropical Agriculture in Nigeria support the notion that the extreme drought resistance of cowpea may involve shoot traits in that they observed the phenomenon with seedlings growing in trays with shallow layers of soil. They also observed that some varieties of cowpea do not have strong drought resistance during the vegetative stage,\textsuperscript{13} and that the resistance may involve only a single gene.\textsuperscript{14}
These results suggested to me that another approach may be used to discover the mechanism(s) of the vegetative-stage drought resistance of cowpea. If a resistant variety were crossed with a susceptible variety and then backcrossed with the susceptible variety several times while selecting to retain the drought resistance, it should be possible to create a pair of near isogenic lines that have very similar genetic backgrounds but differ with respect to the gene conferring drought resistance. The pair of lines would then be carefully compared to search for differences between them. Any differences in degree of root zone clumping or shoot traits between this pair of lines might reflect the mechanism for the difference in vegetative-stage drought resistance. The results may not be conclusive, however, in that there are many ways in which gene mutations can reduce adaptation.

**Novel solution to root-study difficulties**

Present understanding of the functioning of root systems is constrained by the tendency of most plant scientists to focus on the above-ground parts of plants. Studying roots is difficult because observing them is not easy. Many people think of root systems of annual plants as being shallow but, in 60 days under favorable soil conditions, the root systems of cowpea and pearl millet can grow as deep as two meters (about six feet). Breeding typically requires that hundreds or even thousands of plants be evaluated. Quantifying the distribution of roots in two meter depth of soil of this many plants would be an impossible task. Consequently, there has been little progress in breeding plants with different types of root systems.

During the early 1980s, graduate student Barbara M. Robertson came to see me and said she wanted to develop a system for evaluating roots that could be used in breeding programs. I told her it would be very difficult and tried to discourage her. She persisted in her efforts, however, and developed a system for screening cowpea genotypes for differences in rooting under field conditions that did not require large-scale excavations of soil. In this system, an herbicide is injected deep in the soil using a large tractor pulling a tool bar with a long vertical tine containing a spray nozzle. At the same time, different cowpea genotypes are sown in wide rows at each side of the slot made by the tine and well above the herbicide layer.

Barbara compared contrasting cowpea genotypes using this system. She demonstrated that
some genotypes may have had fast-growing root systems because they were the first to exhibit bright yellow patches in their leaves. Presumably their roots grew faster and came in contact with the herbicide sooner than the other genotypes. Subsequently, she demonstrated in a test with another set of plants that the cowpea genotypes which had exhibited early herbicide symptoms did indeed have the ability to extract more water from deep in the soil profile. This test provided convincing evidence that some genotypes have the ability to develop deeper more effective roots than other genotypes. In subsequent years, Jean-Luc B. Khalfaoui used our herbicide system while working in Senegal and discovered differences in rooting among varieties of peanut.\textsuperscript{16}

The herbicide screening system that we developed might be useful for selecting varieties that have enhanced ability to extract water from the soil profile and thus increased resistance to drought where water is available deep in the soil. We tried to breed cowpea with improved adaptation to drought using this technique. We chose a cowpea parent that developed deep roots and crossed it with another cowpea genotype that was well adapted to drought but had shallower roots.\textsuperscript{17} We bred hundreds of genetically stable progeny. We had to use genetically stable lines because plants detected by the herbicide screening system are killed and it is necessary to use seed of the same lines to create additional plants of the same genotype for further studies. We then screened the genetically stable lines to indirectly select ones with deep rooting using the herbicide technique under field conditions.

As a project for his M.S. degree, Etsuo Yamamoto measured the yields and agronomic attributes of the selected lines and parental cowpeas under a drought imposed by growth on moisture stored deep in the soil. Unfortunately, we were unlucky in the choice of parents in that, due to unanticipated genetic interactions, virtually all of the progeny had weak stems and gave low grain yields. I believe the technology and approach were sound, but that we had not made enough crosses and devoted enough effort and resources to make it work. Also, I had concluded by this time that breeding cowpea varieties that developed deeper root systems may not confer a significant gain in drought adaptation in the Sahel. Much of the soil is so sandy that the water-holding capacity is small such that an increment of additional root growth only would result in only a small increase in water supply to the plant in this type of soil.
Two new projects in the Sahel

When Dr. Cannell and the University of California team returned from the Sahel in the fall of 1975 they recommended two future projects for MUSAT. One involved collaborating with scientists in Senegal to quantify crop responses to drought in relation to past and present rainfall regimes. Scientists in Senegal had been quantifying crop responses to drought using mechanical calculators to estimate water balance in the soil based on a knowledge of rainfall, atmospheric conditions, crop water use, and soil physical properties. The team thought this approach was theoretically sound but might be enhanced by using a computerized mathematical model.

I agreed to tackle this project, during 1975 I had taken advantage of increases in computer capabilities and already had begun developing a mathematical model of crop responses to water supply and drought. I suspect that the experienced scientists who reviewed our project then were skeptical that this modeling would be of any use in feeding people in the Sahel. They probably thought it was a typical ‘ivory tower’ response of professors to real-world problems that remains in libraries and collects dust. But, as I will describe later in this chapter, the model was of some practical value.

The second MUSAT project involved a comparative study of traditional farming systems in northern Yatenga in Burkina Faso. This area represents a transition between the Sahelian zone and the wetter Savanna zone to the south. Earlier we had decided that prior to making any recommendations concerning ‘improvements’ to traditional farming systems we should develop a more complete understanding of the traditional systems to ensure that any changes we recommended would not be harmful. Robert E. Ford * undertook this second project while studying for his Ph.D. in geography.

* Dr. Ford continued to contribute to international development returning to the Yatenga region of Burkina Faso in 1991-1992 and subsequently, working for USAID and then as a Professor at Loma Linda University in southern California.
We thought Bob would take a broader approach than a conventional agronomy student and be able to learn not only what farmers were doing but also why they were doing it in these ways. I agreed to visit Bob while he was conducting research in Burkina Faso to advise him on agronomic issues.

His dissertation provides a comprehensive description and analysis of the climate, soils, people, and farming systems in northern Yatenga. He examined farming systems using a ‘cultural ecology’ approach that attempts to provide farmer and herder perspectives of these systems. He made some perceptive analyses of different facets of these systems. His dissertation provides a uniquely important contribution to understanding the nature and reasons behind traditional farming practices used in the Sahelian and adjacent wetter Savanna zones. His dissertation contains many important detailed descriptions based on direct observations that he made while working in northern Yatenga during an 18-month period in 1976–1978.

In a final chapter, Dr. Ford provides important general recommendations that are relevant to agricultural development in the Sahel. For example, he recommends that farmers and especially women be consulted and involved, beginning in the early stages, in the development of improved agricultural practices. Refer to the chapter 6 on “On-Farm Experiments and Progress for Women in Africa” for a discussion of this important issue.

My first visit to Senegal

In the fall of 1976 I left Riverside and traveled to the Centre National de Recherches Agronomiques (CNRA) which is near the small town of Bambey in Senegal (Figure 2 in Chapter 1). This is a major field crops research station of the national agricultural research program of Senegal (L’Institut Sénégalais de Recherches Agricoles i.e. ISRA), which had been established two years earlier.

For my modeling I needed computing capabilities, so I carried an expensive programmable calculator in my suitcase (a Hewlett Packard HP-9825A which cost about $6,000 in 1976). I considered it the best ‘small portable computer’ available at that time and it only weighed 12 kg (about 26 lb). It had a powerful new programming language, HPL, which I found to be more
convenient than the Fortran language I had used in earlier years. It only had about 24 kilobytes of random access memory and no hard drive; but it had a cassette tape system that could store 250 kilobytes of information, and a built-in strip-type thermal printer.

Obviously this portable calculator had much less capabilities than personal computers made some 10 years later, but it did have similar computing capabilities as the large main-frame computer I had used while studying for my Ph.D. in the 1960s. I had no problems running my mathematical models on the HP-9825A because I knew how to make efficient use of slow computers with small memories. Anticipating problems with electrical supplies, I took with me a voltage transformer, a panel meter to monitor voltage and a small multitester. A voltage regulator would have been easier to use, but available models were too heavy to carry in my suitcase.

When I arrived in the airport at Dakar, Senegal, there was considerable confusion; the people who were supposed to meet me never arrived. A customs official wanted to know what the expensive looking equipment was and proposed that I should pay customs duties on it. I did not have sufficient funds to pay several thousand dollars in custom duties. I explained that the equipment was a calculator for my studies with Senegalese scientists. After a series of discussions the official became sympathetic to my situation and let me pass through with the ‘calculator.’ These exchanges took place in French, a language in which I was not fluent, which made the problem more difficult.

I was now in the lobby of the airport with several heavy suitcases and no idea how I was going to get to the agricultural research station where I was supposed to work. Fortunately, I initiated a discussion with a Frenchman and discovered he was an agroclimatologist at the CNRA station. Claude Dancette was employed by the French Institut de Recherches en Agronomie Tropicale (IRAT). He was based at CNRA, Bambey, and had worked in Senegal for many years. During my seven-week visit and in subsequent years when I returned to Senegal and when he visited UCR to conduct collaborative research, I learned much from him about the droughts in the Sahel and possible agronomic solutions to the problems caused by the droughts.20

On a subsequent visit to Senegal, Claude and I made a memorable journey with a Senegalese colleague who was in charge of the small ISRA research station at Louga, Moustapha Diop. We traveled on camels into the sandy wastelands of northern Senegal. The camels were difficult to ride
because they had single humps. They are the dromedary camel species as distinct from bactrian camels that have two humps. Their ‘saddles’ consisted of a gunny sack placed over the hump with a piece of rope tied around the sack and the stomach of the camel to provide a crude handle. In earlier years the camels had been used to transport salt.

I soon learned the difference between a ‘good’ and a ‘bad’ riding camel. The ‘bad’ camel that had been allocated to me was difficult to control and charged under acacia trees, trying to use the thorn laden branches as a broom to sweep me off its back. I had to hold the rope tightly and lay along the side of the camels hump to avoid the long sharp thorns of the acacia. The ‘bad’ camel also would then reach back and attempt to bite me.

This was the first time that I had ridden on a camel, and I suggested to Claude that someone with more experience should ride this particular camel. Moustapha gave me his camel, which was a docile creature and a pleasure to ride, and he had no difficulty controlling the ‘bad’ camel. Crossing the dunes on the back of a swaying camel made me think of stories I had read about the Arabian deserts. In the evening we slept in the dunes. The following morning a French military plane came in low out of the sun and I worried we might be mistaken for Polisario rebels and be strafed. The pilot must have been satisfied by our non-military appearance because the plane did not fire its guns and did not return.

On the occasion in 1976, Claude Dancette had come to the Dakar airport to pick up a friend and offered to take me to the CNRA station, which is about one to two hours drive inland to the east of Dakar depending on road conditions (Figure 2 in Chapter 1). We put my calculator, transformer and suitcase and the suitcase of his friend into Claude’s Volkswagen ‘bug’ and then the three of us squeezed into the remaining small spaces. Before going to the station we went to the beach and had a swim and a pleasant lunch by the ocean with an excellent bottle of chilled rosé wine that had been imported from Morocco.

What is the climate of the Sahel?

On arriving at the station I began my research by examining the rainfall that had occurred in Senegal in earlier years. CNRA had been a major research center of French West Africa from the
beginning of the 20th Century up to 1958, and a comprehensive set of rainfall data was available. I soon confronted a key question that has not yet been answered. What is the climate of the Sahel?

Climate is average weather, and rainfall is a key element of the weather in the Sahel. For the 50 years prior to 1968, the average annual rainfall in the Sahelian town of Louga in northern Senegal had been 442 mm but during the last seven years of 1970 through 1976 it had been only 283 mm (Figure 3 in Chapter 1). A knowledge of future rainfall is critical for predicting the types of agricultural systems that will be successful. Studies by Claude Dancette had shown that an average annual rainfall of 442 mm could provide enough water for a 90-day growing season in northern Senegal. He had demonstrated that this level of rainfall would permit current varieties of pearl millet, peanut, and cowpea to produce some food for people, in most years, and a dependable supply of forage for livestock. His studies also predicted that with an average rainfall of only 283 mm, none of the varieties currently available to farmers would produce much grain for food. The key question, though, was “Would the future average rainfall in Louga (and the Sahel) be 283 mm or 442 mm or something else?”

Studies by other scientists in the 1960s had shown that weather systems can be ‘chaotic’. To me this indicates that certain aspects of climate, which is average weather, may change with time in an abrupt manner. The rainfall data for Louga (Figure 3 in Chapter 1) does appear to have varied abruptly, as if being around one ‘strange attractor’ (i.e. average value) from 1918 through 1967 and then another substantially different ‘strange attractor’ for the period from 1968 through 1998.

This is pure speculation on my part because I do not have a deep understanding of this complex subject. An introductory discussion of the scientific bases of the terms ‘chaos’ and ‘strange attractor’ is presented in the book by James Gleick. This is an excellent book for people who have a broad interest in the physical and natural sciences. It is the only book that I really couldn’t put down once I started reading it. I was on a long airplane journey and I read it from the first page to the last, and then started over at the first page and began reading it again. A flight attendant noticed that I was engrossed in the book and asked me what I thought about it. She said that she had enjoyed reading it. I told her that I also enjoyed reading it because in earlier years I had been captivated by turbulence in water. I had studied fluid mechanics as a student of irrigation science and I also had
made many observations of turbulence while trout fishing in streams in the Sierra Nevada mountains. Once you know the location of trout, you can use turbulence to present a fly or bait to them with optimal speed and direction such that they are encouraged to strike. The lure must move towards the head of the trout, which will be facing into the current, and be neither too fast nor too slow.

The scientific basis of ‘chaos’ had been developed while I was in the early years of my scientific career and had pointed to the existence of emergent properties in complex systems. Emergent properties are those properties of higher level systems that cannot be predicted solely from the properties of lower level systems but depend also on the macro structure of the system. The existence of emergent properties means that reductionist studies of events at the molecular and cellular levels cannot by themselves adequately explain the functioning of whole plant or human systems. Some examples of emergent properties in plant systems are provided in the book I wrote on “Crop Responses to Environment”.

There are alternatives to chaos for explaining the Sahelian rainfall patterns and droughts that occurred in the 20th Century. Average rainfall may change progressively due to progressive changes in local large-scale features, such as the changes in solar reflectance from the earth’s surface that would have resulted from the desertification that had occurred in the Sahel. But the rainfall at Louga did not appear to have changed progressively during the 20th Century (Figure 3 in Chapter 1).

Other scientists have proposed that increases in solar reflection from skies over Europe, due to increased atmospheric pollution, may have caused the increases in rainfall in Europe and decreases in rainfall in the Sahel that occurred during about the same period of years.

Another possible explanation is that the changes in rainfall in the Sahel may represent the beginning of major changes in global climate. In the twentieth century increases in atmospheric carbon dioxide concentration occurred mainly due to combustion of fossil fuels, which influence the long-wave radiation exchange between the earth and space, causing increases in temperature of the earth and changes in rainfall patterns. Despite such potential long-term changes, climates have proved to be sufficiently stable to be useful in guiding agricultural research for many parts of the world in the past. Clearly this has not been true for the Sahel for much of the twentieth century and may not be true for other parts of the world in the next century.
Developing a strategy for enhancing crop productivity

In developing a strategy for enhancing crop productivity, I assumed, in 1976, that the future rainfall in the Sahel would be between 200 and 400 mm. My justifications were that if the rains were greater than 400 mm the farmers could use their traditional crops and would have less need for new varieties and systems, and if the rains were less than 200 mm, cultivation of rainfed crops may not be possible. By chance my assumption was valid for 1976 through 1998 (Figure 3 in Chapter 1).

But what is the significance of these amounts of rainfall for the types of crops that can be grown successfully? For the 50 years prior to 1968 the average rainfall of 442 mm had been sufficient to meet the complete needs of a 90-day annual crop sown in mid July and harvested in mid October (Figure 4). Note that the average sowing date for cowpea can be estimated as the date when average rainfall per day reaches about 0.4 times the average potential evapotranspiration rate. The potential evapotranspiration rate provides an estimate of the maximum water needs of a crop that is growing actively and completely covering the ground. In late August, when a well-managed 90-day crop that was sown in mid July would be actively growing and completely covering the ground, average rainfall per day for the period from 1918 through 1967 was similar to the potential evapotranspiration rate (Figure 4). In contrast, for the period from 1968 through 1998 the average rainfall was only 276 mm, which would have only provided about two thirds of the water required by a well-watered crop that was sown in late July, had a very short growth cycle, and was harvested in late September (Figure 4).

Could any type of crop variety be successful with only 200 mm of rain occurring during a short growing season with very hot temperatures in a sandy soil that is dry at the beginning of the rainy season? When saturated with rain this Sahelian sandy soil retains only about 8% moisture on a volumetric basis. Moreover, about 3% of this water is not available to plants, even with extreme drought. In contrast, loamy soil found in other parts of the world, such as the valleys of California, can retain and provide plants with about three times as much water.
At that time I asked myself the question posed in the previous paragraph there were no crop varieties that had been shown, anywhere in the world, to consistently produce significant amounts of human food under these droughty Sahelian conditions. Claude Dancette had estimated that an average rainfall of 300 mm might support a crop of pearl millet for 60 days, but no varieties of pearl millet were available that could complete their life cycle in only 60 days.
I used a computerized simulation model to predict the performance of cowpea and estimated that a cowpea crop that began flowering about 30 days from sowing might produce 1,000 kg/ha of dry grain within 60 days from sowing with only 200 mm of rain. Unfortunately, no cowpea varieties were available in Senegal or anywhere else in the world that could begin flowering as soon as 30 days from sowing. Also, cowpea was a minor crop in Senegal at this time.

Some traditional cowpea landraces grown by Sahelian farmers are sensitive to day length and began flowering in response to the shortening days in late September. Cowpea are sown just after the beginning of the rainy season which due to the drought was occurring in late July to early August. When sown at that time, local landraces of cowpea required a growing season of 55 to 60 days just to begin producing flowers and an additional 30 days to produce useful quantities of grain. The seasonal rainfall that was occurring could not support crops with growth cycles of 85 to 90 days; consequently, these landraces were producing very little grain.

A few landraces of cowpea grown in the Sahelian zone of Senegal, such as ‘58-57’, were not strongly sensitive to day length and when sown in late July matured in about 75 days from sowing and produced significant amounts of dry grain during some of the dry years. These shorter-cycle-length landraces had greater ability to escape late-season drought than the ones with extreme sensitivity to day length for the initiation of flowers.

The best varieties of pearl millet and peanut that were available for the Sahelian zone of Senegal in 1976 required a long growing season of about 90 days to produce significant quantities of grain. During the dry years these pearl millet and peanut varieties had failed, and most of the cowpea landraces had not produced many pods or grain and mainly had produced only hay for livestock feed.

**Perhaps a variety that would work**

Some cowpea varieties and breeding lines had been selected and bred by a Senegalese scientist, Djibril Sène, during the 1960s and early 1970s that began flowering in 36 to 45 days and produce a grain harvest in 66 to 75 days. I thought these varieties and breeding lines might be more effective than the local landraces, but they had not been fully tested on farmers fields, and had not
been extended to many farmers.

Thus, a possible partial agronomic solution to the droughts occurring in northern Senegal (and the Sahel as a whole) had become apparent but its implementation would involve several phases. First, the available short-cycle varieties, such as those developed by Djibril Sène, and local landraces of cowpea would need to be evaluated under experiment station and farm conditions. Any varieties or landraces that produced significant grain with only 200 to 400 mm of rain and were acceptable to farmers should be distributed to them together with information on appropriate methods for their cultivation.

Second, an attempt should be made to breed better cowpea varieties. This might be accomplished by breeding cowpeas that begin flowering earlier than the available varieties and landraces, and are well-adapted to harsh conditions. This would include incorporating the resistance to vegetative-stage drought we had discovered in the California variety, and resistances to heat and various pests and diseases.

To be very early, the plants must produce their first flowers on low nodes on the main stem and on the first nodes on the branches, which meant they would have to be erect and not spreading like the landraces. This also meant that the new varieties might require different management methods, such as closer plant spacing than the landraces. In the 1970s, most cowpeas were sown at a very wide spacing in Senegal of about 1 m by 1 m (39 inches by 39 inches). Additional improved methods of farm management might also be needed to more fully exploit the new cowpea varieties.

There was a potential major advantage of growing cowpea in the Sahel, compared with the wetter Savanna zones to the south. While visiting farmers’ fields, I had gained the impression that there may be few insect pests of cowpea in the Sahelian zone of Senegal. This impression was shown to be valid by subsequent field experiments with cowpea growing in the drier part of the Sahel. Often there were only small differences in yield for treatments with and without applications of insecticides. Insect pests still are the major problem for cowpea grown in the wetter Savanna zones where the crop often produces virtually no grain unless insecticides are applied.

Developing improved cowpea production systems for the Sahel would require teams of
research and extension scientists. Yet, in the late 1970s, the Senegalese government had virtually no scientists working to a significant extent on cowpea, and the extension service had few trained people or resources.

**Agricultural development should be done by local scientists**

In earlier years through about the 1990s, the approach often used by international development organizations to solve a problem of this type was to send in a team of ‘experts’ from other countries and continents. However, many agricultural development projects conducted in this way in Africa since the Second World War have been abysmal failures. The groundnut (peanut) scheme conducted by the British in the 1950s in an African country that at that time was called Tanganyika is a good example of a project that failed. So, too, did many projects conducted by the French in West Africa.\(^7\) Chap. 1

So I rejected this approach, even though I had worked as an expatriate in Tanganyika. I decided that the long-term development of African agriculture had to be done mainly by local African scientists. Either they would do it or it would not be done effectively.

Outsiders have been, and continue to be, useful in Africa as healers of the sick when no other doctors are available, by helping when catastrophes occur, or by providing a needed skill to accomplish a short-term goal. Plant breeding and agricultural extension, however, require a long-term commitment and deep knowledge of local conditions.

Outsiders typically take the first year to adjust to and learn about local conditions in the region, begin to establish a program in the second year, and may be just beginning to make real progress when they leave. This is a major problem for plant breeding where it can take many years to develop and release an improved variety, since newly hired plant breeders rarely continue the program established by their predecessors. Different breeders usually have different ideas about the most effective approaches, since for much of the twentieth century breeding has been an art as well as a science, and thus new breeders usually made changes to breeding programs. Thus, much of the earlier breeding efforts were wasted.

Hiring expatriates to conduct development projects is expensive and has psychological
costs. In the 1980s it could cost about $100,000 per year to pay the salary, benefits and grant-overhead costs of one experienced scientist from another continent working in Africa. Additional funds were needed for travel and research expenses. The same total amount of funds could have completely paid for the salaries and research of a team of local African scientists.

In the 1980s and 1990s experienced local scientists, who often were earning a salary of less than $5,000 per year, probably felt mistreated when they were working with foreign scientists who did not even have a deep understanding of local agriculture, yet were earning several times more salary. In more recent years, this problem has become even more pronounced in that African scientists and expatriates, who have obtained their doctoral degrees at equally reputable institutions in technologically advanced countries are now working together with similar job responsibilities on the same projects in developing countries but at radically different salaries.

I believed a new approach was needed in which Senegalese personnel would be provided with the training and resources for developing the improved cropping systems. The task was complex because of the recent history of Senegal. Earlier agricultural research had been conducted mainly by scientists working for IRAT and some other French organizations. Since the establishment of the Senegal national agricultural research program (ISRA) in 1974, France had begun reducing its contributions of funds and scientific personnel to Senegal. A cowpea research program that had been initiated in Senegal in the 1950s by organizations supported by France had been discontinued in 1974.

Some Senegalese scientists were available who had been educated in France and other countries. But there was a need for administrators, and they were assigned to that task, which left few Senegalese scientists to do the required field research. Further, high school education in Senegal was in French, and prior to the late 1980s there were no university programs in Senegal that provided the equivalent of either bachelor of sciences or graduate degrees in agricultural sciences. Consequently, Senegalese studying the agricultural sciences were required to go outside the country to obtain their bachelors and graduate degrees. In many cases they had to study in a language different from the one they used in high school.

Many African students followed difficult paths in achieving their education. For example,
a Senegalese student who contributed to our project learned local languages, studied at high school in French, and then studied for a bachelor’s degree in another language in eastern Europe and for masters and doctoral degrees in English at two different universities in the U.S. A Sudanese student who contributed to this project also had a complex educational path, learning local languages, Arabic, and English, and then studying for a degree in another language in eastern Europe and for additional graduate degrees in the United States.

Fully appreciating what professors are trying to communicate requires that students be not only fluent in the language of the university but also have some understanding of the cultures of the societies that influenced the education of their professors. Studying under the guidance of professors in both eastern Europe and the United States would have been a broadening experience, but it also would have imposed some extra challenges not experienced by domestic students in the United States. African students studying abroad also have to re-analyze the concepts and methods they are learning to determine what can be usefully applied when they return home.

**Seeking a better way**

The new approach I was seeking also required the development of more effective ways for using modern technology in Africa. It is not sufficient to simply teach African students some modern methods and then expect them to apply them when they return home. Applying new methods requires research facilities, equipment, and supplies that often are not available in Africa. As an example, I had to take special precautions while working at CNRA, Bambey with the portable ‘computer’ in 1976. I would continuously monitor the line voltage and switch off if the voltage became too low because of potential damage to the equipment. And I had to switch off several times every day! The electrical supply was still bad at CNRA, Bambey in the 1990s, the only difference was that most of the computers now had voltage regulators and automatic battery-based back-up systems.

Many research stations I have visited in Sub-Saharan Africa have unreliable electrical supply systems and it can be very expensive to install voltage regulators and back-up systems for all of the scientific equipment needed in a modern laboratory. Modern molecular laboratories also
require sophisticated chemicals. It can be difficult to obtain these chemical supplies in many parts of Africa. Some chemicals used in research must be handled carefully. The roof of one of the laboratories at CNRA, Bambey had been blown off due to an unplanned chemical explosion in earlier years. I tended to avoid this particular laboratory while working there.

Also, ‘new’ scientific methods continue to evolve and if they are to be effectively used, scientists must have the opportunity to exchange information and learn about further new developments. These exchanges of information typically occur at conferences that usually were held in technologically advanced countries. Many African countries did not have the resources to send their scientists to these conferences. Some of these problems might be solved if there was more effective collaboration between scientists working in Africa and scientists working in the US and elsewhere.

**Importance of crop germ plasm collections**

There are some special advantages for cowpea scientists in technologically advanced countries from collaborating with African scientists. The botanical species to which cowpea belongs, *Vigna unguiculata*, probably originated in southeastern Africa, since many related wild species occur in this region. The further domestication of cowpea took place in the Savanna zones of West Africa, where many wild cowpea varieties and related sub-species can be found. Consequently, the African continent provides a unique resource of domesticated and wild cowpea germ plasm and related species that contain important genes.

Crop germ plasm collections are fundamentally important for plant breeding programs and have inestimable long-term value for humanity. The headquarters of the International Institute of Tropical Agriculture (IITA) that has international responsibility for research on cowpea improvement is located in Ibadan, Nigeria. IITA had about 12,000 cowpea accessions in the 1980s, the largest collection of cowpea germ plasm in the world. In contrast, the cowpea germ plasm collection of the United States Department of Agriculture (USDA) was small in 1974 with about 2,000 accessions.

During my visits to Africa and with the help of colleagues, I obtained cowpea germ plasm
from IITA, other organizations and farmers fields, and multiplied and characterized them at UCR and then sent the seed and data to USDA. The accessions are relatively homozygous genetically and self pollinated; consequently, they can be readily multiplied in either field or greenhouse conditions. When importing cowpea seed into California from other countries, and other states in the United States, we first grew the plants in a greenhouse and checked them to try to make sure they had no seed-borne diseases prior to taking seed from the greenhouse-grown plants and sowing them in fields. Cowpea is subject to many seed-borne viral and bacterial diseases. Transmission of these diseases between continents and countries is a major problem that can be minimized by first growing plants from imported seed in glasshouses or if in the tropics in screenhouses, and then carefully examining them for the presence of diseases. Plants with disease symptoms should be destroyed (if they have no value for plant pathology studies). Seeds from plants that do not show disease symptoms can be considered fairly healthy such that they may now be planted in field conditions to produce seed for storage in collections and for research. Care must be exercised, however, in that some plants can be diseased and not exhibit obvious symptoms and must be tested by laboratory methods that detect viruses.

Largely due to the multiplication and collection activities of our collaborative projects, the cowpea germ plasm collection of the United States Department of Agriculture (USDA) had been increased three fold and had about 6,000 accessions by the late 1990s.

In recent years some people have objected to collection activities of this type they say we are ‘stealing’ the natural resources of other countries. It should be noted that I always have obtained permission from the various institutions and governments when obtaining or collecting cowpea seed. I also consider this type of collection to be beneficial to everyone. I will provide an example of where my collection was beneficial to my colleagues in Senegal. They had requested that I multiply seed from their collection and provide them to USDA, which I did. Several years later the compressor broke down in the cold seed store at CNRA, Bambey. Seeds of some of the local landraces were destroyed by the warm wet conditions that developed in the seed store. ISRA requested replacements for this seed from UCR, and I was able to provide them. Seeds of cowpea accessions in the UCR and USDA germplasm collections are available to all scientists who request
them. Over the many years of this project we have provided thousands of seed samples to many scientists throughout the world.

Another advantage from collaboration arises from the fact that substantial research on cowpea has been conducted by IITA and some of the national research programs in Africa, and there is a storehouse of knowledge in Africa that can benefit scientists from technologically advanced countries. Much of this knowledge rarely reaches libraries outside of the continent but can be accessed by collaborating scientists.

Prior to leaving Senegal in the fall of 1976, I discussed with ISRA administrators the value of establishing a national research program on cowpea. The objective was to develop a partial agronomic solution to the droughts occurring in the Sahel. They agreed with the suggestion and proposed that we (ISRA and UCR) should collaborate to develop a national cowpea team and research program for Senegal. But, to do this in a comprehensive manner we needed to find additional sources of funding. The USAID institutional development grant to UCR was ending in 1979, and it was not designed to provide direct support for national programs in Africa. The only direct support provided to ISRA by this USAID project, was the portable computer and transformer that I left at CNRA, Bambey. During my visit in 1976, I had trained all of the interested CNRA scientists and staff how to program the computer and/or use hard-wired programs to conduct statistical analyses of data sets. It seemed appropriate to leave the computer with them.

My first visits to Burkina Faso and Nigeria

After leaving Senegal, I traveled to Burkina Faso (it was called Upper Volta in 1976) to provide agronomic advice and administrative assistance to UCR graduate student, Robert E. Ford. He was conducting comparative analyses of traditional systems of agriculture in northern Yatenga, an area representing a transition between the Sahelian and wetter Savanna zones.

From his base in the town of Ouahigouya, Bob mainly was conducting a comparative study of farming practices in two contrasting villages. The village of Toulfe is an isolated, traditional settlement with different types of soil including some productive soil that contains a moderate amount of clay. Toulfe is inhabited mainly by sedentary Kurumba farmers who interact with semi-
nomadic Fulani when they bring their herds south at the beginning of the dry season. The other village he studied is Banh which is located on an ancient fixed sand dune system and most of the land area is very sandy. This settlement is dominated by Fulani who mainly are semi-nomadic herders. Crop cultivation mainly is practiced by the Riimaaybe, a caste that originated as slaves of the Fulani, and some Dogon farmers. The long-term average annual rainfall in both villages had been about 600 mm. This region had been affected by the Sahelian droughts, however, and from 1968 through 1976 the annual rainfall had been much less than 600 mm.

Robert Ford had come to the conclusion that the farms of the Kurumba in Toulfe were much more productive than the farms of the Riimaaybe in Banh and I had the same impression. The comprehensive analysis of Robert Ford provides possible explanations for this difference in productivity.18

I then traveled to IITA in Nigeria to learn as much as I could about the research that had been conducted on cowpea at this major scientific institution. The IITA was the only international center in the world that specialized on cowpea. Unfortunately, much of the research that had been conducted by IITA since it started work on cowpea in 1970 was not of much relevance to the Sahel; even though it had much relevance to the wetter Savanna and Forest zones. Prior to 1976, cowpea research at IITA mainly had been conducted at Ibadan, Nigeria which has substantial rainfall and is not in a major cowpea production zone. The IITA had done little research either on cowpea in the Sahelian zone or on the breeding of cowpeas that flowered very early.

I suggested to IITA administrators that they should move the main center of their cowpea research program further north to a part of Africa where large areas of cowpea are grown. Some of the IITA administrators appeared to be extremely unhappy either with my proposal or the fact that I had the temerity to criticize their current operation. However, thirteen years later, IITA did establish a sub-station for their main cowpea breeding program at Kano in a major cowpea production region. Kano is in the Sudanian Savanna zone of northern Nigeria which is next to the southern boundary of the Sahelian zone in Niger. Cowpea breeder Dr. Bir B. Singh was in-charge of this station for many years and conducted a very effective research program that produced many breeding lines that have been very useful for national breeding programs in West Africa and some
other regions of the world including California. He bred cowpea varieties that have been adopted by many farmers in Africa and elsewhere.\textsuperscript{3} From about 1990 until my retirement in 2003, I was fortunate to be able to collaborate with Dr. B. B. Singh in research and reviewing the literature.\textsuperscript{3}

In 1976 I obtained a set of cowpea accessions from IITA: including two accessions that my subsequent research showed to have valuable genes for heat tolerance during flowering and pod set. This research is described in chapter 7 on “Improved Cowpea Production Systems for the Sahel and California”.

On leaving IITA, I went to the University of Würzburg in Germany to consult with colleagues, Professor Otto L. Lange and Dr. E. Detlef Schulze. In 1974, I had worked with Otto and Detlef at Würzburg and participated in an international symposium on “Water and Plant Life” where there was much discussion of plant adaptation to drought in natural environments. Otto and Detlef had studied plant adaptation in the Negev, Sahara and Namibian deserts. Traveling from the hot conditions of tropical Africa to the freezing conditions heralding the beginning of winter in Germany was a challenge that I met by using a set of thermal underwear with my tropical gear on top, a bizarre but effective combination. I then returned to UCR and initiated a project breeding cowpea varieties for the Sahel.

**Breeding a new type of cowpea variety for the Sahel**

In preparation for the potential new project in Africa, I decided to try to breed a new type of cowpea variety that would begin flowering within about 30 days from sowing and produce a harvest of grain within 60 days under the climatic conditions of the Sahel. I will describe this process in some detail to illustrate the effort and time involved in plant breeding.

While in Senegal in 1976 I had obtained seed of cowpea breeding lines developed by the Senegalese plant breeder, Djibril Sène. Cowpea is highly self-pollinated and the varieties were genetically stable. I grew these breeding lines in a field at Riverside during the summer of 1977 and selected one, ‘Bambey 23’. It had an erect habit and flowered early and had desirable agronomic and grain characteristics. In Senegal, this variety begins flowering 36 days after sowing which is not as early as was needed. I also selected the earliest California cowpea variety,
‘California Blackeye 5’ (‘CB5’). It had similar earliness and erectness as ‘Bambey 23’, similar type of grain that was acceptable to consumers in Africa, and had exhibited strong resistance to vegetative-stage drought in our earlier field studies in California.\textsuperscript{6}

In the summer of 1977, graduate student Kenneth A. Shackel cross-pollinated ‘CB5’ with ‘Bambey 23’ and planted the hybrid seed in a glasshouse and produced seed of the first segregating generation. He took 585 of these seed and grew the plants with self pollination for two more generations in a glasshouse producing families that were more uniform and more stable than the original families. In the summer of 1978, we planted these 585 families in a field at UCR together with the parents. I selected plants from 23 of the families. The selected plants began flowering a few days earlier than either ‘Bambey 23’ or ‘CB5’, were erect and productive, and had grain characteristics that would be appreciated by consumers. Subsequently, graduate student David A. Grantz\textsuperscript{*} showed that genotypes which flowered just a few days earlier can have substantially greater grain yield when grown under terminal drought.\textsuperscript{22}

I grew replicated plots of these breeding lines under field conditions at UCR with complete irrigation in 1979, and with complete irrigation and severe drought in two field experiments in both 1980 and 1981. I selected lines with consistently high yields under both irrigated and dry conditions. I also sent seed to Senegal and the selected lines were tested under rainfed conditions in the Sahel at Bambey from 1980 through 1983, and at Louga from 1981 through 1983. The tests were conducted by the first Senegalese scientist to make major contributions to the collaborative ISRA/UCR project, Samba Thiaw\textsuperscript{**} who worked closely with the head of the small ISRA research station at Louga, Moustapha Diop.

\textsuperscript{*} Subsequently, Dr. Grantz worked as a scientist for the California Agricultural Experiment Station and became the Director of the Kearney Agricultural Center of the University of California.

\textsuperscript{**} Samba Thiaw had recently graduated from a two-year agricultural college in Senegal. In subsequent years he obtained BS and MS degrees from UCR and in winter 2003 he completed his Ph.D. at UCR.
Some of the cowpea lines I had bred were more productive under very dry conditions in Senegal than all other available cowpea varieties or breeding lines. For example, in 1982 at Louga with only 181 mm of rain, UCR line ‘1-12-3’ produced 1091 kg/ha of dry grain in only 55 days from sowing. In contrast, a set of local landraces had only just begun flowering at this time and produced virtually no grain due to terminal drought. But, the UCR lines were not released as new varieties for use by farmers in Senegal because of a particular set of circumstances that are described in chapter 4 on “Operation Cowpea” in Senegal: 1984 - 1986.

Based upon the results obtained in UCR and Senegal, seed of selected lines was sent to the Sudan at the request of Dr. Dafalla Ahmed Dafalla, the Director of the USAID-funded Western Sudan Agricultural Research Project. In the early 1980s, Dr. Dafalla had visited my research project at UCR while visiting Sudanese scientists who were studying in the United States. During the 1970s and 1980s many Sudanese scientists studied at UCR. During my career I have been privileged to guide seven Sudanese graduate students.

Starting in 1983, field tests were conducted in the Sahelian zone in northern Kordofan near El Obeid, in which my lines were compared with local Sudanese landraces of cowpea. In 1984, I visited Sudan and developed a plan for improving cowpea production in the Sahelian zone of the Sudan. This visit is described in the next chapter on “Project Initiation in Senegal and Sudan: 1980 - 1984.” After the visit my cowpea lines were evaluated for many years on experiment stations and in farm conditions, by a Sudanese scientist who had recently obtained a Ph.D. under my guidance, Dr. Hassan Elawad. In the 1990s, one of the lines, ‘1-12-3’, was provided to many Sudanese farmers. This line was officially released as the variety ‘Ein El Gazal’ by the Government of the Sudan in 2000.
Developing ‘Ein El Gazal’ took a concerted effort by a group of cooperating scientists working over a period of about 20 years. Our development of additional cowpea varieties for the Sahelian zone did not take this many years and involved making crosses and selections in Africa. The importance of these short-cycle 55- to 60-day cowpea varieties with vegetative-stage drought resistance is that in very droughty years in the Sahel these are the only crops that have produced significant food for people. Pearl millet, sorghum, peanut and traditional long cycle cowpea varieties have failed to produce food and no other crops are known that can produce food in these harsh conditions. Further discussions of this research and the extension of the new varieties to farmers are presented in chapter 8 on "Diffusion of Technology in the Sahel: 1992 - 2001".

Search for funding to support an ISRA/UCR cowpea project

After my visit to Senegal in 1976, I began searching for grant funds to support a cowpea research and training program for ISRA, Senegal with a complementary collaborative research program in California at UCR. A meeting was arranged in Dakar, Senegal in 1978 in which representatives from ISRA and UCR discussed the need and value of a collaborative project with various donor agencies.

Another agricultural university from the US, which is very aggressive in seeking funding for international research projects, arranged an invitation for themselves and participated in the discussions. The meeting was not successful. The representatives of the other university tried to dominate the discussions and proposed a program of mainly molecular and cellular research on plant-water-relations that they claimed would provide practical solutions to the droughts in the Sahel. But, ISRA, the donors and I were not convinced by their proposal. Looking back three decades later, it was clear that, within this long time-frame, their proposed molecular research on plant-water-relations likely would have been of no value to Sahelian farmers. They mainly claimed that in some yet unknown way molecular research was going to provide a way for crop plants to be more productive in the Sahel. Their particular scientific approach to enhancing drought resistance had not yet proved to be effective in any crop species as of 2006, and there are many stresses in addition to drought that confront cowpea, and other constraints to cowpea utilization in the Sahel that were not included in the proposal of the other US agricultural university.

Unfulfilled promises from genetic engineering

In the 1980s people began claiming that genetic engineering could produce varieties of crop plants that have much greater yields and require much less water than current varieties. Yet as of 2006 no varieties had been developed using molecular approaches that had been shown to have improved adaptation to drought under field conditions. Some transgenic lines had been developed that were shown to withstand dessication better than control plants under laboratory conditions. But
these plants were not shown to have greater yield under field conditions, which is what was needed by farmers. Some transgenic lines that may have moderate improvements in adaptation to drought were being field tested in 2006 but there effectiveness had not been adequately established and they had not yet been released as varieties for use by farmers.

The ‘dream’ of producing varieties of crop plants with substantial adaptation to drought that require much less water while producing greater yields most likely is not achievable. Theoretical analyses by experienced crop physiologists have predicted that substantial decreases in water requirements of crops will not be attained without concomitant large decreases in grain yield. This is because the transpirational loss of water and photosynthetic uptake of carbon dioxide, and thus production of carbohydrate, take place through the same stomatal pathway in leaves. Genes that cause partial closure of stomata could reduce transpiration and water use but they also would reduce photosynthesis and yield in most circumstances.

Similarly, the ‘dream’ of producing varieties that produce much greater yields in ideal well-watered environments likely is not achievable for many major crop species. Tom Sinclair proposed in 1994 that “Overall, important advances in understanding of crop physiology in the last 20 years have led to the conclusion that temperature, solar radiation, and water availability quantitatively define limits to crop biomass accumulation and seed yields, and these yield limits have been essentially achieved.” Tom Sinclair was describing the achievements made in increasing yields of major crops under good management. I feel, however, and my discussions with Tom indicate he agrees with this, that moderate increases in yield are still attainable for minor crops under good management and for all crops by increasing crop resistance to pests, diseases and environmental stresses.

In a subsequent paper Tom Sinclair and colleagues provide three examples from the few cases where physiological research has led to the breeding of varieties with increased resistance to environmental stresses. These examples were: 1) the breeding of a wheat variety with a moderate but useful increase in yield per unit of water used in dry environments by Richard Richards, Anthony Condon, Graham Farquhar and their colleagues; 2) the breeding of a cowpea variety with increased pod set and yield in hot environments by me, Jeff Ehlers, P.N. Patel and our colleagues; and 3) the
breeding of soybean lines with enhanced tolerance of nitrogen fixation to soil drying by Tom Sinclair and his colleagues. Tom pointed out that these successes required a long-term multi-disciplinary effort including crop physiology, agronomy and breeding.

Tom proposed that the use of a molecular transformation approach would require a similar but larger team with interactive input from all participants at all phases of the research. He said “This challenge might be increasingly difficult to meet in view of the declining commitment to research in whole-plant physiology and crop breeding.”

On many occasions I have encountered claims from scientists working at the molecular level that their research will solve world food problems, but their arguments were neither clear nor complete. The extent to which these unreasonable claims either resulted from the strong desire of the molecular scientists to obtain grant funds for their research, which can be very expensive, or simply reflected a general naivety of molecular scientists, at that time, concerning large-scale systems and complex real-world problems is not clear to me. Genetic engineering has substantial potential to be of assistance to plant breeding, but proposed modifications to plant genomes must be evaluated in the context of large-scale complex agricultural ecosystems. In addition, the effects of single genes on plant performance can be influenced by unique emergent properties occurring at higher levels of organization (described on page 9 in Preface).

Problems inherent in taking a ‘genocentric’ approach to understanding plant development and function have been discussed by Tom Sinclair. He pointed out that “In reality, the analogy of the genetic code as a blueprint to describe plant development and growth is misleading. A better analogy may be that DNA and genes are more like the prompt-script given to comics at an improvisational club. The prompt-script can be accurately reproduced in a photocopy machine and the same prompts can be given to the performers every night. However, the performance unfolds on any given night according to the imagination and wit of the comics together with the reaction of the audience. That is, the prompts give a general direction and perhaps indicate boundaries but the unfolding of an individual performance depends on both the immediate and general ‘circumstances’ that exist at the time of the performance. So too with plants, the development and growth of plants is to a large extent an emergent product within the boundaries of the genetic code and the
contingencies in the code. The ultimate expression of the code is dependent on the specific biotic and abiotic environment in which cells and organs find themselves as they develop and grow.”

Some of our success with molecular-genetic research

In recent years, some sound projects have been proposed by scientists working at the molecular level and I have been privileged to collaborate with molecular geneticists while conducting more basic research. One of our ventures into molecular research involved developing genetic linkage maps for cowpea based on DNA markers and phenotypic traits. Maps of this type can substantially enhance the efficiency of plant breeding as is discussed in Chapter 9.

Molecular-genetic and physiological research on chilling-tolerance conducted by Abdel Ismail, Tim Close and I produced exciting results. We discovered that a specific dehydrin protein in the seed confers partial chilling tolerance during emergence in cowpea. In subtropical zones, such as the Central Valley of California, seedlings of typical cowpea varieties do not completely emerge from the soil if they are sown too early in the spring when the soil temperature is cooler than 19°C (66°F). Farmers often sow cowpea early because it can be beneficial, if the crop does emerge it can achieve greater yields than with late sowing. The greater yields occur if the crop is able to flower prior to the very hot weather that can occur in early summer or if the crop thereby has a longer growing season. Varieties with the specific dehydrin protein in their seed could be planted early and still achieve adequate emergence even when the soil is cool.

We purified the dehydrin protein responsible for the seedling-stage chilling tolerance, and cloned and sequenced the structural gene responsible for its production in the seed. This probably was the first case where a specific protein had been linked to tolerance to a specific type of abiotic stress in plants. We obtained a United States Utility Patent for this new concept on December 31, 2002. The University of California was hoping that commercial companies working with other crops would want to obtain a license to use this technology. Chilling tolerance during emergence is important for many warm-season annual crops grown in the continental United States, including cotton, maize, soybean and melons. This patent does not limit the use of this technology in cowpea. Breeders would not have to use molecular transformation with cowpea. The trait is present in several
widely available accessions and can be selected using conventional breeding procedures. We developed a non-destructive screening technique for the presence of the dehydrin protein in seed that can speed-up breeding. Chilling tolerance is not very relevant to the Sahelian zone, however, and is not discussed further in this memoir.

**Progress in developing a collaborative project**

During the meeting in Senegal in 1978, ISRA was a generous host providing a memorable multi-course lunch at the Croix du Sud restaurant in Dakar. Afterwards, I was unhappy that ISRA had not gained anything for Senegal from the meeting and had used some of their limited financial resources. In later years, I heard that the Director General of ISRA had been strongly criticized for ‘wasting’ funds on this meeting. For me the meeting was useful in that I left Senegal with a renewed dedication to establishing a collaborative project. The meeting had shown that ISRA strongly supported the idea of a collaborative project with U.S. institutions. I found this surprising because during many years prior to 1978, Senegalese scientists mainly had interacted with French organizations.

Opportunity to develop a project came two years later in September 1980 when the Bean/Cowpea Collaborative Research Program (CRSP) was initiated at Michigan State University under funding from USAID. The philosophy and objectives of this program were ideally suited to a collaborative project between ISRA and UCR. I submitted a grant proposal to the Bean/Cowpea CRSP developed jointly with ISRA during planning visits to Senegal in both 1980 and 1981. Administrators at UCR tried to modify my plan based on non-scientific reasons, but I was able to resist their efforts. Administrators at Michigan State University proposed changes, also based on non-scientific considerations, that I had to accept. The changes they proposed had negative effects on the project for several years. But, I eventually developed an appreciation for the CRSP approach to international agricultural development.

Subsequently, I was asked to testify before a meeting of the Select Committee on Hunger of the U.S. House of Representatives that was convened at the University of California, Davis on July 21st, 1984. The Chair of the committee was congressman Mickey Leland of Texas who was actively
involved in rural development in Africa. Unfortunately, a few years later on August 7th, 1989, Mickey Leland was killed in an airplane crash while leading a mission to the Fugnido refugee camp in western Ethiopia. A congressman from Ohio also was very active on the committee and has the same name as me, Tony Hall, which brought some confusion to the deliberations. Congressman Tony P. Hall has been actively involved in programs for feeding hungry people since his work as a Peace Corps volunteer in Thailand and during his service as the representative for the 3rd Congressional District of Ohio. Tony P. Hall retired from the U.S. Congress on September 9th, 2002 and was appointed U.S. ambassador to the United Nations’ food and agricultural agencies in Rome.

Testifying to the Select Committee on Hunger was a new type of experience for me in that the demeanor of some members of the select committee would have intimidated most people. I suppose that they regarded world hunger as an important problem and were being serious in their deliberations. I felt like I was facing an ‘inquisition’, even though I had received a special invitation to testify before the committee and thought I was a ‘friendly’ witness. I was not affected by the brisk questions of the members of the select committee, however, because I felt I had some important advice for them and I was going to deliver it.

In my testimony to the select committee, I pointed out advantages of the new CRSP approach for involving U.S. universities in international development, compared with the contract approach that had been used extensively in earlier years. The CRSP approach involves the collaboration of scientists in research programs that are mutually beneficial, helping both developing country and U.S. agriculture. The guiding principle of the CRSP is to help people to solve their own problems. The CRSP had the ability to attract very effective U.S. and overseas scientists because it is compatible with their responsibilities to their home institutions. In contrast, overseas projects based on contracts had a tendency to attract either old experienced people who were retiring from U.S. universities and were mainly suited for administration or young inexperienced people who were still learning how to conduct research. These overseas contracts had been effective for short-term well-defined objectives, such as building research centers, but often had not created effective sustainable long-term research programs.

The CRSP approach has the potential to develop sustainable long-term research programs
because it has been very effective for training graduate students from developing countries. The CRSP is designed to enable graduate students to work on a thesis problem that is relevant to their countries and also receive support once they return home to help them establish invigorated research programs.

I also recommended that the select committee support stronger collaboration among U.S. Universities and the International Agricultural Research Centers. Some of these Centers can contribute substantially to improving agriculture in developing countries and the United States, and the Centers can benefit from the more basic research and graduate-training opportunities provided by the Universities. Finally, I recommended that field-oriented research was needed for solving many of the problems confronting agriculture in developing countries and that the emphasis in U.S. Universities, in the 1980's, on molecular-genetic approaches was taking resources away from where they were needed and could be most effectively used.

When I reread my testimony 22 years later I decided I would not change a single word except to say the following. The problem of *over-emphasis* on molecular-genetic approaches has progressively become much worse and much more destructive for agricultural research enterprises, such that it will continue to cripple attempts to improve agriculture in developing countries and the United States.

**Project reviews**

The CRSP approach had one aspect that I did not appreciate. The USAID was too fond of reviews. During some periods our project was reviewed every second year either in California or Senegal, even though it had received high ratings. Reviews are needed but they waste time and funds if done too frequently. I will discuss two of my experiences with reviews, one where I was reviewing another project, and one where my project was being reviewed.

I served on a panel conducting a five-year review of the research programs of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in 2003. Initially, the external review panel went for a short one-week visit to the headquarters of ICRISAT at Patancheru near Hyderabad, India to develop a ‘game plan’ for the review. I left California on a Friday morning
and arrived at Patancheru early on Sunday morning after about 30 hours of flying and waiting for planes in airports. We began our work on Sunday afternoon and kept going all week through Friday afternoon. The atmosphere was tense since this type of review is comprehensive and can have a strong influence on the future directions of the Institute. On the Friday evening when I went for dinner at the buffet-style dining facility of the Institute I stopped at the door because through the glass I saw a large group of people in the area next to the tables with a man speaking to them using a microphone. I assumed it was a special event and since I had not been invited I was hesitant to enter. However, I was hungry and there was nowhere else for me to get some food. The ICRISAT headquarters is located out in the countryside several miles from Hyderabad and I did not have a car. I decided to wait outside until the group social activity had ended.

A man coming from the restroom next door saw me waiting outside and said “Hey Professor Hall you must come and join us.” I followed him into the room and was led to a chair right at the front of the group. A seat for either an honored guest or a sacrificial lamb.

Things began quite well in that I was offered a drink and chose a shandy which is a British beverage consisting of a mixture of beer and carbonated lemonade that is well suited to the hot conditions that often occur in India. The man with the microphone was telling jokes of dubious quality and taste. He began asking other people in the audience to take the microphone and tell jokes, and if they refused he badgered them mercilessly suggesting maybe they would like to sing instead. With a sinking feeling I realized that I was in trouble, I am not very good at telling jokes and I had no experience singing before an audience.

A little later, the master of ceremonies looked towards me and said “I see we are honored by the presence of a member of the review panel, you must tell us some jokes.” As the only member of the review panel who was present I felt I had to do something. I went to the front of the group, took the microphone and told them the following story about “African Ingenuity” based on an experience I had in West Africa, where ICRISAT also had major research activities. The story I present here is somewhat more complete than the one I actually gave because I had to present it off the top of my head with only a few minutes to prepare it.
“African Ingenuity”

“For two decades I directed a collaborative project in Africa that was funded by USAID. If you think the present review schedule of ICRISAT is tough try working for projects funded by USAID. On many occasions my project was reviewed every two years not every five years.”

“On one of these occasions I was in Senegal with my host country collaborators making preparations for the review. Friday night we were staying at the small Nina Hotel in the center of Dakar. We planned to pick up members of the review team who were coming into the Dakar Yoff International Airport in the early afternoon of the following day. On Saturday morning Samba Thiaw and I were having breakfast in the small internal patio of the hotel. Our driver Mamadou Ndiaye came to join us but he looked perturbed. He told us what had happened. He had been sleeping in our Peugeot 505 station wagon. This was the normal procedure when we were in Dakar, it saved him money and it was intended to deter people from stealing the vehicle. At dawn he had gone up into the hotel to get a quick shower, he said he was only gone 15 minutes. When going back down to the wagon he saw two men running down the street and one was carrying a windshield on his head. The windshield had been taken from our Peugeot. He chased after them but they had too good a start and he soon lost them. In this particular Peugeot, the windshield is installed with a large rubber grommet. Car thieves had discovered that it can be easily taken out from the front by cutting the grommet all the way round with a knife and then popping the windshield out with a screwdriver.”

“What to do, we had a review team coming into Dakar in a few hours and we only had this vehicle to take them around. The Peugeot 505 wagon has three rows of seats and we often had eight or more people in it in our travels in the countryside where we traveled on dirt roads and through sand dunes. This vehicle has front wheel drive, large fat tires, good weight distribution and a diesel engine with substantial torque. It went through sandy areas where 4 x 4s had trouble passing. But some of these reviewers had not been to Africa and they might not like being driven on dusty roads and through sand dunes in a station wagon with no windshield. This might worry them and make them think we are incompetent such that they would give us a bad review. The bottom line when looking after reviewers in Africa is to give them good food and drinks, a comfortable bed in an air-conditioned room with no mosquitoes, and a comfortable reliable intact vehicle with air conditioning
when you drive them around.”

“Our team did not have much faith in the Peugeot dealer in Dakar doing the repair in just a few hours on Saturday morning. We also felt that the dealer would be very expensive and our project did not have much money. We decided to look for a secondhand windscreen in an area on the outskirts of Dakar where the informal autoparts people operate. I had substantial cash which I always carried when working in Africa to take care of emergencies such as this one.”

“After a diligent search we found a Peugeot 505 windscreen that looked remarkably similar to our original one, and we purchased it at much less than the dealer price. We then went searching for a rubber grommet and this, not surprisingly, was more difficult to find since thieves destroy them when removing windshields. However, after much searching we found a suitable grommet that looked fairly new. But how to install the windshield into the grommet and then into the wagon. The driver was the most practical of us and could install the windshield into the grommet, but installing the whole assembly into the wagon looked very difficult. The driver gave up after only a few minutes of trying and we couldn’t see how to do it. Clearly, some experienced French mechanic with special equipment was needed to get this job done. We asked people in the streets if they knew of such a person. We were told that an expert at installing windshields lived at a particular address in Dakar.”

“We went looking for the mechanic driving down small winding streets until we came to a small mud brick house. As we arrived, a local man with tattered shorts, no shoes and a torn undershirt came to greet us. We told him we were looking for a mechanic. He said he was a mechanic. We asked him if he could install a windshield in the wagon, what special equipment was needed and what it would cost. He said he could install it, that it would cost the CFA franc equivalent of 20 US $ and that the only equipment that he needed to do the job was this, and he pulled a long piece of stout string out of his pocket. I was not impressed but at only $20 it was worth a try as long as he did not damage the grommet. The man placed the windshield inside the grommet and then placed the string inside the grommet all the way round on the outside of the windshield with one end passing under the windshield to the inside. He placed the whole assembly in the front part of the wagon as far as it would go, and then got inside the wagon. He carefully pulled on the piece of string and ‘pop’ the grommet and windshield dropped into the frame with the string coming out.
It only took the man a few minutes to install the windshield. I was pleased to give him the CFA equivalent of $20 plus a bonus for timely work. This was a fine example of “African Ingenuity”.

“We arrived at the airport just in time to pick up the reviewers who did not appear to be in the best of moods because they had been traveling for many hours in cramped conditions in various airplanes. Traveling in our comfortable, intact, air conditioned, Peugeot station wagon the reviewers appeared to relax and regain their composure.” The audience at ICRISAT seemed to appreciate my story and I sat down somewhat relieved and had another shandy.

**Project initiation in Senegal**

We received the CRSP grant on August 1, 1981. Fortunately, we had anticipated that it would be approved and had already begun field research in Senegal and California. The main period for sowing cowpea in the field is similar in Senegal (July) and California (May to June), and we did not want to waste the main cropping season.

During the first season, Senegalese scientist Samba Thiaw grew out the ISRA cowpea germplasm collection and thereby saved many of the accessions because the seed had been in storage for many years and much of it was losing its vigor. He also conducted yield trials at both Bambey and Louga with the best local varieties and the early cowpea lines I had developed at UCR. In later years, Samba Thiaw conducted field research in Senegal that provided the basis for his masters degree at UCR. He also conducted several years of agronomic research for the project in Senegal before returning to UCR in 1998 to study for his Ph.D., which was granted in the winter of 2003.

In 1981, another Senegalese scientist joined the project, Ndiaga Cisse, who then studied for a masters degree at the University of California at Davis with a collaborating colleague, Professor Kenneth W. Foster. In 1983, Ndiaga Cisse returned to Senegal and initiated the ISRA cowpea breeding component of the project which was very successful. After developing two very useful new varieties of cowpea, he returned to the United States and obtained his doctoral degree at Purdue University under funding from the CRSP project. In recent years, Dr. Ndiaga Cisse has continued to conduct the ISRA cowpea breeding program in Senegal. Through formal educational programs
and other ways the project has contributed to the education of scientists from several African countries who have made substantial contributions to agricultural development.

For the three years from 1982 through 1984, a period of very extreme drought occurred in northern Senegal with only 215, 151, and 174 mm of annual rainfall at Louga (Figure 3 in Chapter 1). Project research during this period demonstrated that the early flowering cowpea lines bred at UCR for use in the Sahelian zone matured in the very short period of 55 to 60 days in the tropical conditions of Senegal. Samba Thiaw conducted the yield trials with a close spacing of 50 cm (20 inches) between rows and 20 cm between plants that we felt was necessary with these erect short-cycle cowpeas. Under severe drought at the Louga experiment station, the best of these lines produced excellent grain yields averaging 1,012 kg/ha in 1982 with only 181 mm of useful rain, and 237 kg of grain per hectare in 1983 with only 135 mm of useful rain. One of the parents that was used in breeding the short-cycle cowpeas, ‘California Blackeye No. 5’ (‘CB5’), which was bred in California during the early part of the 20th century, also gave good yields of 922 and 195 kg per hectare at Louga in 1982 and 1983, respectively. The best early cowpea variety developed by Djibril Sène of ISRA during the late 1960's and early 1970's, ‘Bambey 21’, only produced moderate yields of 699 and 51 kg/ha in 1982 and 1983, respectively. Crops of local landraces of cowpea, pearl millet, and peanut grown on the experiment station at Louga (and farmers’ fields in the Louga region) were much less effective than the experimental cowpea lines and produced virtually no grain during 1982 and 1983.

We also learned from field trials that the parts of Senegal with the greatest potential for grain production by the early cowpea lines were in the semiarid sandy soil areas of the Louga, Thies and Diourbel regions in the northern and center-north parts of the Peanut Basin (Figure 2 in Chapter 1). In these regions of Senegal, low rainfall often had imposed a serious limitation to plant performance, and the earliness of the new breeding lines might enable them to produce a useful grain yield in most years. In addition there had been only moderate damage to cowpea from insect pests and diseases such that the crop often could be grown without pesticides. Areas to the south of Diourbel had more rainfall but too often they also had substantial infestations of flower thrips and other insect pests that severely reduced cowpea grain production. In the area north of Louga, there usually was too little
rainfall to support rainfed crops of any of the breeding lines or varieties of cowpea or any other annual crop species.

In the fall of 1984 a catastrophe was developing in northern Senegal. A bad drought had occurred during the summer of 1984 as it had in the previous two years. Due to negligible yields many granaries of pearl millet were nearly empty, and the farmers had little seed of traditional cowpea or peanut for the next year's planting. Also, the Government of Senegal, which at that time was the major supplier of peanut seed, had decided to allocate its limited quantity of peanut seed only to farmers in the central and southern parts of Senegal which had been receiving more rainfall than in the north. Prior to 1984, little consideration had been given to cowpea because it was regarded as a minor crop by the Senegal Government and the USAID Mission in Senegal. The government’s New Agricultural Policy in 1983 and USAID’s planning documents for the early 1980s did not even mention cowpea.

**Project initiation in the Sudan**

During the 1982 to 1984 period similar very severe droughts were occurring throughout the Sahelian Zone stretching from Senegal to the Sudan (Figure 1 in Chapter 1). In the early 1980s, several graduate students from the Sudan were working with my program at UCR. A Sudanese government scientist who was the Director of the USAID-funded Western Sudan Agricultural Research Project (WSARP), Dr. Dafalla Ahmed Dafalla, visited UCR in 1982 to meet with Sudanese students and other members of my program. Two initiatives resulted from this visit that have contributed to rural development in the Sudan. First, I was asked to provide seed of the cowpea lines that we had bred at UCR for use in the semiarid zone of the Sudan. I sent the seed to the Sudan in time for sowing in the 1983 season. Second, I was asked to visit the Sudan and develop a plan whereby WSARP could increase cowpea production.

In the fall of 1984, after finishing my work in Senegal, I traveled east to evaluate the role of cowpea in agricultural systems in western Sudan. My visit to the Sudan was supported by several collaborating agencies. The Bean/Cowpea CRSP paid for my international travel and per diem, UCR contributed my salary, and WSARP provided local transportation in the Sudan. On my arrival in
Khartoum I stayed downtown in the Araak Hotel, which was an imposing old-style hotel that was not too expensive. There was a Hilton Hotel in Khartoum but when traveling in Africa I have always tried to avoid staying at opulent hotels. Spending as much money in one day on a hotel and meals as many local people have as income for the whole year made me feel uncomfortable.

On my free time I walked around the city and was pleasantly surprised that it had not suffered too much from western influences. The city also did not appear to have benefited very much from western influences. The influence of Islam on the city was strong and I found it to be a safe but somber place for western visitors. A year earlier, President Nimeiri had decided to incorporate traditional Islamic punishments drawn from the Shari’a (Islamic law) into the penal code of the Sudan and this had been controversial even among different Muslims. In April 1984, President Nimeiri had declared a state of emergency and special courts had been established to try to insure that the Shari’a was applied uniformly. During my visit in the fall of 1984 people were discussing how a governor had been publically lashed for having drunk alcohol.

The USAID Mission was a somber place with more antiterrorism measures than any other U.S. Government facility that I have visited in Sub-Saharan Africa. This probably was a consequence of the murder in the Sudan of the US Ambassador and Deputy Chief of Mission by Palestinian terrorists of the “Black September” organization in 1973. I spent a few days meeting with people at the USAID Mission and at the headquarters of the WSARP in Khartoum. The WSARP people sent me to visit with scientists of the Agricultural Research Corporation (ARC) at the Wad Medani research station which supports the Gezira irrigation scheme. Unfortunately, the vehicle provided by WSARP broke down before we had reached the outskirts of Khartoum so I sent the driver back to the headquarters and took a public bus instead.

The Sudanese scientists at Wad Medani were very helpful providing scientific advice and making sure I had plenty of Pepsi-Cola to drink. While at Wad Medani I stayed at a small country hotel. There I met an expatriate scientist who was involved in a project producing hybrid sorghum

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*The ARC is a government research organization that has similar responsibilities as the USDA, ARS in the United States and was the main collaborator with WSARP in the Sudan.*
seed for use in the Sudan. I was of the opinion that this project was a bad idea. Farmers who used the hybrid sorghum seed would need to buy new seed every year, but the institutions present in the Sudan at that time (and during the remainder of the twentieth century) were too fragile to guarantee that the hybrid seed would be available every year. A hybrid seed production scheme was developed in the Sudan as a consequence of the work of the expatriate and other scientists in the 1980s. A hybrid sorghum variety was released, ‘Hageen Dura-1’, that was moderately successful for a few years. The scheme was not sustainable, however, and a Sudanese colleague informed me that as of 2003 the policy of the ARC and the Government of the Sudan was to not develop any more hybrid varieties but to develop pure-line varieties of sorghum whose seed could be reused by farmers.

While returning to Khartoum from Wad Medani the bus had to stop at a barrier and all passengers were required to step down and be searched. Presumably the Sudanese northern army was worried about the possibility of southern rebels infiltrating Khartoum. I was concerned about the young army men who manned the barrier and carried their AK-47s in a very casual manner. I worried they would shoot most of the passengers and me if they suspected someone of being a rebel.

After my return to Khartoum, I was transported to the project site in southern Kordofan at Kadugli by a small plane contracted by WSARP. The flight was unusual in that the pilot appeared to be following features of the terrain, such as wadies, and not making much use of modern navigational devices. Later during the evening I asked the pilot if her passengers had ever reacted adversely to being flown over this wild and desolate country. She said that many Sudanese men and women who had flown for the first time with her in her plane seemed to enjoy the experience. In contrast, some tough looking oil-field employees from Texas who had flown with her in Sudan, appeared to have been frightened by the experience and had consumed large quantities of alcohol during the flight. At that time some US companies were searching for oil in southern Sudan, even though there was a civil war in that area.

My initial reaction to the research station at Kadugli was that its location on a hill and tall perimeter fence and water tank made it look like a ‘concentration camp’. This station is a relic of the cold war in that its construction was started by the Soviet Union and finished by the United States under the WSARP. Many of the WSARP scientists at Kadugli were expatriates from the United
States and several African countries.

While I was at the station there was a riot in the town of Kadugli with people complaining about the hoarding of food by local merchants. I was surprised by the rioting in that I did not think there was a shortage of food in this region. While working and in my free time I had walked around villages and farmlands in the Nuba mountains. I had seen large areas of moderately productive food crops and some were ready for harvest. I also had gained the impression that the society had not changed much since the ‘old’ days. Many people still wore traditional clothes and carried spears and clubs as they traveled to and from the fields. They told me that the arms were for protection against wild animals but I suspected that there might also be some rivalries among different tribal groups. I had not sensed any danger from wild animals while walking unarmed in the countryside, and the southern rebel armies were not operating in the Nuba mountains at that time.

Dangers in the African bush

Some movies and books have given erroneous impressions of the dangers from animals that can occur in Africa with lions attacking out of every bush. From 1961 through 1963, I had worked as an agricultural Field Officer (‘Bwana Shamba’) for the Government of Tanganyika * in the South Mara and North Mara districts which are adjacent to Lake Victoria and the Serengeti National Park and include some very wild areas While working in Tanganyika, I had walked many miles, unarmed, in Savanna grasslands surrounded by wildlife. The farmers who walked with me typically only carried pangas (machetes). Also, on other occasions, I had hunted alone for food and, as part of my job responsibilities, removed wild animals that were causing problems for local people.

I had several encounters with animals that can be dangerous, including several species of poisonous snakes, leopards, lions, rhinoceros, elephants, hippopotamus, baboons, wild dogs, wart hogs and hyenas. While working in North Mara I lived in a small house on the outskirts of the town of Tarime. The house consisted of two small round huts (rondavelles) with a connecting area that

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* This country did not get the name Tanzania until it was joined with Zanzibar in 1964.
served as a kitchen and dining room. It was surrounded by bush, and hyenas often visited my backyard at night and annoyed my dog. She had come to my house as a stray in poor condition and I had fed her back to good health. She decided to adopt me but chose to live outside. One night while relaxing in the rondavelle that served as a living room I heard her growling and opened a window and leaned out. She was just below me in a crouch with her hair sticking out. She was surrounded by a pack of hyenas who were several times bigger than she was and in a semicircle only a few paces away. I thought I would have to save her but my rifle was in the other rondavelle that served as my bedroom. Fortunately, she took advantage of the diversion created by my opening the window and leapt at the nearest hyena. She bowled it over and chased the whole pack away. She was a good watch dog and whenever I returned to my house in the dark I did not have to worry too much about hyenas or leopards.

The big game animals of Africa and some others, such as hyenas and baboons, are powerful and can and do kill people. However, they rarely stalk people with the intent of killing them. An exception to this are young children and people with bleeding wounds who are very vulnerable in the bush. Also hunting and trying to take close-up pictures of big game substantially increases the chances of being harmed by animals. Simply observing animals, giving them adequate ‘space’ and being cautious substantially decreases the chances of being harmed. One time I was hunting alone a few miles from camp. I was trying to shoot a gazelle because we were short of food. I was walking in a Savanna with grass at about knee height and scattered acacia trees. I climbed a low ridge and dropped down into a valley where there were closely spaced trees. I noticed that some of the trees had been devastated by a herd of browsing elephants. Further along I encountered a pile of elephant dung and felt it, its warmth suggested the elephants were only minutes away. The rifle and ammunition I was carrying were only suitable for killing gazelle and would have been of no value against a charging elephant. I carefully retraced my steps back out of the valley and over the ridge into the Savanna and then chose another direction for pursuing a gazelle for our dinner.

I learned how to walk and live in the bush in a cautious manner and was not hurt by any wild animals and usually enjoyed the experience. However, I am frightened of poisonous snakes. One encounter in South Mara gave me a sleepless night.
I was on safari and spent the night alone in a grass hut. I had a low camp bed that was close
to the ground. I placed a small flashlight, which was turned off, on the ground by the side of the bed.
I laid down on the bed and pulled a cotton sheet over me, my arms were down by my side under the
sheet. Laying in the darkness, I was surprised by how quiet it was on this particular night. On other
occasions while sleeping in grass huts there had been continuous noises from rats and other creatures
moving in the grass roof. There was a reason why the thatch was so quiet. Before I was able to begin
sleeping something fell from the grass roof and landed on my chest, very close to my throat. It was
too dark for me to see but I am fairly certain it was a large snake because of its weight and length as
it rested on my chest. I did not move and after several minutes it slithered slowly along my chest for
a small distance and then rested again. I kept perfectly still because my arms were trapped under the
sheet and I did not want to disturb the snake since it was too close to my throat. A bite in the throat
by a poisonous snake would have killed me. The snake spent a long time on my chest, it seemed like
a few hours. I assume that it appreciated the warmth of my body. Eventually, to my relief, the snake
slithered off my chest down to the ground.

I still had a problem because my bed was only a few inches from the ground and it was dark
and I didn’t know where the snake had gone, it still could be very close to me. I decided to not move
for another hour or so. Eventually, I carefully brought one arm out from under the sheet and picked
up the torch and turned it on. There was nothing in the hut, the snake had left. The walls of the hut
were made of stalks and had many holes through which the snake could have passed.

On another occasion I discovered that lions can be very intimidating. A friend and I had taken
a family of missionaries on a camping holiday in a Tanganyikan wildlife reserve next to the Mara
river in North Mara. This was a much wilder area than the Serengeti in that few people had ever lived
in or visited the reserve and the animals behaved naturally. On previous visits I had seen leopards
during the day-time, whereas in most areas you only see them at night. I also had seen beautiful little
antelope called klipspringer that are very shy and rarely seen in other areas. Klipspringer is the only
antelope that walks on the tips of its hooves. I saw them standing on rocks, like ballerinas, as bighorn
sheep do in the United States. On this occasion we had set up several tents, and in the evening the
missionary was leading a prayer service for his family next to one of the tents. My friend and I are not
particularly religious and we were not involved in the prayer service. I am a secular agnostic, I believe there is a force of good in the world but I do not have faith in a particular god or religion. I appreciate people of different faiths who follow sound philosophies of life. But, I am an environmentalist and find this to be inconsistent with the many religions that do not recognize that people must live in harmony with nature.

My friend and I were sitting next to another tent resting and having an evening drink of whisky. As the sun was setting a magnificent mature male lion bounded out of the bush and loped between the tents, about twenty paces from us and only ten paces from the missionaries, and then disappeared into the bush on the other side. The lion showed no fear but he certainly disturbed both the prayer service and our evening drinking session. I was embarrassed because I felt that my friend and I had a responsibility to see that the missionaries were not harmed. What could we have done if the lion had attacked the missionaries? Our rifles were loaded and near by, but there was insufficient time to grasp a rifle, raise it, aim and shoot, and the lion was between us and the missionaries.

There is an African saying told to me by a Luo that may have some merit but would be difficult to follow, “If a lion confronts you, shake a stick at him because he is bluffing, but if you meet a leopard, lay down and pray.” Leopards typically are encountered by people at night and this saying gives the impression that they are more aggressive and can be more dangerous than lions. Later I will describe an encounter I had with a leopard at night.

More people were killed by encounters with African honey bees than they were with mammals or reptiles in the Mara region of Tanganyika during the early 1960s, according to the reports I saw. On one occasion a swarm of bees attacked a group of people waiting to get on a ferry boat that crossed the Mara river from North Mara to South Mara. At that time there was no bridge over the river. One man became enveloped by a swarm of bees and tried to get into cars but no one would let him and the swarm of bees into their car, and he died. Other people who were being attacked by bees jumped into the river. They were saved by an alert ferryman who threw gunny sacks to them so that they could submerge under the water to escape the bees and then come to the surface, under the gunny sack, to breath.

Similar types of Africanized honey bees have now entered the southwestern United States and
when swarming should be considered as potentially dangerous. Their sting is similar to that of a domestic (European) honey bee but they can be much more aggressive and a swarm can rapidly deliver hundreds of stings. If attacked by a swarm of bees, run away fast. These bees tend to attack the head and orifices. A sting in the ear can incapacitate you, so cover and protect your head and ears as much as you can but without slowing your escape. Seek the protection of the nearest house or car and close the doors and windows. If a few bees follow you into the car, drive a few hundred paces to get away from the swarm and then open the doors of the car to let the few bees out. If you jump into a river or a pool to escape the bees, use a handkerchief or some other cloth to cover your face when you come up to breath to protect it from more bee attacks because the bees will still be there. Once you are safe, quickly remove any sting structures from your skin. The sting structure continues to inject venom for several seconds after it becomes detached from the bee. Prompt removal of the stings can reduce the amount of venom injected into you. Some medical literature says stings should be scraped off and not removed by pinching or with tweezers. But, recent studies showed no differences in venom injection when removing stings by either scraping or pinching them and pulling them out.\(^8\) Apparently, it is best to remove them as quickly as possible using whatever method works best for you.

After working in Tanganyika for about a year, I bought a rifle for personal protection and other uses. I was not worried about wild animals, but since independence in 1961 I had been involved in setting up farmer cooperatives to manage the sale of cereals, and this required that I travel with large quantities of cash to pay the farmers who had provided cereals to the cooperatives. On some occasions the receipts I had received from the truckers who had taken the cereals showed fewer bags than the cooperatives claimed to have received from the farmers and given to the truckers. I had to carefully check all of the available information and it took much time to resolve problems of this type which made the farmers angry. Often the sun had set by the time I began paying the farmers and we only had light from kerosene lamps. The degree of danger was enhanced by the fact that I was working in a district, North Mara, which is next to the border with Kenya. At that time, groups of armed felons from Kenya were operating on the border terrorizing people by taking over villages.

The Government of Tanganyika had provided me with a policeman for protection who carried
an old Lee Enfield rifle. But the policeman was not young and tended to sleep much of the time. He would have been very slow bringing the rifle on target and firing multiple shots using its slow bolt action. So I bought a lever-action rifle --- a solid-frame Savage Model 99. I am ambidextrous and can shoot a rifle using either shoulder, though I am faster and most accurate off the left shoulder. A lever-action rifle was far more effective for me than a typical bolt action that is designed for use with the right shoulder and with me tends to have slow reloading action. The Savage Model 99 can be very fast especially when using open front leaf sights. In addition, its lever has a short throw such that it can be kept on target while reloading permitting one to place several shots into the target area in rapid succession. My rifle had a 5-shot rotary magazine that can accommodate high pressure cartridges with pointed bullets that have a very high muzzle velocity. The high-velocity, pointed bullet can be very accurate and have a very flat trajectory that makes it easy to sight-in the rifle, since it requires little adjustment for variation in range, and the bullet is not strongly affected by wind. For me this rifle had perfect reliability, was fast, never jammed and was very accurate up to about 200 paces. It is unfortunate that the Savage Arms company discontinued selling the Model 99 in 1998.

I also used the Savage Model 99 to hunt game for meat while on working safaris, which was appreciated by my staff and the farm families who worked with us. In addition, I was responsible for removing wild animals that were causing problems. On one occasion, I was approached by people who lived in a Kuria village on an escarpment. They were worried about a leopard that had been taking goats quite close to their houses, they thought it might kill their children. I borrowed a goat from them and, during the afternoon, I tied it with a rope leash to a stake in a small clearing on a hill side. Then I hid behind a rock on an opposite slope with a good view of the goat some 50 paces away and waited for the leopard. I had one concern, the cartridge I was using was not ideal. It was a Winchester .243 inch (6 mm) caliber with a very fast but light bullet. The bullet was fine for hunting warthogs, baboons and gazelles but too light for hunting dangerous game. In this case a bullet is needed that has sufficient mass and momentum to stop the animal even with a shot that does not hit a vital area. The type of cartridge I was using required that if I was to stop the leopard I would have to make a perfectly placed shot that would kill it. It was imperative that I not just wound the leopard. Tracking down wounded leopards can be very dangerous. On occasions like this I would have
preferred a larger caliber rifle and a bullet with more mass.

For several days, I staked out the goat and waited for the leopard. I watched the clearing and its surroundings. I also took care to watch my surroundings because the wind was swirling and I did not know which direction the leopard would use to approach the goat. I would not smell the leopard if he came, but he might smell me if he was down wind from me on his approach to the goat. Each day I waited until it was too dark for me to see to shoot and then took the goat back to the village and went back to my government house in Tarime. During this period I did not see either the leopard or any tracks.

I then tried another approach, I asked the game rangers working in the Serengeti National Park to loan me a cage trap and advise me on how to use it. The cage trap was made of steel bars and had two compartments, a large one with a sliding door and trigger mechanism to trap the animal without harming it, and a small compartment next to it for the bait. I was surprised when a game ranger advised me to put a chicken in the bait compartment not a goat. He said that a chicken was better because it would attract the leopard and make less noise than a goat when the leopard approached the trap. Too much noise would make the leopard reluctant to close in on the bait and enter the trap. We installed the trap in a wild area adjacent to the village on the escarpment, and placed thorn tree branches around the trap so that the only way to approach the chicken was through the trap door into the main compartment. Nothing happened for several days.

While on safari in the lowlands near Lake Victoria I met another government officer on the road. He told me that a leopard had been caught in the trap and that the people might kill it. I returned to Tarime as fast as I could, taking the curves on the dirt road up the escarpment at higher speeds than I normally did with the Land Rover. The cage containing the leopard already had been brought out side of my office. The leopard was a mature male and in fine form, snarling viciously at anyone who came within a few paces of the cage. Many local people had come to see the leopard and a local politician was trying to feed it with pieces of bloody liver. For a long time the leopard ignored the pieces of liver and then, suddenly, he leaped at the iron bars next to the politician. The leopard had such a violent presence that when he leaped at the bars most of the people around the cage ran away at high speed and some climbed trees, even climbing over people who had begun to climb a tree but
were too slow.

A few hours later, game rangers arrived and put the cage and leopard in the back of a truck and transported it down from the North Mara highlands and across the Mara river out into the Serengeti National Park. Later they told me that releasing the leopard from the trap required a delicate procedure. The game rangers tied a rope to the top of the trap door, passed the rope over a branch of a tree that projected above the cage, and then retreated inside the cab of the truck while holding the rope. They then opened the trap door from the safety of the cab by pulling the rope. They said the leopard was very annoyed and upon leaving the cage slashed at some young tree saplings for a long time before taking off into the bush. The relocation was effective in that the people in the village on the escarpment did not have any more trouble with leopards while I was working in North Mara. I was pleased that I did not have to shoot the leopard because among other considerations he was a magnificent animal.

Since leaving Tanganyika in late 1963, I have not carried firearms for personal protection in Africa or elsewhere. When hiking in parts of the United States where there are many mountain lions, such as the Cuyamaca Rancho State Park just south of the town of Julian in southern California, I carry a stout walking stick. When hiking in grizzly bear country, such as the back country of Yellowstone National Park, in addition to the stout walking stick, I carry a pressurized can of pepper (capsaicin) spray. These precautions make me feel better because I do not feel comfortable with the widely accepted view that in case of a grizzly bear attack (but not a black bear attack) one should play dead even if partially eaten. I prefer to stand my ground and fight. The book by Stephen Herrero provides a comprehensive and practical analysis of how to look after yourself when traveling in bear country. Interestingly, the strategies he recommends for dealing with grizzlies are radically different from those he recommends for dealing with black bears, and are similar to Luo folk lore concerning how to deal with leopards and lions. But in no case was Stephen Herrero able to give firm recommendations only educated guesses about the best things to do, because individual bears can vary tremendously. A sensitive, practical, broad and balanced analysis of the nature of grizzly bears is presented in the wonderful book of Andy Russell. He spent much of his life as a trapper, hunter and professional guide in grizzly country but in later years devoted his efforts to photographing grizzlies
and other wildlife. With respect to grizzly bears and mountain lions, I have been fortunate in not having to test my primitive self-protection systems.

The only time I have been attacked by dangerous game was when a leopard attacked me at night. This occurred at the Ilonga Agricultural Research Station near Kilosa in Tanganyika. Warthogs had been destroying experimental maize plots we were using to determine the best adapted varieties for use by farmers. I had been asked to help the guard to stop this from occurring. One night the guard and I were sitting around a small fire smoking local ‘kali’ cigarettes that were very strong and kept us awake. About midnight, we heard the sound of an animal moving through tall dry grass at the edge of the experimental field area about half a mile away. We assumed that a warthog was coming into the experimental fields. We put our cigarettes in the fire, picked up our weapons and moved towards the sound. The guard had a single-shot 12 gauge shot gun with buck shot cartridges and I had the Savage 99. We had flashlights attached to our foreheads with battery packs in our belts, but left them turned off as we moved through the tall grass towards the animal that was making the noise.

Suddenly we became aware that another animal was tracking the warthog and was just in front of us. We switched on our flashlights. A leopard, who was following the warthog, looked back at us when the lights came on, turned round and leapt at us in one motion from a distance of about 12 paces. Fortunately, we were abreast of each other and both of us could shoot at the leopard. I fired the Savage 99 and about the same time the guard fired his 12 gauge. The leopard was hit and rolled over only a few paces away from us. I fired two more shots into the leopard while it was rolling. I had made the three shots into the leopard in only 2 to 3 seconds after we switched on the flashlights. By then the guard had reloaded his shot gun and he fired a second shot into the leopard. It is unfortunate that we had to shoot the leopard but if attacked I am not about to follow the luo saying and “lay down and pray”.

If there is a possibility that you might confront a leopard at night a double-barreled 12 gauge shotgun with three inch magnum cartridges and buck shot is a much better weapon than either of the weapons that we had. A double barrel is safer than a semi-automatic because typically there only will be time for one or two shots and a semi-automatic has a greater probability of jamming which could have catastrophic effects on your health. The barrel of the shotgun should not be too long so that it
can be brought on target fast, since at night leopards can launch an attack from very close quarters and very quickly. We were lucky that the leopard was 12 paces away when he began his leap.

**Plan for increasing cowpea productivity in the Sudan**

While working at the Kadugli station in Sudan in 1984, I evaluated cowpea crops growing in farmers fields in the Nuba mountains. I soon came to the conclusion that there might not be much potential for improving cowpea production systems in this area, at this time, due to problems with insect pests. This part of the Nuba mountains is located at the wetter boundary of the semiarid zone (Kadugli has a long-term average rainfall of about 734 mm) and many insect pests were present on the cowpea. I had observed similar insect pest attacks on cowpea in a similar climatic zone in Senegal at Nioro Du Rip which is south of Bambey near the border with Gambia (Figure 2 in Chapter 1). The only available solutions to the insect pest attacks occurring around Kadugli and Nioro Du Rip involved multiple sprays with insecticides, which often would not have been either practically possible or economic or environmentally safe in many parts of Africa. Also, much of the soil in the Nuba mountains did not appear to be ideal for cowpea production. I asked the WSARP people to arrange ground transportation to El Obeid in the north so that I could evaluate cowpeas in a drier region with more sandy soils.

The WSARP project provided me with a very old small rear-wheel drive pickup and a driver. I asked if the vehicle was reliable because I had the impression that there were few if any repair facilities on the dirt roads between Kadugli and El Obeid. The project agreed to provide a ‘mechanic’ and we set out. A few miles out of town the engine began to sound very rough. The driver stopped and the mechanic proceeded to tap the carburetor with a wrench. I did not have much confidence in this system and decided to go back to the Kadugli station. I had noticed several fairly new pickups on the station. I had heard that one only was being used by the wife of the local project administrator for shopping trips to the Kadugli town, which was just a short distance from the station. My recollection is that the town was so close that you could just about see it from the top of the water tank of the station. I successfully argued that it was more appropriate to assign a reliable vehicle for a trip of about three hundred kilometers (186 miles) on mainly dirt roads through a desolate area with
few services, and to use the old vehicle for shopping trips to the Kadugli town. The new vehicle performed well and I had a most useful journey. North of the town of Dilling I began to see areas well-suited for cowpea production with large fields of sole-cropped cowpea that were in excellent condition with few insect pests.

My stay at El Obeid was rewarding, the Sudanese scientists and villagers were very hospitable, and I learned much from them on visits to experimental plots and farmers fields. I had some outstanding breakfasts at the research station that were served about 10 am. We would start work at dawn and then return for breakfast. The breakfasts were very nutritious and substantial and would sustain me for the rest of the day. Breakfast always included fava bean dishes (Ful), which were cooked in a manner similar to the refried beans served in Mexico, and unleavened pita bread. They often also included eggs, meat and vegetables, such as tomatoes and okra. Parts of the Sudan can be very hot and okra has substantial resistance to heat and is a popular vegetable. Local people prefer the small fruit of the wild okra that are abundant in the Kordofan region over the large fruit of modern cultivars of okra. The bounteous breakfasts made me feel I was being treated as an honored guest.

A type of hot tea is served in the Sudan that is refreshing and delicious. The tea often is prepared by boiling milk with tea and then adding fresh grated ginger and ground cardamom and boiling a little more and adding much sugar. Further to the west in the Sahel, tea is mainly spiced with mint and served without milk but with much sugar in an elaborate ceremony. One pot of tea is brewed and then served by pouring from a large height into individual small shot-type glasses. A second and then a third pot is brewed using the same set of tea leaves and mint but with additional sugar. Cups from the first pot are usually quite strong, whereas the subsequent cups from the second and third pots are weaker and for my taste, more delicious. But if you are ever involved in a formal ‘Moroccan’ tea ceremony of this type make sure that you drink a glass from all three brews. It can be a discourtesy to your host not to do this. I thoroughly enjoy Sudanese and Moroccan tea but I have to be prudent when drinking Moroccan tea. On one occasion in Senegal, plant pathologist Mbaye Ndiaye served me three small glasses of Moroccan tea in the evening. The tea was excellent but so strong that my eyes seemed to ‘lock’ open such that I could not sleep for 48 hours.

The region around El Obeid has a climate and sandy soil that are very similar to Louga in
northern Senegal. The climate at El Obeid is semiarid tropical with monomodal rainfall (Figure 5).

Average rainfall from 1918 through 1967 was 388 mm at El Obeid, and as for Louga (Figure 4 in Chapter 2) sufficient to support the water needs of an annual crop sown in early July and harvested after about 90 days. Note that the potential evapotranspiration rate provides an estimate of the water requirements of an actively growing crop that is completely covering the ground surface. But from 1968 through 1996 there have been droughts in El Obeid with an average rainfall of only 300 mm and a short growing season (Figure 5) as was experienced at Louga during the same period (Figure 4 in Chapter 2).

The cowpea breeding lines I had developed were being grown at the El Obeid experimental
farm without using pesticides and their condition was good with no major attacks by insect pests, similar to what I had observed in northern Senegal. I became convinced that the strategy for achieving large increases in cowpea productivity that we were using in Senegal also would be effective in the Sudan.

This strategy consisted of developing early flowering, short-cycle cowpea varieties with vegetative-stage resistance to drought for production in very dry areas where there are relatively few attacks from insect pests and diseases. With this system it is not necessary to use insecticides, but row widths and distances between plants must be closer than the traditional 1m x 1m spacing because the short-cycle varieties are erect and more compact than the landraces which have spreading branches. The system I proposed to the Government of the Sudan for increasing cowpea production did not require many changes or additional inputs and thus might be easy for farmers to adopt. The closer seed spacing was a potential problem in the Sudan. In the Peanut Basin of Senegal, many farmers have small one-row planters that are pulled by horses, and it is relatively easy for them to adjust row widths and seed spacings in the row with only small effects on labor requirements. In the areas of Sudan I had visited, farmers usually sowed cowpea seed by hand. The recommended increase in planting density would substantially increase labor requirements at a time when labor is in short supply because the work must be done quickly to achieve an optimal sowing date. With respect to other considerations, the system I recommended appeared to be sustainable and should not cause problems for either the environment or human health.

While visiting a village to the west of El Obeid, farmers told us that cowpea and pearl millet were favored foods for the evening meal during the month of fasting for Ramadan. They said that these foods enabled them to withstand the rigors of working in the fields during the daylight hours when fasting required that they neither eat nor drink. I have heard similar stories about the value of cowpea for sustenance from California farmers who talked about the dust bowl period in the United States in the 1930s. During this time, millions of people migrated westwards to escape the bad conditions due to drought and other problems in the Great Plains. Many people had traveled from Oklahoma to Bakersfield, California under extreme circumstances, and they now worked long hard days picking cotton. The people from Oklahoma relied on a mid-day meal of blackeye peas, which
are cowpeas, to help them to survive the harsh conditions. On our return from the village to the west of El Obeid, we were caught by a violent sand storm and had to wait inside our vehicles until it subsided. Traveling on camels or horses in these conditions, the practice of many local people, would have been very difficult.

**Cowpea grain storage methods and the misuse of pesticides**

During my stay in the Sudan, I visited local markets and was surprised to see many bowls of cowpea grain that did not have weevil holes. The vendors told us that the cowpeas were from last years harvest which would have been about 11 months ago. In other parts of Africa that I have visited, supplies of cowpea grain in markets that had been stored for several months usually showed much weevil damage, which consists of perfectly round holes drilled in the seed by the larvae that permit the adult insect to emerge. Damage usually is apparent about two months after harvest and within six months most of the seeds are damaged. Why were the cowpeas in these markets free of damage? I soon discovered the answer. While picking up handfuls of grain, I noticed that large quantities of a white powder had been mixed in with the grain. I asked the vendors and scientists what it was but no one gave me an answer. From the smell of the powder I was fairly sure that it was an insecticide and not one that had been approved for use on grain for human consumption.

On another occasion while in the Sudan I experienced the misuse of insecticide. I was invited to dinner while staying in Khartoum. The evening and food were very pleasant except for one dish, a local beverage. A plant called kerkadeh (*Hibiscus sabdariffa*) is grown as small hedgerows around fields throughout the Sahel. The leaves are used in cooking and the succulent parts of the flowers contain citric acid, which is an organic acid also present in orange juice. These flower parts are used to make a fruit juice drink. Commercial companies in the Sudan and Senegal market this product as a liquid or as a dry powder to which water is added. In Senegal the drink is called bisap and is very refreshing. The host at the dinner party offered me a glass of bisap, it was ice cold and the usual beautiful red color and I was very thirsty, which is often the case after a typical hot day in the Sudan. I took a sip and was horrified to detect the strong taste of an insecticide in the bisap. I had no idea how the insecticide got into the bisap or the glass. The other people appeared to be enjoying the party, so
I felt it was not the time to mention my concern to the host and requested a glass of water.

My reading of the scientific literature and history of the Sudan confirms these casual observations that misuse of insecticide is a major problem for both human health and the environment in this country. Senegal is much more fortunate in that there is less agricultural-use of pesticides than in the Sudan where insecticides were extensively used with the cultivation of cotton in the Gezira scheme. An exception to this for Senegal was a project conducted by the French organization ORSTOM in which soil in parts of the Peanut Basin was fumigated with dibromochloropropylene (DBCP) during 1981 through 1983. These fumigations were designed to control a particular species of plant parasitic nematode (*Scutellonema cavenessi*), which is a small worm-like creature that inhabits the soil and damages roots of plants that are hosts to them. Single fumigations substantially increased yields of peanut, pearl millet and sorghum for up to three years and may be effective up to eight years. Unfortunately, DBCP is quite toxic to humans with respect to both acute and chronic exposures and soil fumigations can result in contamination of groundwater. The ORSTOM scientists considered the risks of groundwater contamination from their small, shallow applications of DBCP to be minimal. However, it probably is fortunate that farmers in the Peanut Basin of Senegal did not adopt this technology because it would have been difficult for them to precisely follow the fumigation practices recommended by the scientists.

Many years later in 2001, Ndiaga Cisse and ISRA scientist Mame Birame demonstrated that certain cowpea varieties may resist this nematode and prevent its multiplication. Consequently, research with crop rotations is needed to see if cowpea varieties with resistance to the nematode can boost yields of subsequent crops of peanut, pearl millet and sorghum in a manner similar to the soil fumigations with DBCP but with no adverse environmental effects.

I am not opposed to the use of pesticides in agriculture or in the home as long as they are used properly. The problem in Sub-Saharan Africa is that farmers may not follow either the recommendations of manufacturers or any government regulations concerning the proper use of insecticides. A specific insecticide may be approved for controlling a pest in cotton but what might a farmer do if a similar pest is destroying a food crop for which the use of the pesticide is not approved. The problem is aggravated if the farmer doesn't know that the insecticide is dangerous to
humans when used on the food crop. The manufacturer may have provided this information on the container but it is not of much use if it is stated in English, since many of the farmers cannot read English. Also the food crop could be inadvertently sprayed with the insecticide by drift if the food crop is being grown in a mixture with cotton that is infested with insect pests.

While attending an international scientific meeting in Accra, Ghana in 1995, I was horrified by a suggestion made by a scientist working for a major international agency. He proposed that African farmers should intercrop their food crops with cotton so that they could ‘benefit’ from spray drifting from the insecticide applied to the adjacent cotton plants. This agency has provided funding to support several projects in Africa that are studying this flawed concept.

Disposal of vessels that had contained concentrated forms of pesticide also can be a major problem in Africa. In poor societies few things are thrown away and those that are discarded by one person can be picked up and misused by others. For example, ‘empty’ pesticide containers should not be used for storing liquids that are consumed or used in cooking. Washing these containers with water will not remove all of the pesticide residue if it is not soluble in water. In contrast, the pesticide residue may be soluble in a cooking oil at levels that are damaging to humans. Some insecticides can have detrimental chronic effects on humans that may not be diagnosed in societies with few medical services.

On returning from the market in the Sudan where I had observed the insecticide powder on the stored cowpea grain, I had a discussion with the Sudanese scientists about pest control methods. I explained that ISRA scientist Dogo Seck and Khady Diop, a Senegalese student working at UCR, had investigated a method being used in Brazil in which cowpea could be stored without using insecticide and without suffering damage from weevils. In this method, the cowpea grain is placed in a drum as soon as the grain is dry enough to prevent fungal attacks. The drum must then be kept closed and sealed such that it is air-tight for at least two months. During this period of time, the respiration of the grain and any insects on or in the grain decreases the oxygen concentration to low levels, and increases the carbon dioxide concentration inside the vessel. After about two months in the closed vessel all life-stages of the weevils --- eggs, larvae and adults --- will have been asphyxiated and killed. The drums of grain should be kept in the shade under trees or in huts so that
they do not become too hot.

Drums that had been used to transport oil or fuel were available in the El Obeid region. After being carefully washed out with detergent and then with water, these drums would be suitable for storing cowpea providing vegetable oil (or grease) is placed on the grooves of the cap to give an airtight seal. Our project had shown that this method for storing cowpea was both effective and economical in the conditions of northern Senegal. Grain has maintained good quality for use as either food or seed after being stored for many months in drums as described above. I had wondered why African farmers had not developed the sealed-vessel technology for storing cowpea grain through many years of empirical testing. It occurred to me that it would have been very difficult for them to build a vessel that was air-tight using locally available materials. The closest I have seen to such a vessel are closed clay pots, which are used to store cowpea as seed for the following season, but they are not completely effective because oxygen diffuses through the clay.

“Africa Tomorrow”

The following year, 1985, I participated in an event organized by a group in Hollywood called “Africa Tomorrow”. The group wanted to know how they could help people in the Sahel. I tried to persuade the actors and other celebrities present to help out by providing used oil drums to African farmers for storing cowpea grain. The technology I proposed would have been very useful because it is effective, simple, and robust. A used oil drum could be used for many years and store several batches of cowpea grain.

Unfortunately, prior to the meeting, the organizers of Africa Tomorrow already had decided to provide funding support for a high technology project involving production of algae in concrete ponds and converting it into a protein supplement for feeding to people. I was fairly certain that the algae project would not be successful in the Sahel. Rural people often are conservative with respect to what they will eat, and high technology machinery does not survive very long in the harsh conditions of the Sahel. Also the main food problems in the Sahel are shortages of both calories and protein which cannot be solved by only providing a protein supplement. My arguments did not convince the celebrities. I wonder what happened with the project of Africa Tomorrow. I have not
seen or heard of any ponds for growing algae for human consumption in my travels in the Sahel. Subsequently, I heard that in later years Africa Tomorrow was promoting the production of Tilapia (a tasty fish) in ponds, which appeared to have more merit than algae production.

Surveys conducted during the late 1990s established that most Senegalese farmers are now effectively storing their cowpea using the drum method developed by the project. Unfortunately, most cowpea farmers in other African countries did not have access to either reasonably priced drums or information on methods for safely storing cowpea grain.*

Living in the town of El Obeid was a challenge in that the electricity and water were turned on only for about one hour in the evening due to fuel shortages. I took my daily shower and shave at this time and then used a kerosene pressure lamp while eating dinner and reading research reports provided by the ARC scientists.

I began preparing my report in which I recommended that substantial opportunities existed for improving and expanding cowpea production and storage in northern Kordofan around El Obeid, and I explained how it could be achieved. I also recommended that there was much less potential for improving cowpea production in southern Kordofan around Kadugli. The expatriate scientists working at Kadugli disagreed strongly with my assessment in that they thought there also was substantial potential for increasing cowpea production in southern Kordofan. They wrote a critical addendum that was attached to my report. Empirical evidence that supports my assessment is presented in chapter 8 on "Diffusion of Cowpea Technology in the Sahel: 1992 - 2001".

When my work was completed, I took the small WSARP plane from El Obeid to Khartoum and a more substantial British Airways plane to London. On the latter flight I asked for a beer with my breakfast, which seemed to surprise the flight attendant. During my three weeks in the Sudan I had drunk virtually no alcohol in deference to the local customs of the mainly Muslim areas that I had visited.

* Refer to chapter 6 on “On-Farm Experiments and Progress for Women in Africa” for a discussion of a method for disinfesting cowpea grain that uses solar heating and is very effective and practical and complements the drum storage method.
Chapter 4. ‘Operation Cowpea’ in Senegal: 1984 -1986

Impending famine in the Sahelian Zone

While working in Senegal in the fall of September 1984, I came to the conclusion that a famine could occur in the Sahelian zone if the extreme droughts of the previous three years (Figure 3 in Chapter 1) continued in 1985. Pearl millet and peanut harvests had been very poor in northern Senegal in 1982, 1983, and 1984, and people told me that most of the pearl millet granaries would become empty during the dry season in the beginning of 1985. Cash reserves were low due to the negligible peanut harvests. Consequently, I went to the headquarters of USAID and ISRA in Dakar, and recommended that they evaluate the possibility of a famine occurring in northern Senegal in 1985, and determine what steps could be taken to prevent it. I then traveled to work in the Sudan as was described in the previous chapter, after which I returned to UCR.

European Economic Community to the rescue

One day in December 1984 while working in my office at UCR preparing lectures for a course on ‘Crop Ecology’, which I taught each winter quarter, I received a telephone call from Emmanuel Mersch. He said he was advising the European Economic Community (EEC) delegation in Dakar and was working on two problems for northern Senegal: impending famine and a serious shortage of seed for farmers. The Government of Senegal was the main supplier of peanut seed and it had only a very small quantity. Government officials had decided that the peanut seed only should be given to farmers in the southern and central zones of Senegal where the expected moderate to high rainfall could assure reasonable yields per unit area sown. They also had recommended that farmers in the north, where lower rainfall was expected to occur, should sow more pearl millet and cowpea instead of their usual fields of peanut.

Emmanuel Mersch asked my opinion of these proposals. I told him that the government decisions concerning peanut and pearl millet were sound but that the proposed expansion of cowpea production, which was based on the promising results from recent field trials by our project, posed some serious problems due to shortages of seed of appropriate cowpea varieties.

Emmanuel Mersch agreed with my assessment and told me that the government had
estimated that 1000 tons (equal to 1 million kg or 2.2 million lb) of cowpea seed were needed for 1985 and had asked the Food and Agriculture Organization of the United Nations (FAO) to help them obtain it. The FAO had been financing a cowpea seed multiplication program in Senegal for several years but doubted that this quantity of cowpea seed could be either found or multiplied in Senegal in time for the 1985 season. The FAO reported that only about 1 ton of cowpea seed was available in official stores. Subsequently, the FAO obtained 150 tons from an aggressive purchasing campaign in many villages. These seed were of local varieties which, though valuable as a source of diverse germplasm, would not produce much grain and food for people if the rainy season was short in 1985 as it had been in all but one year since 1968. The local cowpea varieties require a longer growing season than was likely to occur.

Clearly, most of the cowpea seed required for a major expansion of cultivation could only be obtained outside of Senegal. Emmanuel Mersch explained that the EEC had provided Senegal with $1 million for famine relief and had recommended that some of these funds be used to purchase cowpea seed. In November 1984 President Abdou Diouf of Senegal had approved this proposal and had asked the EEC to launch a cowpea production program in Senegal in 1985.

Emmanuel Mersch told me that ISRA scientists had recommended three possible cowpea varieties: ‘TVx 3236’, developed by the IITA in Nigeria; ‘TN 88-63’, developed by the national program in Niger; and ‘CB5’, developed by the University of California, and asked my opinion of these varieties. I explained that variety ‘TVx 3236’ has a medium cycle from sowing to maturity, resistance to some major diseases and partial resistance to some insect pests. Project research had shown that it could be reasonably productive in northern and central Senegal, but there were concerns about the acceptability of the grain to consumers. We had observed that the grain can develop unsightly brown discoloration of the seed coat in hot conditions and farm families had rated the grain quality of this variety as being low in surveys conducted by our project. Subsequently, the IITA only could provide 150 kg of seed of ‘TVx 3236’. I explained that variety ‘TN 88-63’ had exhibited moderate yields in project trials but had some sensitivity to day length that could cause it to have a long cycle and small grain yields when the rainy season was short. Subsequent investigations indicated little seed of ‘TN 88-63’ was available since the export market to Nigeria had taken most of the cowpeas produced in Niger in 1984. I explained that project research had
shown that the breeding lines I had developed by crossing ‘CB5’ and ‘Bambe 23’ could be more
effective than ‘TVx 3236’ or ‘TN 88-63’ or ‘CB5’ in northern Senegal, but that we did not
have large quantities of seed of those lines. This left ‘CB5’ as the only variety with some adaptation
to Senegal for which large quantities of seed could be obtained. In 1984 ‘CB5’ was the major variety
grown by farmers in California and large quantities of high-quality commercial seed were available.
I pointed out that in our trials ‘CB5’ had performed reasonably well in dry years in the Sahelian zone
of both Senegal and the Sudan.

Early in 1985 I had further extensive telephone discussions with Emmanuel Mersch. I
advised the EEC that ‘CB5’ could be very effective in the very dry conditions of Louga Region due
to its short cycle length, and could be moderately effective in the Central Peanut Basin but that it
should not be planted south of Bambe where wetter conditions often occur (Figure 2 in Chapter 1).
‘CB5’ can be badly damaged by certain insect pests and diseases, such as the pod rots that can occur
when there is frequent rain during pod development.

I also advised the EEC that the cowpea production program should emphasize minimal use
of pesticides. This included using specific chemical seed dressings, which should be applied in
California, and where necessary a specific locally-available insecticide to protect the cowpea from
attacks by hairy caterpillar. A film produced in Senegal of ‘Operation Cowpea’ for the EECs Contact
Magazine shows that the subsequent EEC project gave substantial emphasis to the use of pesticides,
contrary to my recommendations. The EEC was obtaining advice from several people and
presumably some conflicting advice was being given to them.

I also recommended that any surplus cowpea grain that was produced should be stored in
sealed drums with no insecticide being needed at this stage. But this advice also was not followed
by the EEC project.

In addition, I advised the EEC and ISRA that if there was a massive importation of ‘CB5’
seed, they also should take steps to preserve seed of local landraces of cowpea because ‘CB5’ was
not sufficiently adapted to Senegal to provide a long-term solution. In this regard the campaign of
the FAO which collected 150 tons of cowpea seed from villages in Senegal was very useful. Also,
the EEC contracted with two large commercial farms in Senegal to multiply seed of two local
cowpea varieties (‘58-57’ and ‘Ndiambour’) and the ‘TVx 3236’ variety obtained from IITA. The
seed was sown during the dry season in March and April 1985, and provided with irrigation. Seed from most of the crop was harvested in June. This project produced about 50 tons of cowpea seed just in time for planting in the main rainy season which occurred in July in 1985.

By now I had confirmed that many tons of high-quality ‘CB5’ seed were available in California. I advised the EEC concerning procedures for accessing this seed and gave them the name of an organization that could provide them with the names of all companies that could sell seed of ‘CB5’ to them. I did not mention and thus favor any specific company. I also pointed out that time was a major problem in that, for this seed to be of any use it must be in the hands of Senegalese farmers prior to the beginning of the rainy season, which could occur as early as the end of June.

‘Operation Suicide’

Because of the many uncertainties concerning the timetable for importing ‘CB5’ seed, the extent to which farmers would accept this or any new variety, and the rainfall, pests and diseases to be experienced in 1985, many people in Senegal facetiously labeled the EEC and government program as being ‘Operation Suicide’. The various criticisms that were raised about ‘Operation Cowpea’ were legitimate concerns. Importantly, ‘CB5’ had not been tested on farmers’ fields. The project was risky, but other alternatives such as shipping food into Senegal or doing nothing also entailed serious potential problems for the people in the Sahelian zone of Senegal.

‘Operation Cowpea’

The EEC bought 450 tons of ‘CB5’ seed from a commercial company in California. About this time President Abdou Diouf visited President Ronald Reagan in Washington and following this visit the USAID Mission in Senegal bought an additional 200 tons of ‘CB5’ seed from California. The 650 tons of seed were collected in the Central Valley of California, processed and put in 50 lb sacks, and placed on a boat in San Francisco harbor on the 8th of May, 1985. The boat went south in the Pacific Ocean and through the Panama canal, across the Atlantic Ocean to Rotterdam and then back to Dakar, arriving on the 13th of June, 1985. The bags of seed were unloaded in an amazingly short period and delivered to farmers in time for sowing, which began on the 4th of July in the Louga and Diourbel regions. Following a good rain on July 19th there also was substantial sowing on the
21st of July in the Thies and St Louis regions.

Farmers enthusiastically accepted ‘CB5’ seed provided by the program. In addition, farmers planted other seed provided by the EEC and their household seed stocks of local landraces, thereby preserving a diverse set of cowpea germplasm. The EEC and Government of Senegal had put in place a system of advisors including a European who had worked in Senegal for eight years and spoke Wolof. Antoine Leroueil and the advisory team worked hard to make the project effective. The advisors provided farmers with seed, some insecticides and sprayers, and advice on their use and methods for growing cowpea. They had obtained much of their scientific information from ISRA personnel through the efforts of the scientific director of ISRA, Moctar Toure.

The seed was not provided free, farmers had to agree to give back 1.5 kg of seed after the harvest for every 1.0 kg of seed they had received at sowing time. This procedure provided a mechanism whereby the EEC-Government project intended to obtain cowpea seed that would be supplied to farmers for the following years’ planting.

Rainfall was low in 1985, 208 mm in Louga (Figure 3 in Chapter 1) and 398 mm in Bambey, but well-distributed during the growing season. This rainfall provided adequate growing conditions for ‘CBS5’ but not for the other crops sown in the Louga region and Central Peanut Basin that had a longer cycle from sowing to maturity. The program was executed effectively, except that the wrong insecticides were used in some cases and increased rather than decreased damage due to insect pests. Also, some ‘CBS5’ seed was planted too far south, contrary to my advice, and plants suffered from substantial insect attacks and disease problems that occur in the south due to the higher rainfall.

But, in general, ‘Operation Cowpea’ was a resounding success in 1985. The area of cowpea production was estimated to be 128,000 hectares, which is double the average value for the previous 25 years (Table 1). For the first time, I saw large fields of cowpea growing in Senegal with many fields of ‘CBS5’ being in excellent condition. I particularly appreciated a large field of Moustapha Ndongo near Thilmakha. His field had a dense stand of ‘CBS5’ plants sown on rows 50 cm apart with no bare patches or weeds in the field. The plants were actively growing with no symptoms of insect attacks or diseases and had abundant well-filled pods. The field appeared to be producing extremely high yields of grain that were similar to yields achieved on the CNRA, Bambey research station and 6 to 7 times the long-term average yield obtained by farmers in Senegal (Table 1).
Table 1. Cowpea Production Data for Senegal

<table>
<thead>
<tr>
<th>Year</th>
<th>Area Planted</th>
<th>Yield/Area</th>
<th>Production</th>
<th>Rainfall</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Louga &amp; Total for Senegal &amp; St Louis</td>
<td>Louga &amp; Total for Senegal &amp; St Louis</td>
<td>Louga &amp; Total for Senegal &amp; St Louis</td>
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<td>1980</td>
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<td>145,487</td>
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</tbody>
</table>

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Data from the Ministry of Rural Development in Senegal

Rainfall at Louga and the average for the main cowpea production zone (Bambey + Louga)/2

Introduction of ‘CBS’ seed by the European Economic Community and the USAID

Farmers were very impressed by the quality of the ‘CB5’ seed from California. They remarked that every seed that they had sown produced a plant, something that they rarely saw when using their own seed. The seed from California had no weevil damage and a high germination percentage, and it also was protected with a chemical seed dressing that combined a fungicide (arasan) with an insecticide (lindane). This chemical seed dressing was being used by farmers in California and is relatively cheap and safe, and has a bright red color which should have discouraged eating by people. With an impending famine, it was critical that people sow the seed, even though some might want to eat it. Untreated seed would have been slightly more safe for use in this project but much of it might have been eaten. I am not aware of any cases where people ate the seed or were harmed by the chemical dressing on the seed.

Grain yield per unit ground area provides a useful measure of efficiency --- the ratio of what the farmer obtains in relation to the inputs and effort required to produce it, which is related to the area cultivated. In 1985, the average grain yield of cowpea in Senegal as a whole was 543 kg/ha (a hectare is 10,000 square meters which is equivalent to 2.47 acres), and in the northern peanut basin it was 726 kg/ha, which is more than double the average values for the previous 25 years, many of which had more favorable environments with more rainfall than 1985 (Table 1). In contrast, yields of other food crops grown in the Louga region, such as pearl millet, peanut and some local cowpea varieties, were very low due to the short season of rainfall.

Overall production of dry cowpea grain in Senegal was estimated to be 70,000 tons in 1985, which is about four times the average annual production over the past 25 years of only 18,000 tons. The greatest increases in cowpea production occurred in the Louga region. It should be noted that this represents a very large increase in production of 289%. Typical successful agricultural projects only achieve increases in national production of a few percent.

Not surprisingly, with this large increase in national production there were some major problems with marketing the surplus. Export of cowpea grain was initiated to neighboring countries, including Mauritania, Gambia, Mali and Guinea-Conakry, but could not accommodate all of the surplus.¹ Large stocks of cowpea were built up for use as food or seed, but some of it was not stored with effective methods, such as the sealed-drum method developed by the project, and was destroyed by weevils during the dry season.
The second and last year of ‘Operation Cowpea’ was effective but not as successful as 1985. In 1986, there was a reduced level of financing from the EEC and only modest support was provided to promote cowpea production. No cowpea seed was imported, some of the cowpea seed distributed to farmers by the government had poor quality and some seed was provided too late to farmers, arriving after the optimal sowing date. There was more rainfall in 1986 than 1985 (Figure 3 in Chapter 1 and Table 1), but it was poorly distributed in time. The rainy season started extremely late in northern Senegal with sowing occurring in August in some cases, and yields of pearl millet and peanut were very low in 1986 as they were in 1985.

However, the area planted and yield of cowpea in 1986 were still much greater than in years prior to ‘Operation Cowpea,’ and national production of cowpea grain was estimated to be 55,000 tons (Table 1), which is three times the long-term average annual production. In subsequent years, until the second major cowpea extension program in 1993, national cowpea production was smaller than in 1986 (Table 1) due to drought, insect pests, diseases and shortages of seed, and the area sown to ‘CB5’ progressively decreased.

**What did we learn from ‘Operation Cowpea’?**

My overall assessment is that ‘Operation Cowpea’ was very successful for famine relief but much less successful for long-term development in that the varietal and seed-supply components of the new system that were introduced were not sustainable. The project did show that early cowpea varieties could be useful, but also that a specific type of early variety was needed that had greater resistance to various biotic stresses and thus would be more robust than ‘CB5’. In addition, it was clear that systems were needed for producing high quality cowpea seed, and making it available to farmers on credit. Also, an export marketing infrastructure was needed to sell cowpeas to neighboring countries for the cases where production exceeded the domestic demand in Senegal. The amount of exporting of cowpea grain that occurred in 1985 and 1986 indicated, however, that the potential existed for Senegal to become a major exporter of cowpea grain to other African countries.

The success of this famine-relief effort may be seen from the following data and concepts. The total cost of ‘Operation Cowpea’ was about $2 million, which is much less than the more than $60 million that would have been required to import and distribute 89,000 tons of cowpea grain for
use as food. The 89,000 ton value is the estimated total increase in production of cowpea grain achieved by ‘Operation Cowpea’ in 1985 and 1986 over the average production for 1960 through 1979 given in Table 1. Also, the alternative approach that often has been used to combat impending famine --- importing food and distributing it free of charge --- can severely depress local agriculture, hinder self-sufficiency and have major long-term negative effects on rural development.

In general, when the possibility of future famines appears on the horizon, it is preferable to take steps to promote local food production, if there is sufficient time. Potential famines can be predicted about one year ahead in the Sahel, as I did in September 1984 and again in September 1992.\(^*\) A major beneficial long-term consequence of ‘Operation Cowpea’ was the realization by many people that through the use of early varieties, cowpea could become a major crop in the Sahelian zone of Senegal and other African countries. Another beneficial consequence of the project, especially for women, was the establishment of the ‘green pod’ industry in Senegal, which will be discussed in the next chapter on "Cowpea and the ‘Hungry Period’ in the Sahel."

\(^*\) Refer to chapter 8 on “Diffusion of Cowpea technology in the Sahel: 1992 - 2001” for a discussion of the second potential famine and some of the parameters used in famine prediction.
Chapter 5. Cowpea and the ‘Hungry Period’ in the Sahel

Fresh southern peas

One of the surprising features of ‘Operation Cowpea’ was the large number of bowls of near-mature, but green, pods of cowpea that began appearing on roadsides in Senegal in late August 1985. The Senegalese newspaper ‘Le Soleil’ described the green pods as being a new type of food. When shelled, these pods produce what is known in the United States as fresh southern peas, which after boiling produce what is widely regarded as one of the tastiest cowpea foods.

I have not seen cowpea in the form of fresh southern peas in markets in Africa, except for in Senegal beginning in the summer of 1985. In contrast, immature green pods of cowpea are sold in some markets, such as in Nairobi, Kenya, as an alternative to Phaseolus-type green beans. They also are a popular food in Trinidad where they are called ‘bodie beans’. In addition, immature green pods of cowpea are a popular food in India, Pakistan and other parts of Asia. Two types of cowpea varieties are grown for producing a crop of immature pods: bush type plants, and climbing types that produce very long pods. The climbing types of varieties are called Sesquipedalis or yard-long bean or asparagus bean but genetically they are very similar to other types of cowpea. When cooking immature pods of cowpea they often should be boiled for less time than is used with Phaseolus-type green beans (snap beans) or they will not remain firm. In locations and seasons where it is too hot and dry to grow snap beans, snap cowpeas can be grown instead, but special varieties of cowpea should be used that have tender succulent pods.

Convenient lunches

In Senegal the near-mature pods of cowpea with well-filled seeds usually are boiled intact. Then the consumer has to shell the pods to obtain and eat the fresh southern peas. It might be preferable for people to shell them prior to boiling as is done in the U.S. This could reduce the extent to which any pesticides and other residues that might be on the pod surface from getting into the cooking water and the food. Nevertheless, on several occasions I have enjoyed a mid-day meal of southern peas from boiled pods in villages in Senegal while visiting on-farm experiments with the ISRA cowpea research team.
The southern peas made a nice change from our typical lunch taken on the road which consisted of half a baguette partially split using a knife with a can of sardines in vegetable oil poured into the loaf. These sardines are very attractive to flies so we tried to eat them out in the countryside and away from livestock. This is a convenient lunch in that fresh French baguettes are available most days in most towns in Senegal, and cans of sardines can be carried in vehicles for long periods without spoiling.

For our lunch of southern peas, we would sit in a circle around a bowl of cooked pods. We shelled the pods and ate the fresh peas, mainly only using the right hand. At the same time we had discussions with the villagers. This provided a good opportunity for the research team to obtain opinions from farm families about the potential new cowpea varieties and crop management and storage methods that were being tested in the villages.

Of particular importance were the opinions of villagers concerning the food quality of the potential new cowpea varieties with respect to their consumption either as fresh southern peas or in different dishes based on dry grain. Useful tests of grain quality can be made in food science laboratories. But, the ultimate test, in my view, is to obtain the opinions of families who have had the opportunity to cook and eat their favorite dishes prepared using different cowpea varieties.

Another useful test is to go back to villages a few years later and determine the extent to which farmers are growing and eating any of the new varieties. Valuable information can be obtained by asking farm families why they have chosen certain varieties and are not growing or eating the other potential new varieties that had been included in the on-farm experiments they had conducted in earlier years. When discussing different varieties with farmers, I recommended that my colleagues not solely rely on varietal names, which can get changed during their extension by the villagers. I recommended that my colleagues should carry small packets of seed of the different varieties and show them to farmers, since their distinctive colorings, marks, shapes and sizes were usually well recognized by people. Information from villagers concerning what they did and did not like about the different varieties was used to modify the breeding methods such that traits desired by the farm families were incorporated into the design of the next new cowpea varieties that were being developed by the breeding program.
A cheap nutritious meal

Fresh southern peas and dry cowpea grain often are cooked with a cereal, such as pearl millet or rice. When one part of cowpea grains (on a dry weight basis) is combined with about three parts of cereal grains, they make a food with a near-complete and balanced set of nutrients. It only is necessary to add some green leafy vegetables, such as boiled leaves of cowpea, fruit and a little vegetable oil to obtain what should be a complete healthy diet. Cowpea grain provides substantial protein (about 25%) and carbohydrate (about 64%), and thus food energy, and various B vitamins, including folic acid which is particularly important for pregnant women. As of 1993 the U.S. Recommended Dietary Allowance for folic acid was 200 micrograms per day for men and 400 micrograms per day for pregnant women. The larger amount of folic acid recommended for pregnant women is thought to be useful for preventing birth defects in their developing babies involving the brain (Anencephaly) or spinal cord (Spina Bifida). Cowpea grain is one of few foods that contains substantial quantities of folic acid. Studies have shown that one cup (170 g) of cooked cowpea grain can contain about 400 micrograms of folic acid; although some variation can occur depending on the cooking method and possibly the variety.

The cereal in this diet would provide much of the carbohydrate (and food energy) and some protein with essential amino acids that complement those present in the protein of the cowpea. For example, protein from cereal grains has a higher level of methionine than does protein from cowpea grain, whereas protein in cowpea grain has a higher proportion of lysine than do the proteins of grains from pearl millet, rice, wheat and most varieties of maize. When one part of cowpea grain is combined with three parts of cereal grain, the mixture has the equivalent of about 13% high quality protein, depending on the protein content of the cereal, which can vary substantially, and processes such as dehulling of the cereal which can result in a loss of protein.

Customs concerning cowpea as a food

Many people living in the southeastern United States believe that eating a plate of blackeyed peas (cowpeas) and rice on New Year’s Day brings luck but the origins of this old custom are mysterious. People in Austerfield, a village in Yorkshire, England where I grew up, had many superstitions that I tended to question. My father always insisted that he should be the first person
to enter the house on New Year’s Day, and he always brought a lump of coal with him. Local custom had it that it brought good luck to have a man with ‘dark hair’ or ‘dark eyes’ be the first to enter the house, particularly if he carried a piece of coal. Sue Hubbell speculated that this may be the origin of the custom involving eating ‘blackeyed’ peas on New Year’s Day in the United States, but she pointed out other possibilities also. The ‘Hopping John’ dish is very popular on New Year’s Day, and one of the delicious recipes for this dish used by my wife Bretta is described below.

‘Hopping John’ recipe

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>½ lb (454 g) dry blackeyed peas</td>
<td>½ US teaspoon (2.5 ml) salt</td>
</tr>
<tr>
<td>3 US cups (710 ml) hot water</td>
<td>½ US teaspoon (2.5ml) garlic salt</td>
</tr>
<tr>
<td>2 US tablespoons (30 ml) olive oil</td>
<td>½ US teaspoon (2.5 ml) oregano</td>
</tr>
<tr>
<td>1 US cup (237 ml) chopped onions</td>
<td>2 US cups (473 ml) chicken stock</td>
</tr>
<tr>
<td></td>
<td>1 quart (946 ml) hot steamed rice</td>
</tr>
</tbody>
</table>

Rinse the blackeyed peas in cold water and remove any debris and defective grains. Place the blackeyed peas in a pan, covering them with hot water (about three cups). Bring the blackeyed peas and water to a boil. Let them boil for two minutes and then remove the pan from the heat and let it stand for one hour. Using another saucepan (about 2 quart or 2 liter in size), cook the onions in oil until they are transparent, and then add the chicken stock and seasonings to the onions. Drain the blackeyed peas discarding the liquid, and then add the blackeyed peas to the chicken stock and onions. Cook slowly until the blackeyed peas are tender but still firm, which will take about 30 minutes. Serve the blackeyed peas in the chicken stock, seasoning and onion mixture over a portion of steamed hot rice. In other recipes ham and peppers are added. The recipe should suffice for about six people.

Note that dry California blackeye beans, such as varieties ‘CB5’, ‘CB46’ and ‘CB27’, that have not been stored for many months imbibe water quickly. Consequently, there is no need to soak them overnight as is necessary with varieties of some other species of dry beans. A similar ‘Hopping John’ dish might be made with fresh southern peas but in this case it would not be necessary to pre-boil them. Simply add the shelled southern peas to the chicken stock, seasoning and onion mixture, cook them for a few minutes and then serve them over steamed rice. If you decide to try this recipe
with fresh southern peas you should test it first because I am only guessing that it will taste good.

**Importance of southern peas during the ‘Hungry Period’**

‘Operation Cowpea’ established the southern pea (locally called ‘green pod’) industry in Senegal. The importance of this industry is that it provides food during a time of year when it can be in short supply in the Sahelian zone, and the sale of ‘green pods’ provides an opportunity for farm families to obtain cash. In the Sahel, harvesting of traditional food crops, such as pearl millet, peanut, and local varieties of cowpea, typically occurs in October and November. Consequently, if previous crops were not very productive and granaries are becoming empty there is a tendency for local food supplies to be depleted by mid August to late September - - this is the ‘Hungry Period.’ which is called the ‘Soudure’ in the Sahel. Considerable quantities of cowpea are consumed as ‘green pods’ in Senegal and sometimes this is the main food that is available to families during the ‘Hungry Period’. In the early 2000s it was estimated that 30% of cowpea was consumed as ‘green pods’ in Senegal. Smaller proportions of cowpea are consumed as ‘green pods’ in Mali and Niger, estimated as being 10 to 15% in 2006. But, as early varieties of cowpea are extended to farmers in the Sahel it is likely that the consumption of ‘green pods’ will increase during the ‘Hungry Period’.

One time when we were eating some ‘green pods’ that had been offered to us in a very poor village, a young boy complained to us that he hated ‘green pods’. Further discussion brought out the fact that this was the main food he had eaten for a whole month. I felt that when he became older he would realize that when there is little other food, eating ‘green pods’ would be preferable to eating grass seeds or the few other wild plant foods available during August.

Cash from the sale of ‘green pods’ during the ‘Hungry Period’ also is important, because it can be used to buy staple foods such as pearl millet or imported rice. The harvesting and sale of ‘green pods’ mainly was done by women. Green cowpea pods can have a price that is about double that of dry cowpea grain on a per pea basis. This estimate was made in the 1994 to 1996 period in Senegal. Consequently, the industry can be lucrative, especially for farm families living close to roads, such as the one between Thies and Louga (Figure 2) that provides many opportunities for making sales to travelers. Some of the vendors shell pods while they are waiting for buyers and put the shelled fresh southern peas in plastic bags, but this product though attractive and more
convenient does not keep as well as intact ‘green pods’. For the longest storage and best taste, shelling of the fresh peas should be done just prior to cooking.

Other foods available during the ‘Hungry Period’ in the Sahel

The types of food eaten during the ‘Hungry Period’ differed in different parts of the Sahel and in different time periods. In the dry northern areas of Yatenga, Burkina Faso that have sandy soils, the two most important foods eaten during the ‘Hungry Period’ were cowpea and white fonio \((Digitaria exilis)\). In the late 1970s when these observations were made, early cowpea varieties were not available in Burkina Faso, so cowpea would not have been as effective as it now is in Senegal. In contrast fonio was an extremely important famine food. Fonio is an agronomically primitive cereal crop that is grown throughout the Savannas of West Africa. Seed typically are broadcast and then covered with a thin layer of soil by hoeing. Landraces of fonio are available with a short cycle from sowing to maturity. A report of a Board of the U.S. National Research Council said “They are perhaps the world’s fastest maturing cereal, producing grain just 6 or 8 weeks after they are planted.” I am skeptical about the claim that fonio can produce grain in as short a period as 6 weeks, but some fonio landraces do have the ability to produce grain during the ‘Hungry Period’. A nutritious and delicious couscous can be made from this grain. However, there are numerous major problems when growing fonio. Yields usually are very low, seeds can shatter and fall to the ground and thus not be harvested, birds are fond of the seed, and the seed are very small such that harvesting, threshing and dehulling are difficult and laborious.

Another even more primitive wild cereal that has been consumed during the ‘Hungry Period’ is kram kram \((Cenchrus biflorus)\). Thousands of years ago kram kram was the dominant cereal crop in the Sahel being a more important food crop than pearl millet. A Senegalese farmer told me that in earlier years when the droughts were very bad, people would eat kram kram during the ‘Hungry Period’. I suspect, however, that very few people in Senegal eat kram kram at this time. Kram kram

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* The average weight of an individual fonio grain is about 0.5 mg whereas a pearl millet grain is about 8 mg and a wheat grain can be 100 times larger than a grain of fonio.
is not deliberately sown on prepared land but grows wild and I have never seen anyone deliberately
harvesting kram kram grain. On many occasions I have inadvertently harvested the mature burs of
wild kram kram while walking in cultivated fields and grazing areas in the Sahel during September.
It is a most troublesome plant. The burs latch onto clothing, covering socks and trousers with a host
of burs that are difficult to remove. Once the burs are mature and black, their spines are very sharp
and will penetrate your fingers when you try to remove them. Later the puncture points in the fingers
can become infected.

Once when talking to a farmer about cowpeas, he taught me a useful trick. I was wearing
cotton trousers and socks, and they were covered with kram kram burs. He had no burs on his
clothes, he was wearing the ubiquitous tough sandals of Africa that had been made in the village
from a piece of an old tire with a canvas strap attached, and just a pair of shorts. We were sitting on
our heels talking and he started removing the burs from my trousers and showed me that if you lick
your fingers prior to doing this the spines do not stick into them.

In my travels in the Sahel I also found that it can be useful to have shoes with tough soles.
Initially, I used a pair of stout walking shoes. These shoes were very comfortable and I could easily
walk many miles in them. But, their soles were not tough enough and on occasions were completely
penetrated by acacia thorns. Subsequently, I used hiking shoes with extremely tough soles that
prevented the penetration of acacia thorns. Avoiding puncture wounds, rapidly removing burs or
thorns, and disinfecting and cleaning wounds are important in Africa. Infections can have graver
consequences in many parts of Africa than in other regions of the world that have more and better
health service centers.

**Types of southern pea varieties of cowpea needed in the Sahel**

Establishment of the ‘green pod’ industry in Senegal in 1985 resulted from two factors: 1)
the introduction of a unique cowpea variety, ‘CB5’, that begins flowering early, and has large grains
and pods that are well-suited to this industry; and 2) the preceding three years of drought, which
increased the tendency for famine and demand for food during the ‘Hungry Period’. The early
flowering variety had a major advantage over traditional varieties for this use because the highest
prices are received for ‘green pods’ that are marketed early in the year when the demand is greater.
In the 1990s the project released a new variety, ‘Melakh’, that is even more effective in Senegal than ‘CB5’ for the production of both ‘green pods’ and dry grain. This variety is described in the next chapter.

‘Green pods’ have now become a popular food in villages and some cities in Senegal. By using different cowpea varieties that begin flowering at different times, farm families can market fresh ‘green pods’ and consume the fresh peas over a period of several weeks both during and after the ‘Hungry Period.’

The fact that the ‘green pod’ industry is mainly conducted by women and for the financial benefit of women was a particularly important consequence of ‘Operation Cowpea’. Living conditions for women can be particularly difficult in the Sahel, as will be discussed in the next chapter which describes "On-Farm Experiments and Progress for Women in Africa".
Chapter 6. On-Farm Experiments and Progress for Women

Experiment station research

Some people have questioned the relevance of research on experiment stations in Africa suggesting that it might be more effective to conduct experiments on farmers’ fields. Some private voluntary organizations conduct experiments only on farmers’ fields. However, important components of our project research in Senegal were conducted on ISRA experiment stations.

Experiment stations are essential for conducting those components of research projects that cannot be done effectively on farmers’ fields. Each year, we grew large populations of plants on the experiment stations for crossing and to increase generations as part of the breeding program. These plants would have been of little value to farmers. In fact many of these plants were not genetically stable and it would not have been prudent to provide farmers with the opportunity to take them for their own use. In addition, early generation breeding lines were screened for resistance to diseases or pests on specific fields on the experiment stations where populations of these potentially dangerous organisms had been deliberately introduced or enhanced under controlled conditions. It would not have been appropriate to release these organisms on farmers’ fields. Trials were conducted each year on the experiment stations to test for varietal differences and management effects on yield. It should be noted that trials on farmers fields do not usually have the careful control of environmental conditions that is possible on experiment stations and thus might not detect varietal differences or management effects that are potentially useful.

On-farm experiments

In 1984 the project also initiated on-farm experiments in Senegal. The on-farm experiments were designed to complement the research being conducted on the experiment stations. We had several reasons for conducting on-farm experiments. One objective of the on-farm research was to test potential new cowpea varieties that had performed well on experiment station fields, under conditions that better approximated average farm conditions.

Conditions on the ISRA experiment stations differed from many farmers’ fields. The soil on the stations tended to be more fertile due to the use of longer fallow seasons, when no crops were
grown on the land, and greater applications of fertilizer than were used by farmers. Also, fields on
the stations were plowed prior to planting. Plowing had been shown to be beneficial to the crop
because it reduced the bulk density of the soil and resulted in enhanced root development. But
virtually all farmers in the Peanut Basin of Senegal did not plow their fields. There are several
reasons for this. The main reasons was that most farmers did not have tractors and could not plow
the land fast enough at the beginning of the season, using animal-traction, to also take advantage of
early sowing.

On-farm experiments also enabled us to test the extent to which the sealed-drum method for
storing cowpea grain is effective under village conditions and this complemented the varietal tests.
It was desirable that farmers store grain of the potential new varieties in conditions that ensured it
would be effective as seed in case they chose it for planting on their main fields the following year.

The on-farm tests enabled us to seek opinions of farm families concerning the cooking
qualities and tastes of the potential new varieties. Consumer appreciation is critical for the
acceptance of new varieties and it cannot be adequately gauged by laboratory tests.

During our visits to the on-farm experiments and villages we also obtained useful
information concerning the constraints that limit cowpea production in different regions of Senegal
and the qualities that new varieties should have.

**Initiating the transfer of technology**

We had an additional reason for conducting on-farm experiments that we did not publicize.
Our grant was for research, and we were not supposed to spend funds on the extension of technology
to farmers. But, we could not assume that our research results and materials would be efficiently
extended to farmers, since the government extension agencies in Senegal were not strong at this
time. While conducting on-farm experiments we also initiated the transfer of technology to farmers.
In addition, while conducting research on farms we increased our interactions with extension
personnel and taught them what we had learned about cowpea, and the new technologies we were
developing. This provided an unanticipated benefit to our project.

One of the Government extension agents who worked with us during this phase of the project
was Mansour Fall. A few years later he began managing the agricultural operations of World Vision
International (WVI) in Senegal. Subsequently, Mansour Fall and WVI made important contributions to the extension of cowpea technology in Senegal and other African countries that are described in chapter 8 on “Diffusion of Cowpea technology in the Sahel: 1992 - 2001”.

By conducting on-farm research our team gained a better understanding of development needs and conditions at the village level. This increased the chances that the technology being developed would be truly relevant and hence more likely to be adopted by farmers.

Problems with on-farm experiments

A major problem of on-farm experiments should be recognized. Many of our on-farm experiments failed to produce any useful scientific information on yield because of different types of unplanned events. For example, uncontrolled livestock, such as goats, ate the plants in some cases. While working in Guinea-Conakry in 1974 I had seen an effective method for controlling the foraging of goats. A herder had tied three sticks around the neck of each goat. The sticks formed a triangle which prevented the goat from removing them from its neck. The ends of the sticks projected outwards about 30 cm (a foot) from the three points where they were tied together, thereby preventing the goat from penetrating fences made of branches that were placed around the gardens. Of course this method won’t work with fields that are too extensive to fence in an effective manner.

Another problem occurred that had pluses as well as minuses, neighbors liked the look of certain cowpea varieties so much that they ‘borrowed’ some pods from plants in the experimental plots to obtain seeds to sow in their own fields the following year. Some of the best varieties had low yields in some experiments due to these premature harvests. This made it more difficult to determine which was the most effective variety based on yield data alone.

Who should conduct the on-farm experiments?

Initially, we worked with farm families as units. This approach has been effective with family farms in the United States and many other countries. We had assumed that if you work with a farm family, all members of the family would benefit to a reasonable extent. It soon became apparent that in Senegalese villages there were at least two overlapping social units -- family units led by men, and women’s groups. We learned that by only working with family units led by men we would neglect
an important part of the community that included some very poor people. Consequently, in future years we expanded the on-farm experiments to include both family units led by men and womens’ groups.

The project hired a Senegalese women socioeconomist, Seynabou Tall, to work for ISRA. Her main task was to enable the project to interact more fully with womens’ groups in the execution of on-farm experiments. It should be noted that Senegal already had made significant progress in the emancipation of women. The groups we worked with were part of a far-sighted government program that helped women to obtain loans and other resources. Seynabou Tall made valuable contributions to the project until 1991 when she was offered and took a much higher paying job with the Canadian Embassy in Dakar. African governments have difficulty retaining talented staff because the various embassies, development organizations and even the private voluntary organizations usually pay much better salaries than do the governments.

My colonial experiences

Further emancipation and empowerment of women are major needs in many Sub-Saharan countries of Africa. When I worked as an extension officer in Tanganyika in the early 1960s one of my European colleagues took a new approach in his work. He decided to hire local women to assist him in his extension work. He argued that most of the people doing the work on farms in his district were women, and the government could best communicate with them by hiring women assistants. The other extension officers only hired men as assistants and, at that time, all of the extension officers were males, most were European and some were Tanganyikan. Some of the European extension officers and higher level administrators criticized the man who hired women assistants. They made crude jokes about him having ulterior motives because extension officers spent considerable time living in villages. But it seems to me that he simply was perceptive and ahead of his time.

The district I was responsible for already had a team of male assistants. I did not hire any new people because no positions became vacant and Tanganyika was soon to become independent. When I arrived in Tanganyika on September 19, 1961 it still was under indirect rule by Britain as a Trust Territory of the United Nations. But on December 9, 1961, Tanganyika gained independence. In
addition to being a full-time extension officer, I also served part-time in a unit of the Special Police force eventually becoming the commandant of this unit. During the transition to independence the unit was responsible for helping the regular police force to insure that the district remained peaceful. On Independence Day many people marched upon the government boma, which caused us some concern, but it simply was to express their happiness at achieving independence. Our small police detachments had developed contingency plans and were on alert status, but we had no need to take any action and the Mara District remained peaceful. The Republic of Tanganyika was established on June 9 1962. Subsequently, I served as a polling officer overseeing the elections which resulted in Julius Nyerere gaining much of the vote (97%) and becoming the first President on December 9, 1962.

There have been many criticisms of colonialism but during my stay in Tanganyika from 1961 through 1963 the members of the colonial service that I met were dedicated to helping the people of Tanganyika. One of the reasons I took the job in Tanganyika was that I had a deep respect for Julius Nyerere. He was born in the Zanaki village of Butaiama in South Mara. I interacted with his elder brother Edward Wanzagi Nyerere while working in South Mara. The Zanaki people had just completed building a dam and were interested in using the water for irrigating crops. Several missionaries who I met in Tanganyika were doing very useful work. Most of the medical care available in North Mara in the early 1960s was provided by missions. They also provided useful educational opportunities. The Maryknoll Fathers who had missions in both South and North Mara spoke highly of Julius Nyerere. He was a catholic and had taught in a catholic school in Tanganyika. The Maryknoll Fathers had partially funded his attendance at a meeting of the United Nations in New York in 1956 and had helped him in other ways. I met Julius Nyerere when he visited the research station at Ilonga in 1963. I would like to have talked to him about the Mara District where he grew up. But as a government officer I felt that you do not speak to *The President* unless spoken to and he did not ask me any questions. I left Tanganyika when my contract ended late in 1963 because I felt that to be most useful in agricultural development I needed to learn more.

**Womens’ involvement in cowpea marketing and processing**

The plight of women in the Sahel has been aggravated by the consequences of the drought.¹
Many men have left their farms to find work elsewhere, and the women must now do much of the farm work. Yet their access to land and other resources can be limited by local customs and the women are seeking alternative ways to earn a living. In addition to cowpea production, the women’s groups have become involved in marketing cowpea as ‘green pods’ and dry grain, and cowpea processing.

In 1995, I visited a women’s group in the small village of Kandala which is northeast of the town of Mékhé on the road from Thiès to Louga (Figure 2 in Chapter 1). The women were making several processed products which were being sold in small plastic bags. These products included: cowpea flour; flour mixtures made from cowpea and pearl millet or maize; cowpea grits for couscous or for the broken rice dishes that are very popular in Senegal; and a high energy snack food for eating on the road, like trail mix sold in the United States, that consisted of a mixture of coarsely ground grains of cowpea, maize and peanut. The WVI was assisting them with the packaging operation.

The amount of work needed to process cowpea can be influenced by breeding. With current cowpea varieties that have dark pigments in the seed coat or eye of the seed, it is considered necessary to remove the seed coat prior to milling. Traditionally this is done by soaking the seed in water and removing the seed coat by hand. This process involves considerable hand labor and the cowpeas are then wet milled. Consequently, the flour can become contaminated by organisms in the water and it also has a short storage life. In Africa water often contains unhealthy organisms. A system now has been developed whereby flour can be produced by dry-milling whole cowpea grain but this method is most effective if the grain has a white seed coat and a white eye.

A variety with all-white seed, ‘Bambey 21’, was bred by ISRA scientist Djibril Sène in earlier years which grows well in Senegal. Advanced breeding lines with all-white seed also have been bred by J. D. Ehlers at UCR for production in California by selection from crosses between ‘Bambey 21’ and California blackeye varieties. Tests conducted by Kay H. McWatters and R. Dixon Phillips as part of a collaborative CRSP project at the University of Georgia at Griffin demonstrated that useful flour can be produced from the lines with all-white seed. They also demonstrated that it is possible to produce the special type of flour needed for preparing the food ‘akara’ by dry milling whole grain and using appropriate screen sizes during the dry milling.

The concept of making cowpea flour by using varieties with all-white seed and dry milling
the whole-grain had not been adequately tested at the village level in Senegal as of 2006. This approach would require less labor to produce the flour, and the dry flour could be stored longer and have fewer contaminants than the cowpea paste produced by wet milling. Presence of the seed coat in the flour may, however, affect the quality of foods made from it compared with foods made from grain from which the seed coat has been removed and this should be evaluated.

**Dishes and products made from cowpea**

‘Akara’ is a popular snack food sold on the streets of cities and towns in West Africa and is one of my favorite foods. Preparing ‘akara’ involves making a whipped paste from cowpea flour, seasoning it and then deep frying small portions of the paste.²,³ ‘Akara’ balls have a bread-like character that resembles cornmeal hush puppies but they have a lighter texture and are much more tasty and nutritious. Recipes for this dish are provided below.

**Making ‘Akara’**

**Step 1.** Either a) soak 2/3 cup (158 ml) of dry blackeye cowpeas in 1 1/3 cup (315 ml) of water until the seed coats begin to wrinkle (about 5 minutes) then remove seed coats by hand keeping the dehulled peas submerged in the water. Note the cowpeas should be dehulled within about 30 minutes from putting them in water to avoid excessive absorption of water. Drain the water and blot dry.⁴  
  or b) soak 2/3 cup (185 ml) of dry blackeye cowpeas in about 2 cups (473 ml) of water for about 4 hours or overnight. Use an electric blender to break the seeds and separate the seed coats. Put the broken seeds in a bowl with sufficient water to float the seed coats and remove them. Discard the water, drain and blot dry.⁵  
  or c) soak 2/3 cup (185 ml) of dry all-white cowpea grains for 25 to 30 minutes and then discard the water.⁴

**Step 2.** Blend dehulled or all-white cowpeas with 1/3 cup (79 ml) of water in an electric blender at low speed to make a smooth paste. This takes about 5 minutes. Use a rubber spatula to scrape the contents of the blender jar occasionally during this step.⁴,⁵

**Step 3.** Transfer paste to a mixer and whip as for egg whites (usually a high speed setting) for 3 minutes to incorporate air and obtain a foamy batter.⁴,⁵
Step 4. Either a) stir in 1 ½ U.S. tablespoons (22 ml) of finely chopped onion, 1 ½ U.S. tablespoons (22 ml) of finely chopped bell pepper, with both items drained of excess liquid, and 1 U.S. teaspoon of salt into the batter.4

or b) add only the salt to the batter and make a dip to go with the akara by frying some chopped onions and chili peppers in vegetable oil, and then adding tomato paste, black pepper and salt to taste.5

Step 5. Drop small heaping U.S. teaspoon (12 ml) portions of the whipped batter into a pan of vegetable oil at 380 °F (193 °C) and deep fry for 3 ½ to 4 minutes until golden brown, turning occasionally. Drain on absorbent paper and serve warm. Each batch makes about 18 akara balls.4,5

A modified ‘akara’ called ‘Acarajé’ may be found in the port city of Salvador da Bahia and other parts of Brazil. For this dish ‘akara’ balls are cooked somewhat as described above but larger ones are used. They are then cooled, sliced and stuffed with coconut flavored shrimp, nuts, chili peppers and cilantro. Following traditions of Afro-Brazilian culture, ‘acarajé’ vendors dress in white hooped skirts and lace blouses like priestesses of candomblé the goddess of the wind. They set up their stalls to sell ‘acarajé’ at sites said to be chosen only after divine consultation.

In the Sahel as in most parts of the world there is a substantial interest in foods that take less time to prepare than traditional foods. Rice, which mainly is imported into the Sahel, often is more popular than the traditional staple food grains, pearl millet and sorghum. Polished rice does not have to be dehulled and can be cooked quicker thus requiring less fuel than pearl millet or sorghum. This is an important factor since fuel always is in short supply due to there being too few trees in most parts of the Sahel. Processed cowpea products are important because they also can be cooked more quickly than can dry whole-grain cowpea.

As women become more involved in field work, marketing, processing and off-farm jobs, the demand for quicker-cooking foods will substantially increase. This already has occurred in the United States with consumers showing less interest in dry blackeye beans and more interest in processed foods that can be cooked more quickly. The cowpea farmers of California worry about the future market for dry blackeye beans, and processed cowpea products are needed that are attractive to U.S. consumers. The UCR breeding program has been developing cowpeas with a wide array of grain types in the hope that some may be useful in processing: all-white grain types, persistent-green grain
types and sweeter tasting ones. The first commercial production of persistent-green grain type
cowpeas, bred by Jeff Ehlers, took place in the Central Valley of California in the summer of 2006.

The cowpea with sweeter tasting grain that UCR is using as a parent in the breeding program
was discovered as a consequence of farmer participation in a CRSP cowpea breeding program
conducted in Cameroon in cooperation with Purdue University. Over several years, farmers chose
a particular breeding line because they said it tasted sweeter. My wife Bretta cooked two lots of a dish
of ‘Hopping John’ using the recipe given in Chapter 5 and either the ’sweet’ line from Cameroon or
a California blackeye variety we had developed at UCR, ‘CB27’. Four of us tested the two dishes and
we all felt the one made with the Cameroon line tasted much better. The dish made with ‘sweet’ grain
wasn’t sweet like a garden pea but it had a pleasant nutty taste and an improved firmer texture than
the ‘Hopping John’ made with ‘CB27’.

Other potential products that can be made from cowpea include ‘bean chips’. I have eaten a
prototype version of these chips made from a blend of cowpea and cereal flours and they were much
tastier than either corn chips or potato chips. The fat- and water-binding, and heat-induced gelation
properties of cowpea flour also are beneficial for some meat-based applications such as vegetarian
burgers. These burgers would be appropriate for those vegetarians who are allergic to products
containing soybean proteins because cowpea proteins do not have these detrimental effects.

‘Mini-kit’ experiments

The on-farm experiments conducted by the project in Senegal have proved to be very useful.
Scientists often make on-farm experiments complicated because they want to study many different
treatments. In contrast, we decided to use simple experiments. We felt that for farmers to work with
us and provide feedback they needed to understand what we were trying to do. We also felt that it was
an imposition on the farmers: that the experiments should be easy for them to manage and provide
a net benefit to them.

We called the approach we used a ‘Mini-Kit’ in that it provided all of the tools and guidance
needed for effective production and storage of cowpea. Farmers could adopt and repeat either the total
system or the individual components that they liked without any further assistance from the scientists.
Initial experiments compared three of the best potential new varieties with a local cowpea variety in
single large un-replicated plots (10m x 10m) with appropriate plant spacing and weed control. In addition, farmers evaluated the effectiveness of drum storage using grain from these varieties, which also enabled them to keep some for use as seed in the following year. In addition, the quality of the grain for producing local dishes was evaluated by farm families.

The replications needed for scientific analysis of the statistical significance of varietal differences in yield and quality were obtained by working with five family units in each village, thereby, having five replicate ‘Mini-Kits’ in each village. The project provided farmers with seeds of the potential new varieties, a metal plate so that they could modify their horse-drawn peanut planter to sow one cowpea seed every 33 cm (about a foot), advice on row spacing (typically 50 cm between rows) and other aspects of growing cowpea, and four small metal drums (one for each variety) with advice on their use to store cowpea grain.

Project staff visited the experimental fields. On the rare occasions when insect pests, such as flower thrips or hairy caterpillar, were above threshold levels, they provided the farmers with hand sprayers and insecticides. The insecticides had been used in Senegal for many years and were approved for this use by the government. In most years many of these on-farm experiments have not been sprayed with insecticides.

The simple design developed for the on-farm experiments was popular with farmers and very effective. Initially the project worked with family units led by men, but while visiting the experiments, women came to see us and asked to be involved in the research. Subsequently, Seynabou Tall arranged for several women’s groups to conduct ‘Mini-Kit’ experiments.

**Results of the ‘Mini-kit’ experiments**

The on-farm experiments demonstrated that two of the potential new varieties from the ISRA breeding program of Ndiaga Cisse, ‘Mouride’ and ‘Melakh’, were robust, productive, and acceptable to farmers, whereas others were not as effective or as popular. The on-farm evaluations also demonstrated that the sealed-drum storage method was very effective once farmers understood how to apply it. A key feature of the method is that the drums should be filled with grain and must then be carefully closed placing vegetable oil or grease on the grooves of the cap and not opened for at least two months to permit the anaerobic conditions to develop that will kill the weevils.
Another storage method we considered was less useful for bulk storage under village conditions. CRSP scientist Professor Larry Murdock and colleagues at Purdue University and collaborating scientists at the national research program in the Cameroon had shown that by mixing cowpea grain with equal volumes of sifted ash from fires it is possible to reduce weevil attacks. This method of storage is effective. But the farmers did not have enough ash to store substantial quantities of cowpea in this way. The ash method is useful for storing the small amounts of cowpea seed needed for the next year’s sowing.

The scientists from Purdue University and the Cameroon also developed a useful practical method for disinfesting cowpea seed based on solar heating. Temperatures of 57 to 70°C (122 to 158°F) for one hour will kill all stages of the cowpea weevil without harming the germination capability of dry cowpea seed. These temperatures can be achieved by placing a layer of cowpea grain on top of a black plastic sheet that is placed on top of dry grass to reduce the amount of heat transferred to the soil. The grain is then covered with a transparent plastic sheet that is stopped from blowing away by bricks, stones or logs placed along the edges of the plastic sheets. This procedure is begun late in the morning on a sunny day and within two to four hours this system will generate the temperatures needed to disinfest the cowpea seed without harming its germination capability. The grain must then be placed in closed containers to prevent any re-infestation by weevils.

The solar-disinfestation method is useful if the cowpea grain has become infested with many weevils during harvest and threshing. But if the cowpea grain has been promptly harvested and threshed, such that it has a low level of weevil infestation, then it only is necessary to use the sealed-drum storage method. Grain from the drum-storage, solar-disinfestation and ash methods is suitable for use either as food or as seed.

**Constraints for cowpea production in the Sahelian zone**

By examining the on-farm experiments we gained information about additional problems and possible solutions. In many but not all areas of Africa where cowpea is grown, plants are attacked by a parasitic weed, *Striga gesnerioides*. Seeds of the weed germinate when they sense a chemical signal produced by roots of cowpea. The Striga seedling produces a structure that attaches to and invades the roots of the cowpea and then produces an above ground shoot and subsequently the plant produces
flowers and many very small seeds. *Striga* is parasitic in that it obtains most of its carbohydrates, inorganic nutrients and water from the cowpea plant to which it is attached. In some parts of Africa, such as the Mandara Mountains of northern Cameroon, *Striga* can completely devastate cowpea plants and substantially reduce their grain production.

Initially, we thought the *Striga* species that attacks cowpea was not present in Senegal. But, we placed one of our first on-farm experiments in the village of Ndatt Fall, which is east of Mheké on the road to Thilmakha, and soon discovered substantial infestations of cowpea *Striga*. Subsequently, we discovered that many of the cowpea producing areas of Senegal were infested with cowpea *Striga*, including the village of Ngalbane which is close to the main experiment station at CNRA, Bambey. Consequently, ISRA assigned a high priority to solving this problem.

I can only conclude that in earlier years, when I had not noticed the *Striga* on cowpea in Senegal, I must have been walking through the fields with my eyes shut. This is not to be recommended. On one occasion I was walking through a plot of cowpea plants growing on a ‘Mini-Kit’ experiment on a farm in Senegal. The cowpea plants were about 60 cm (two feet) high and growing vigorously and completely covering the ground. I was just about to put my foot down when I noticed a red handkerchief tied to a nearby cowpea plant. I then noticed that next to the handkerchief and under my raised foot there was a large snake, coiled up but resting. Just in time, I took my foot back and retreated to the edge of the field. The snake was a gaboon viper and highly poisonous. I had just reached the stage of transferring my weight to the foot poised above the snake. If I had stood on it there is a good chance that I would have been bitten. I might have died since the nearest hospital was many miles away over poor roads.

The farmer who had first observed the snake had left his handkerchief there to warn others. I wondered why the farmer had not killed the snake and wished that someone had told me about it as we walked from the village to the field. But, I suppose it was a common occurrence for the farmers to see snakes in their fields.

When I first went to work in Africa in the early 1960s, I adopted the system of walking behind African farmers as we went through the bush. The farmers were far more perceptive about potential dangers than I was and this system enabled me to observe the conditions of the crops and countryside without worrying too much about what I might be stepping on or too near to. Later when I walked or
hunted alone in the savanna, bush and forested areas I learned to be careful about where I put my feet and hands.

We soon discovered a partial solution to the Striga problem for cowpea in Senegal. Cowpea plants of one of the ISRA breeding lines exhibited virtually no attacks by Striga, even though neighboring plants of other lines were devastated. The resistant line was released by ISRA as the new variety, ‘Mouride’, in 1992 and proved to be very successful.

Farmers in the village of Ndatt Fall benefited from the new variety much earlier than 1992 because they had obtained seed from the on-farm experiments conducted on their farms. Their fields were so badly infested with Striga that, with the farmers’ permission and assistance, ISRA used some of their land as a nursery to screen cowpea breeding lines for resistance to Striga.

The discovery that ‘Mouride’ had resistance to Striga was due to serendipity. We had not known that one of the parents used in breeding ‘Mouride’ had resistance to some of the biotypes of Striga present in Senegal. When the cross was made we did not even know that Striga was a problem for cowpea in Senegal. It is surprising that while selecting ‘Mouride’ from the many progeny from the cross, the resistance to Striga had not been lost. We also were lucky in other ways in that the parents used in the cross that produced ‘Mouride’ had resistance to some other stresses, including drought, heat, two seed-borne diseases and cowpea weevil. Only the resistance to drought and weevils was known to be present in the parents at the time the cross was made. The two parents Ndiaga Cisse had chosen for the cross were well-adapted to Senegal and West Africa and the decision to make this cross was sound. Breeding is a numbers game and an art, many crosses should be made and thousands of progeny should be produced and evaluated with the recognition that only one or two have the chance of being good enough to be released as new varieties.

Subsequent research by ISRA scientist Moctar Wade showed that the resistance of ‘Mouride’ to Striga is only partially effective. He also discovered that certain IITA lines bred by B. B. Singh at the IITA substation at Kano in Nigeria have very strong resistance to the Striga biotypes present in Senegal. The challenge for ISRA is to now transfer the gene responsible for this very strong resistance from these IITA lines into genetic backgrounds that enable the varieties to be useful to farmers in Senegal.

While visiting on-farm experiments and adjacent fields, the team discovered that numerous
cowpea plants had symptoms of two diseases that can be transmitted in seed. Bacterial blight symptoms were present in some erect varieties, such as ‘CB5’ and ‘Bambey 21’; whereas cowpea aphid-borne mosaic virus symptoms were present in some spreading varieties, such as ‘58-57’ and ‘Ndiambour’. This represented a major problem because disease organisms that are carried in seed can be particularly damaging. These disease organisms can rapidly infect subsequent crops even if only a few of the seeds are infected. Early in the growing season, the few infected seedlings are sources of the pathogen that then can be spread to many adjacent plants by either the feeding of cowpea aphids (these insects can transmit the virus) or drops of rain water (which spread the bacterium).

Also, since these disease organisms are transmitted in the seed this problem continues to get worse where there are no public or private agencies that are producing significant quantities of healthy seed for use by farmers. Effective seed-producing agencies were not present in Senegal or many other African countries during the years of this project. In more technologically developed parts of the world, such as California, public agencies and seed companies cooperate in insuring there is an adequate supply of healthy, pathogen-free seed of good quality. Farmers have the cash or credit that enables them to buy new seed. The extension service in California recommends they buy new seed every year.

This is not the case in Senegal where farmers typically use cowpea seed from their previous year’s crop. Consequently, ISRA scientist Mbaye Ndiaye immediately began to screen cowpea breeding lines to search for resistance to the diseases. The CRSP project had hired Mbaye Ndiaye because expertise in plant pathology was critical if progress was to be made in breeding cowpea varieties with resistance to diseases. He was advised in this work by an expert on the bacterial blight disease who worked with me, Dr. P. N. Patel, and an expert on viral diseases of cowpea, Dr. R. O. Hampton of the Agricultural Research Service of USDA based at Oregon State University. Subsequently, Mbaye Ndiaye spent a few weeks in the laboratory of Dr. Hampton and learned some advanced serological techniques for detecting viral diseases in plants.

After he returned to Senegal, the CRSP project purchased the equipment and supplies that Mbaye Ndiaye needed to apply the techniques to facilitate his screening for viral diseases. The new varieties that resulted from the work conducted by Ndiaga Cisse, Mbaye Ndiaye and Samba Thiaw
(‘Mouride’ and ‘Melakh’) have resistance to both of these diseases. They do not become infected and they do not transmit the disease in their seed. ‘Melakh’ also has resistance to the cowpea aphid and partial resistance to flower thrips; therefore it is less likely to require sprays with insecticide than other cowpea varieties in Senegal. ‘Melakh’ was officially released as a new variety in Senegal in 1996. It had been pre-released in 1993 as a consequence of an extension program of World Vision International which is described in chapter 8 on “Diffusion of Cowpea Technology in the Sahel: 1992 - 2001”.

The team also discovered that the ashy stem blight disease can be a problem for cowpea in some hot dry conditions in Senegal, as it is in Botswana. Strong resistance to this disease had not been discovered in cowpea (and has not yet been discovered or at least comprehensively described as of 2006). Experiment-station tests by ISRA scientist Mbaye Ndiaye demonstrated that growing pearl millet may partially suppress this soil-borne disease organism. Thus cowpea grown in the same field after two or more crops of pearl millet may suffer less from ashy stem blight than cowpea grown on the same land as a previous crop of cowpea.

This indicates that rotations of sole crops of pearl millet and then cowpea may have some advantages compared with the species intercrops typical of many cowpea production zones of Africa where several crop species are grown together in the same field. There is considerable controversy about whether species intercrops or rotations of sole crops are the most effective systems for the future for many parts of Africa, and this topic is discussed in the next chapter on "Improved Cowpea Production Systems for the Sahel and California."

For the Sahelian zone of Senegal the main crops, pearl millet, peanut and cowpea, are almost always grown as sole crops. The only exception is at the wetter boundary of the cowpea production zone near CNRA, Bambey. In this area, Séréré farmers traditionally have grown cowpea as a relay intercrop with pearl millet, called the ‘derobé’ system. In this cropping system, pearl millet is sown into dry soil and germinates at the beginning of the rainy season. Just before the pearl millet plants begin flowering, cowpea seeds are sown in between them. The cowpea plants mainly grow during September, October and November relying on moisture stored in the soil. Unfortunately, droughts made the relay intercrop ineffective for producing cowpea grain in most years from 1968 to 1998 in the area near Bambey. Relay intercropping can be very effective, however, in wetter years and
locations that have an adequately long growing season. Pearl millet yields are not reduced by this relay intercrop and the cowpea plants flower and produce pods in the dry season when there is less damage from flower thrips than during the rainy season.

Hairy caterpillar can be a major pest of cowpea. The project was quite familiar with this problem. The man who led the cowpea team in Senegal for several years, Dr. Mbaye Ndoye, had studied the biology and ecology of hairy caterpillar as part of his thesis for which he obtained his doctorate from L’Universite Paul-Sabatier de Toulouse, France in 1988.*

In some years and locations, hairy caterpillars have totally destroyed cowpea seedlings in the Sahelian zone of Senegal. Yet if the cowpea plant is large when the caterpillar infestation occurs, the plant can grow fast enough to escape serious damage.

We made an observation in an on-farm experiment where several women were removing hairy caterpillars by hand that suggested a possible solution to this problem. A man showed us plants of a local crop called beref (*Citrullus vulgaris*) that were growing next to the cowpea plants and were completely covered with hairy caterpillars. The hairy caterpillars appeared to prefer feeding on the beref plant and be attracted away from the cowpea plants. Could beref be sufficiently attractive to hairy caterpillars to enable cowpea sown in mixtures with beref to grow past the seedling stage where it is vulnerable to attacks by hairy caterpillar? The mixture should not have too many beref plants because the seeds it produces are not as valuable as cowpea grain and hay. This possible solution to the problem of hairy caterpillar has not been tested adequately and should be, because few other solutions are available to farmers.

Another possible partial solution to the hairy caterpillar problem was suggested by the manager of the ISRA research station at Louga, Moustapha Diop. He proposed the team should evaluate whether sowing cowpea seed into dry soil just prior to the first rains of the season, as is done with pearl millet seed, might be effective against hairy caterpillar. The cowpea seed would germinate

*In later years Dr. Mbaye Ndoye worked for the Scientific, Technical and Research Commission of the Organization of African Unity (OAU). Unfortunately, while working for the OAU, Dr. Mbaye Ndoye died in an airplane crash. The crash occurred on February 6th, 2000 just after the airplane left the airport of Abidjan in the Ivory Coast.*
with the first rain and provide the young cowpea plants with a few extra days of growth prior to the
attack by the hairy caterpillars, whose larvae arrive just after the first rains. A few extra days of
growth could result in cowpea plants growing fast enough to survive attacks by hairy caterpillar.
Farmers typically sow cowpea after the first major rain storm has moistened the soil and the seedlings
emerge a few days later than where seed has been sown into dry soil before the rains. There are some
disadvantages of sowing into dry soil. It can be unreliable in that either the seed may be eaten by
insects, if it is not protected by a chemical seed dressing, or the seed can be wasted if it is germinated
by a brief shower that does not provide enough moisture to sustain the seedlings. But cowpea does
have has considerable ability to survive this type of drought. Reliability of the sowing method is
important when either the supply of cowpea seed is limited or the seed is more expensive than farmers
can afford to pay.

Dry sowing of cowpea seed should be tested to determine if it provides sufficient protection
from hairy caterpillar to out-weigh its disadvantages. These tests would need to be conducted over
large areas because typical trials that use small plots are unlikely to provide reliable results. Small
plots of dry-sown cowpea plants surrounded by native grasses might attract much higher populations
of hairy caterpillars per plant than where a whole field of cowpea has been sown into dry soil. With
a large field, many cowpea plants would emerge at about the same time, a few days after the rains
have begun to fall, and the extent that hairy caterpillars attacked individual plants would be small.
Tests of the protective effects of beref plants sown with the cowpea also should be done using plots
as large as the relatively large fields used by farmers if they are to provide relevant results.

These examples show the value of on-farm experiments and the importance of determining
the optimum size of field plots for different types of experiments. They also show how careful
observations and discussions with farmers and other people who have local experience can provide
ideas for developing improved methods for managing crops.
Chapter 7. Improved Cowpea Production Systems
for the Sahel and California

Values and problems of using new crop varieties

People have asked me why our program has emphasized varietal breeding, and put less emphasis on developing improved crop management practices. The simple answer is that for a self-pollinated crop, such as cowpea, where farmers can renew their supplies of seed by using the harvested grain, improved varieties provide a way for increasing productivity and profits that can have very low cost for farmers.

New varieties of annual crops also often are adopted more readily than improved management methods. Farmers tend to resist changing their crop management methods if they and their fathers have been doing them for many years. New varieties can provide an opportunity to enhance extension of new management methods if they have a synergistic relation with the new varieties. An example of this is the combination of early erect cowpea varieties and close plant spacing. The early erect varieties are more responsive to closer plant spacing than the later spreading landraces that were sown at extremely wide spacing of more than 1m x 1m in many cases.

For new technology to be adopted by many African farmers it must be cheap. In principle, farmers have to buy seed of new cowpea varieties only on one occasion, because seed produced on the farm can be used in subsequent years. In practice, because of infection by seed-borne diseases, an occasional cross pollination with other varieties and contamination of seed by mixing during and after harvest, farmers should obtain new lots of seed of new or traditional landrace varieties of cowpea at least every few years.

Seed should be obtained from an agency with the ability to produce pure lots of pathogen-free seed, because cowpeas are susceptible to many seed-borne diseases. However, even with the need to purchase new seed every few years from an agency, the cost to farmers of new cowpea varieties can be very small. Also, the cost of seed of new varieties is not much different than the cost of seed of old cowpea varieties, and relatively small compared with other production costs. It should be noted that the seed of traditional landrace varieties may deteriorate faster than seed of the new
varieties we have developed, because the landrace varieties are susceptible to more seed-borne diseases.

The additional production costs associated with using new varieties of cowpea can be lower than the additional costs of effectively using new varieties of cereal crops. For cereals, obtaining higher yields of grain typically requires the additional expense of greater applications of fertilizer. In contrast, improved cowpea varieties have given greater grain yields than traditional varieties in both Senegal and California with no application of fertilizers. This is a consequence of their ability to fix atmospheric nitrogen and obtain substantial phosphate from infertile soils.

The importance of farmers using varieties that are well-adapted to the local area cannot be overstated. On several occasions I have been contacted by people working for private voluntary organizations who have requested seed of cowpea and other crops for use in the countries where they are working. They said that the farmers in their area had little seed and they wanted to give some to them.

I always refused to provide seed unless the organization could guarantee that an agronomist would test my varieties before any seed is provided to farmers. In these tests, the varieties should be compared with all available varieties, especially local varieties, at the locations where they are to be used. The agronomist must select only the best varieties and they must be very effective in the locations where they are to be grown by farmers. The agronomist or an agency that specializes in seed production should then multiply seed for farmers insuring that it is not infected with seed-borne pathogens and is of good quality.

These procedures are critically important because farmers who plant seed of poorly adapted varieties may work hard for the whole season and then get little or no harvest. These varieties may have been very productive in another country, but this in no insurance that they will produce high yields for these farmers. Our research has shown that varieties of cowpea which are productive in one region often perform poorly in another region. For example, in 2004, the best cowpea varieties available for Senegal, ‘Mouride’ and ‘Melakh’, performed very poorly in California, and the best varieties available for California, ‘CB46’ and ‘CB27’, were not very effective in Senegal.
Hybrid varieties, open-pollinated varieties and inbred-line varieties

An additional problem occurs if farmers in developing countries are given seed of hybrid varieties. The seed that the farmer obtains after the first cropping season with a hybrid variety will not breed true and can produce plants in subsequent seasons that are much less productive than those of the first season. Crop species for which hybrid varieties are available include: pearl millet, sorghum, maize, tomato, onion, watermelon and many other vegetable crops. This is not a problem with cowpea because the varieties are not hybrids but are pure inbred lines that usually breed true-to-type and produce similar plants when the farmer uses seed produced by either his own or his neighbors crops. Landraces and other traditional varieties of pearl millet, sorghum and maize grown in many parts of Africa also are not hybrids and their seed can be effectively reused by farmers.

For cross-pollinated crops such as maize and pearl millet, farmers can attempt to maintain or improve the quality of the seed of open-pollinated varieties by practicing some selection. For maize, some farmers make their selections after the cobs are brought back to the village but this is not the most effective way. The largest cobs may have simply come from large plants that have benefited from the improved soil fertility of an old termite mound and the large size would not be inherited and the seed would not be genetically diverse. Instead, several individual plants should be selected from several areas distributed throughout the field to maintain some genetic diversity in the population. From each part of the field an individual plant should be chosen that is the best among nearby plants in the area based upon heritable useful traits. A cob is taken from this plant and pooled with cobs taken from other individual plants chosen in other parts of the field. Seed from the pooled cobs can then be used as a source of seed for the following year.

Selecting seed in this manner is particularly important for open-pollinated varieties of pearl millet when grown in Africa. There are many related wild *Pennisetum* species in Africa that will cross with pearl millet producing weedy ‘half-breeds’ called shibras that are common contaminants of the farmer’s crop. By selecting plants in the field to obtain seed for the following year’s sowing, farmers can choose plants that do not have weedy traits and have the traits desired by the farmer and hopefully are heritable. Scientist Samba Thiaw, who is a Sérére from the village of Patar in Senegal, said that his father selected plants of pearl millet in the field while obtaining seed for the following year. When selecting plants, he emphasized various traits including grain which had awns,
since these spiky structures can partially deter seed-eating weaver birds.

The development of new varieties has a cost to society. In the United States and many other countries the costs of developing new crop varieties are born by either private companies or the public sector depending to some extent on whether it is possible to produce hybrid varieties for the particular crop species. Private companies tend to favor producing hybrid varieties because there can be more opportunities for making profits than with the inbred-line varieties used for cowpea or the open-pollinated varieties of pearl millet and maize. Hybrid varieties with substantial hybrid vigor can be very productive; consequently, a higher price is justified for the seed. In addition, farmers growing hybrid varieties must buy new seed every year, which further enhances profits for the seed company. Also, companies producing hybrid varieties can easily prevent people from stealing their improved germ plasm. Hybrids do not breed true from their seed, and the company simply has to protect the seeds of the parental inbred lines used to make the hybrids. This can be accomplished by growing them on company farms that have controlled access. Consequently, private companies involved in breeding often have given priority to working on species for which hybrid varieties can be produced that are very effective and very profitable.

**Use of facultative apomixis in plant breeding**

It is unlikely that hybrid varieties of cowpea will be developed for many years, even though our work has shown that cowpea often exhibits substantial hybrid vigor for both early vegetative growth and grain yield. Hybrid seed of cowpea produced using conventional techniques would be far too expensive. In principle, extremely effective hybrid cowpea varieties might be developed using a radical new technology called facultative apomixis, but this technology has not yet been applied commercially with any crop species.

In a review of facultative apomixis, Richard A. Jefferson pointed out that it’s use in plant breeding could result in an agricultural revolution that would be particularly beneficial to developing countries. Apomixis can be used to develop hybrid varieties that have true-breeding seed because the seed would have the genetic constitution of the mother plant. This means that farmers would not have to buy new seed every year. Facultative means ‘switchable’, apomixis would be the default state that enables farmers to reuse their own seed. Breeders would need to use a chemical application or
some other method to switch off the apomixis so that they can make improved varieties by incorporating additional beneficial traits to the current variety.

There could be additional major advantages to the use of varieties with facultative apomixis if an apomictic plant can be developed that does not require pollination for endosperm formation. These varieties could have greater resistance to the many stresses, such as hot temperatures, that impair the pollination of conventional varieties.

Unfortunately, it probably will be very difficult to breed varieties with facultative apomixis, even though some of the genes that are needed may be present in some *Pennisetum* and few other species. It likely will require an approach emphasizing molecular methods to transfer a cassette of genes, with many of the genes not being available in most crop species.¹ Biotechnological methods of gene transfer would have to be used. Commercial companies may not assign a high priority to apomixis since it provides farmers with a means to avoid buying new seed every year. Also, the extent to which hybrid varieties with facultative apomixis retain their hybrid vigor after several cycles of sowing and harvest has not been determined and this may depend on the genetic mechanism of heterosis which has not yet been completely elucidated.²

**Future of plant breeding**

As of 2006 there were only about a dozen active cowpea breeding programs in the world, and I was not aware of any private company that were breeding improved varieties of cowpea. Recent advances in biotechnology, however, may result in private companies becoming more interested in breeding varieties of self-pollinated crops, such as cowpea. A new technique has been developed that would enable private companies to protect the germplasm of crops that normally breed true, such as cowpea. It involves the use of a lethal gene that initially is incorporated by genetic transformation, and prevents the variety from producing viable seed in the next generation. While this biotechnology would enable private companies to protect their investments in developing improved varieties, since it would force farmers to buy new seed each year, it would not be beneficial to the poorest farmers such as those in the Sahel. I was not aware of any private companies that were using lethal gene technologies to protect their crop varieties as of 2006, and I am hoping this technology will not be used.
The future of public breeding programs has been threatened in that many retiring practical plant breeders have been replaced by molecular geneticists. In addition, the presence of applied plant breeding programs in U.S. universities has been criticized by some private breeding companies, presumably because they resent the competition. This is unfortunate because a healthy competition between private and public plant breeders is beneficial to society. The private sector has shown little interest in breeding many of the minor crops thus this work must be done by the public sector. The development of varieties with facultative apomixis probably only will be done by public plant breeders cooperating with public biotechnologists.

Plant breeding programs in universities also provide useful training opportunities for graduate students who wish to work for either private or public plant breeding programs. Unfortunately, as of 2006 relatively few practical plant breeders were being trained in universities in the United States compared with earlier years.

**New cowpea varieties for Senegal**

The new semi-erect cowpea varieties developed by the project in Senegal, ‘Mouride’ and ‘Melakh’, produce more grain but less hay per unit ground area than traditional Sahelian landraces. They do not require any additional inputs, other than more labor to harvest a larger crop, due to their effective fixation of atmospheric nitrogen and resistance to various pests and diseases. Because there is a greater need and a higher price for grain than hay in Senegal, the new varieties are very useful in this country.

In parts of Niger where cowpea hay is very valuable, different types of varieties are needed that are prostrate and spread over the ground surface. Such varieties have the potential to produce much hay but they only produce a moderate amount of grain. The earliest maturing of these prostrate and spreading cowpea varieties have a cycle length from sowing to maturity under optimal conditions of about 75 days. Consequently, they would not be as well adapted for grain production when the rainy season is very short as shorter-cycle varieties, such as ‘Melakh’ and ‘Mouride’.

The resistance to seed-borne diseases that has been incorporated into ‘Mouride’ and ‘Melakh’ enables them to experience less loss of yield due to these diseases and less deterioration of the seed from year to year than some local landraces that do not have resistance to these diseases. This should
enable farmers with the new varieties to use home-grown seed for more years, which is a distinct advantage in developing countries that do not have effective agencies for producing seed.

The resistance to cowpea aphid and partial resistance to flower thrips in ‘Melakh’ results in this variety suffering less damage due to these insect pests and thus requiring less use of insecticide. This also is a distinct advantage in countries, such as Senegal, where most farmers do not have access to insecticides or sprayers, and in places where there is a distinct possibility that insecticides will be misused. The partial resistance to cowpea weevil in ‘Mouride’ complements the sealed-drum storage method providing more complete protection against this storage insect and can eliminate the need to use insecticides during storage. The partial resistance to Striga in ‘Mouride’ is particularly useful for farmers whose fields are infested with this parasitic weed because the resistance is effective and no other practical ways were available to solve this problem for cowpea as of 2006.

‘Mouride’ and ‘Melakh’ have adaptation to different types of drought which together with their other complementary traits enable farmers who grow both varieties to gain a degree of stability. This is of critical importance in the Sahel due to the extreme variability of the rainfall and other factors that influence productivity, such as pest infestations.

One of the main objectives of our collaborative breeding program was to develop varieties with improved adaptation to the extremely dry conditions of the Sahelian zone. This was achieved by breeding many genetically different lines and then growing them in the harsh conditions of the Sahelian zone in several locations for many years and selecting the ones that consistently gave the highest yields. ‘Mouride’ and ‘Melakh’ have excellent but somewhat different types of adaptation to Sahelian conditions. Both varieties have resistance to drought during the early vegetative stage. In addition, ‘Melakh’ is extremely early in that it begins flowering within 34 days and can produce 2000 kg/ha of grain within about 64 days, which enables it to escape most of the late season drought. In contrast, ‘Mouride’ is not as early as ‘Melakh’ and requires about 70 days to mature, the longer cycle enables it to produce more grain than ‘Melakh’ (up to 3000 kg/ha) when there is no late-season drought. ‘Mouride’ also has greater ability than ‘Melakh’ to withstand intermittent drought during the middle of the growing season. The greater resistance of ‘Mouride’ to mid-season droughts may be partially due to its less intense flowering than ‘Melakh’, which has synchronous flowering producing many flowers and pods over a short period of time. ‘Mouride’ has consistently produced
the highest grain yields in most but not all trials, whereas ‘Melakh’ has produced the highest grain yields in those years that have a very short rainy season with no mid-season droughts and has the additional benefit of producing an early yield of high-quality ‘green pods’ during the ‘hungry period’.

Breeding varieties with delayed leaf senescence

We have conducted research to try to overcome the sensitivity of early varieties to the droughts and other stresses that sometimes occur during flowering. We have discovered a delayed-leaf-senescence trait that is present in some California blackeye breeding lines which can partially solve this problem. Graduate student Owen Gwathmey* demonstrated that delayed-leaf-senescence enables early varieties to overcome drought at flowering in that it provides the plants with greater ability to survive the stress which gives them the potential to produce another flush of flowers and pods when environmental conditions improve.4

Varieties with both extreme earliness and the delayed-leaf-senescence trait might be useful at the wetter boundary of the Sahelian zone and in the wetter Savanna zones to the south where the rains often support a growing season of at least 100 days but with occasional mid-season droughts. We developed breeding lines with extreme earliness and delayed leaf senescence that can produce about 2000 kg/ha of grain within 60 days on the first flush of pods, and then another 1000 kg/ha of grain on the second flush of pods providing the rains will support a growing season of at least 100 days. This type of variety is well suited to developing country agriculture where pods are harvested by hand over multiple periods during the growing season. These lines have been screened in Senegal to incorporate resistances to seed-borne diseases and pests, and also have been provided to our collaborators in Ghana and the Sudan. As of 2006, however, there are no indications that varieties will be developed from these materials.

The delayed-leaf-senescence trait provides cowpea with the ability to consistently produce two separate flushes of pods. Interestingly, there is a period after the first flush of pods are produced

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* He had worked on agricultural development projects in West Africa for several years prior to coming to UCR. After leaving UCR, Dr. C. O. Gwathmey obtained a position as a Professor and Agronomist at the University of Tennessee.
when the plant appears to go to sleep in that it stops producing flowers for about 10 days. The ‘sleep’ appears to be internally programmed in that we have not been able to prevent it by different environmental treatments or by removing pods. In earlier years, scientists were not fully aware that cowpea has this flushing behavior and ‘sleep period’, because discovering it required careful daily measurements of flower production. At that time, most farmers and scientists in California who were carefully monitoring their crops to save water, noticed when plants stopped producing flowers (after producing the first flush of pods), assumed that the plants were dying, stopped irrigating them, which caused them to die, and obtained moderately high yields within about 100 days from sowing.

Some farmers, however, kept providing irrigation during the ‘sleep period’ and in some cases the plants recovered and produced additional pods (a second flush). These farmers obtained very high yields that other growers found difficult to believe. During the early 1980s, in grower meetings that I participated in, a few farmers talked about obtaining 60 bags of cowpea grain per acre (this is 6000 lb/acre = 6700 kg/ha). This yield was 3.8 times the current California state-wide average yield. Other growers did not believe that yields of this magnitude were possible. I heard muttered comments from growers sitting at the back of the room suggesting that the farmers who talked about obtaining 60-bag yields must have spent too many hours working in the hot sun.

In the mid 1980s, some of the ‘60-bag-yield’ farmers complained to me that they could no longer obtain the very high yields in some field conditions because the crops were ‘cutting out’. We subsequently learned that when cowpeas are grown in the same field in California for several years, even with alternate year rotations with other crop species, an organism builds up in the soil (we suspect it is the fungus *Fusarium solani* f. sp. *phaseoli*) that causes many plants to die after producing the first flush of pods. The delayed-leaf-senescence gene we have discovered probably provides resistance to this disease possibly by elevating the carbohydrate status of the roots.

We now have obtained world record yields for cowpea grown in large plots. The studies were conducted in the southern San Joaquin Valley of California using a cowpea breeding line that has the delayed-leaf-senescence trait. In these studies, the crop produced 5,628 kg/ha on the first flush of pods in 100 days and an additional 2,547 kg/ha on the second flush of pods by 150 days from sowing to give a total yield of 8,175 kg/ha. It should be noted that it normally does not rain during the summer in this valley so that two flushes of pods can be accumulated on the plants without
suffering damage from pod molds and then harvested by machine at the end of the season.

Unfortunately, the breeding line that provided world record yields also lodges (many of the branches and peduncles fall down by the end of the season). Lodging causes some pods to either suffer from pod rots when they contact the wet soil or be lost when harvested mechanically. We have been breeding cowpea lines that combine the delayed-leaf-senescence gene with resistance to lodging and other desirable traits so that they can more consistently produce very high yields under commercial double-flush production systems. As of 2006 it is not known whether these lines will be released as varieties for use by farmers in the southern San Joaquin Valley of California.

Breeding varieties with heat tolerance

Another objective of our project was to incorporate tolerance to heat. In the late 1970s, we had observed that grain yields of cowpea tended to be smaller at Riverside when the weather was hotter during flowering, and it can be even hotter in the Sahelian zone. Graduate student Mohamed Warrag began our studies of this problem. We had observed that the damage due to hot weather was associated with low pod production. While working in a very hot environment in the Imperial Valley of California, Mohamed Warrag showed that most cowpea varieties either do not produce flowers or if they produce flowers they do not set any pods. In late July and early August this valley can be one of the hottest crop production environments on earth. Daily maximum air temperatures in weather station shelters sometimes exceeded 50°C (122°F) and temperatures near the soil surface would have been much hotter and could have exceeded the lethal limit for people.

Surprisingly, the vegetative growth of cowpea is strong in this environment, but we had to be very careful when working there. Typically we began work at dawn and worked until about 11 am when I required that we stop working and seek an air-conditioned place to drink liquids, eat food, and relax. If we had more jobs to do, we waited until 5 pm and then went back into the field and worked until dusk.

* After leaving UCR, Dr. M. O. A. Warrag returned to the Sudan and subsequently obtained a position as a Professor at King Saud University, Burieda, Saudi Arabia.
Most cowpea genotypes did not produce flowers or pods under these field conditions, even though they exhibited vigorous vegetative growth. Consequently, we hypothesized that the very hot daytime temperatures were damaging a reproductive process but were not significantly damaging processes involved in vegetative growth. We tested this idea using controlled-environment chambers with either hot or moderate day temperatures, and field test sites in hot environments with different levels of shading to reduce day-time temperatures -- but the results were negative. We also tested whether hot roots due to the hot soils were causing the damage -- here also the results were negative. We then tested whether the cowpea shoot is sensitive to high temperatures at night, and the results were very clear. With high night temperature, most genotypes did not produce flowers while others that produced flowers did not set any pods, even though their vegetative growth was vigorous.

The extent that high night temperatures can reduce grain yields of cowpea under field conditions was quantified by Cindi Nielsen as part of her MS Thesis. She used an innovative system involving plastic enclosures that were placed over plants only during the night. These enclosures contained fans, heaters and differential thermostats that raised air temperature a specified number of degrees above ambient air temperature. This work required some dedication in that every day during the early period of flowering Cindi went to the field at sunset to place the enclosures over the plots of plants and then returned at dawn to remove them. With this system, she demonstrated that small increases in night time temperature can cause large reductions in both the numbers of flowers producing pods and grain yield. These and subsequent studies demonstrated that pod set and grain yield of cowpea can be decreased by 4 to 14 % for every degree C increase in minimum night temperature above 16°C (61°F).

But why is reproductive development of cowpea damaged by moderately high temperatures during the night but not by the much higher temperatures that can occur during the day? Graduate student Cass Mutters investigated this question while studying for his PhD and proposed that some specific plant reproductive process that influences pollen or anther development is controlled by an internal rhythm and only occurs at night and is particularly sensitive to high temperatures.

* Since leaving UCR, Dr. R. G. Mutters has worked for the University of California, Cooperative Extension as a Farm Advisor in northern California.
Using controlled-environment chambers, Cass demonstrated that it is high night temperature between midnight and dawn that is damaging, and that high night temperature between dusk and midnight is not damaging. I have a possible evolutionary explanation for the possibility that many cowpea accessions are sensitive to high temperature just before dawn. If plants have a particular developmental process that is sensitive to heat, and if it is under circadian control and can occur at different specific times during the 24-hour period, then natural selection would favor individual plants where the sensitive process takes place during the coolest time during the 24-hour period, which is just before dawn. The problem of cowpea sensitivity to high temperature during the late night-time may be particularly relevant to tropical zones, such as the Sahel. Late night temperatures are much higher in tropical zones than anywhere else in the world.

It should be noted that I am using an agroclimatological definition of zones. Tropical zones are regions where all monthly mean air temperatures are greater than 18°C (64°F) and night-time temperatures are always relatively warm. In tropical zones, chilling-sensitive perennial evergreen plants such as mango grow well all year, do not suffer chilling damage and can be very productive. Damage to plants due to chilling can begin when temperatures become less than 10 to 18°C (50 to 64°F) with variation in the threshold temperature depending on the plant species and plant process that is being damaged.

The widely-used definition of the ‘tropics’ as the region around the equator between the tropic of Cancer and the tropic of Capricorn is not useful for the evaluation of farming and living systems. There are some places near to the equator that are at high elevations and can be very cold. One of these places where I worked in the Southern Highlands of Tanzania was at 9° S latitude but above 2000 m elevation. I experienced hail storms in this place and there were streams with water that was so cool that trout thrived in it. The environment in this location is not typical of the image that people have of Sub-Saharan Africa and it would not support mango trees.

We proceeded to breed heat-tolerant cowpea varieties. We planted cowpea accessions collected from different parts of the world in irrigated field trials in the summer in Imperial Valley. This valley is in the lower elevation desert in southern California and is extremely hot in the summer. We found that out of several hundred accessions only two from Africa would produce flowers and set pods, but they had poor agronomic qualities and would not be useful as varieties.
Patel, who was working with me, crossed these two accessions, ‘Prima’ and ‘TVu 4552’, with varieties from California and Africa. We then screened the progeny in summer field trials in Imperial Valley and selected those that could produce flowers and set pods under very hot conditions and also had other desirable characteristics. Dr. Jeff Ehlers and I have now repeated this process for many years and developed stable lines. In later years we conducted our summer screening for heat tolerance in the Coachella Valley of California because the sandy soil in this valley is more suitable for growing cowpeas than the more clayey soil in the Imperial Valley. One of the heat-tolerant lines we developed, ‘CB27’, was released as a new variety for California in 1999.

Initial studies of the inheritance of heat tolerance in cowpea were conducted at UCR by graduate student Kwadjo O Marfo. He also crossed heat-tolerant breeding lines developed at UCR with cowpea landraces from Ghana and continued making selections for local adaptation after his return to northern Ghana. I visited Dr. K. O. Marfo at the Savanna Agricultural Research Institute in Nyankpala, Ghana in the fall of 1997 and we established a strong collaboration in cowpea breeding. Unfortunately, Dr. K. O. Marfo died in an airplane crash in Ghana on June 5th, 2000. Two of the cowpea lines that he had bred while studying at UCR and selected in Ghana were released as new varieties in northern Ghana in 2003. Line ‘ITP 148-1’ was given the name ‘Apagbaala’, whereas line ‘Sul 518-2’ was appropriately named ‘Marfo-Tuya’ to honor the memory of Dr. K. O. Marfo.

**Heat tolerance is a complex trait**

We encountered several complications when breeding heat-tolerant varieties. Our screening for heat tolerance had been conducted under the long days of summer in California. We subsequently discovered that plant responses to heat also are influenced by day length. Some of our first studies of day length effects on responses to heat were conducted by Ibrahim Dow El-Madina as part of his MS Thesis. The day length effect is related to the complex system that regulates the initiation of

* Since leaving UCR, I. D. El-Madina has worked for the Agricultural Research Corporation at Kadugli in the Sudan.
flowering through influences of photoperiod on a pigment in the plant called phytochrome. Dr. Jeff Ehlers conducted a series of studies in a hot greenhouse that had either long-day conditions of California in the summer or the short-day conditions that can be encountered in some tropical zones in Africa. These studies indicated that our heat-tolerant lines also should exhibit high yields in the tropics but that high night temperatures are much less damaging to flower production and pod set under short-day than they are under long-day conditions. These studies also indicated that some varieties bred and selected for yield in hot tropical zones, such as ‘Mouride’, have greater heat tolerance than others such as ‘Melakh’.

One surprising result obtained by several plant breeding programs is that some varieties of cowpea, tomato, and snap beans that were bred for adaptation to very cold environments also have heat tolerance at flowering. Even though selections were not made from segregating populations growing under high temperatures.

We have discovered a possible explanation for this strange phenomenon. A cowpea line developed for use in Minnesota has heat tolerance at flowering, even though the breeding program had never selected for this trait and had in fact selected for the opposite trait, chilling tolerance. The line, however, is extremely early with respect to the initiation of flowering. We have hypothesized that the earliness is responsible for the adaptation to the short growing season in Minnesota, and that in some unknown way, which may involve the plant pigment phytochrome, the earliness genes also confer heat tolerance during flowering and pod set under long-day conditions.

Our studies with cowpea have shown, however, that selecting only for earliness of flowering does not guarantee that all of the heat-tolerance genes will be selected. Consequently, the breeding conducted in Minnesota also must have incorporated some heat-tolerance genes by chance or by genetic linkage.

Genes can have unintended effects on plants. We developed pairs of genetic lines with and without the genes for heat tolerance during flowering. Then the pairs of lines were evaluated in different environments in California with temperatures ranging from being extremely hot to cool.
by Abdelbagi Ismail.* He discovered that in the hotter conditions the heat-tolerance genes not only confer higher pod set and greater grain yields but they also cause the cowpea plants to be shorter. Abdel also showed that these dwarfing effects have both potential advantages, increasing yield potential of plants grown on narrow row widths [50 cm (20 inches) between rows], and potential disadvantages, increasing weed problems when growing the crop in wider rows [100 cm (40 inches) between rows].

The dwarfing effects can be pronounced in tropical zones, as we have seen when our heat-tolerant plants have been grown in Senegal. In the tropics high night temperatures enhance the dwarfing effect by causing plants to develop faster and be smaller when they begin flowering. This problem potentially can be solved by incorporating juvenility genes that cause the plants to begin flowering at a higher nodal position on the plant, and thus at a later date when they are larger.

These examples show why breeding plants with improved adaptation requires the incorporation of many complementary genes. The pairs of cowpea lines with and without the heat-tolerance genes were evaluated by Dr. K. O. Marfo in Ghana and Dr. Ndiaga Cisse in Senegal. No differences in grain yield were observed among the pairs of lines. This indicates that either these heat-tolerance genes have insufficient value in tropical zones to justify their incorporation into varieties or that complementary genes need to be incorporated that confer local adaptation and thereby enhance the effectiveness of the heat-tolerance genes.

An example of the needed complementary genes is the fact that the pairs of lines were bred for sunny conditions in California and have papery pod walls that make them easy to thresh. But this trait makes them susceptible to the ‘dry’ pod rots that occur under rainy conditions in the tropics. I observed that my heat-tolerant lines often had many pods when growing in Senegal and Ghana but that they did not achieve high grain yields because many of the pods became shriveled.

For the Savanna zones of Africa, genes need to be incorporated that confer enhanced resistance to the several organisms that cause both dry and wet pod rots. ‘Wet’ pod rot can begin at

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* Abdel came from the Sudan and worked with me for several years as a graduate student and postdoctoral scientist. After leaving UCR Dr A. M. Ismail obtained a position as a Crop Physiologist at the International Rice Research Institute (IRRI) in the Philippines.
the point where petals remain on the pod after it begins to form. In some unknown way, the presence of petals promotes the establishment of the fungal organism responsible for ‘wet’ pod rot. Resistance to this pod rot may be achieved by selecting genotypes whose flowers fall to the ground as soon as pod set has occurred.

When breeding plants with resistance to stresses it sometimes is useful to ask whether natural selection would favor the trait. The observation that the heat-tolerance genes cause both increased grain yield and dwarfing suggests a reason why natural selection does not appear to have favored the heat-tolerance genes. In natural populations, plants that are dwarfed would experience a strong competitive disadvantage. The types of plants that perform most effectively in agriculture, in terms of grain yield, typically are not competitive whereas plants favored by natural selection usually are very competitive. Note that the varieties of wheat and rice that were responsible for the “Green Revolution” were semi-dwarfs as is cowpea variety ‘CB27’ when grown in California.

I now knew that the heat-tolerance genes we had discovered could be useful when hot weather occurred at flowering in subtropical zones such as California. But we did not know whether these genes had any value in tropical zones.

Genetic selection studies conducted by Samba Thiaw as part of his Ph.D. studies at UCR indicated that the heat-tolerance genes we have discovered may not be effective under the short-day conditions that often occur in the tropics. He has, however, developed a screening methodology that could be used to search for genes that confer heat tolerance under either long-day or short-day conditions. This method was adapted from a method claimed but not proven to be effective in breeding for heat resistance in other crops such as wheat. The method of Samba Thiaw consisted of taking leaf discs from cowpea plants during the vegetative stage and subjecting the leaf discs to a heat stress consisting of 6 hours in aerated water at 46°C. He then measured the amount of electrolyte leaking from the leaf discs into the water. This provided a measure of membrane thermostability. Genotypes whose leaf discs are less leaky are assumed to have membranes with greater heat tolerance.

Samba Thiaw demonstrated that slow leaf-electrolyte-leakage under heat stress was closely associated with heat tolerance during pod set. The evidence he obtained is quite rigorous. Plants he selected for slow leaf-electrolyte-leakage also had high pod set in very hot long-day conditions. In addition, plants he selected for high pod set in very hot long-day conditions also had slow leaf-
electrolyte-leakage.

Studies are now needed to try to discover cowpea genotypes that have very low levels of leaf-electrolyte-leakage under heat stress for plants grown under short-day conditions. These plants might have heat-tolerance genes that are effective under tropical short-day conditions. Direct selection of cowpea for high levels of pod set under field conditions in the tropics is difficult due to the many other factors that influence pod set in these environments.

The studies of Samba Thiaw also provided a method for speeding up the breeding of heat tolerant cowpeas in subtropical zones, such as California. This method combines a) selection for abundant flower production and pod set in very hot long-day environments, which only can be done in the summer, with b) selection for slow electrolyte leakage from leaf discs subjected to heat stress, which can be done with plants growing in moderate temperatures and short days during the fall and winter seasons in glasshouses. In this way it is possible to achieve three generations of selection for heat tolerance in each year compared with only one generation when only screening for abundant flowering and pod set under very hot long-day conditions. Also, it may be possible to increase the effectiveness of screening advanced generations during the summer in hot long-day environments. During the vegetative stage, families would be screened and families with slow leaf-electrolyte-leakage would be selected. Subsequently, during the reproductive stage, single plants would be chosen from these selected families that also have abundant flower production and pod set.

Heat tolerance genes and global climate change

We have studied how useful the heat-tolerance genes would be in future environments that may result from the combination of elevated atmospheric carbon dioxide concentration and global warming. Graduate student Faisal Elgasim Ahmed * from the Sudan obtained some answers to this question. He subjected different cowpea varieties that either have or do not have the heat-tolerance genes to either elevated or normal atmospheric carbon dioxide concentrations with either optimal or high night temperatures in controlled environment chambers.

* After leaving UCR, Dr. F. E. Ahmed served as a Professor at the University of Khartoum in the Sudan.
His studies provided exciting results. They suggested that under the elevated carbon dioxide concentrations expected by the end of the twenty-first century the heat-tolerance genes might enhance grain yield of cowpea under optimal as well as high night temperatures.\(^{23}\) As a consequence of these studies I was asked to prepare a review of strategies that plant breeders might find useful in developing varieties for future global environments. This issue is important because breeding varieties can take many years and therefore it always is necessary to develop varieties that will be adapted to future, not present, environments.

I invited Dr. Lewis H. Ziska* to help me with this task and we produced the required review.\(^{24}\) We recommended that since elevated carbon dioxide concentration would enhance the photosynthetic capabilities of many crop plants, breeders working with responsive crop species should select for traits that would enhance the utilization of the carbohydrates produced by the enhanced photosynthesis. Presumably, the heat-tolerance genes enhanced the yield response to elevated carbon dioxide concentration because they enhanced the partitioning of carbohydrate to pods, thereby retaining a balance between the greater potential for photosynthesis and the capacity for using the carbohydrates produce by photosynthesis.

**Improving crop management methods**

Developing improved varieties is not always the most effective way for enhancing farming systems. For pearl millet and sorghum grown in the Sahelian zone, the most effective way to increase grain yields may be to increase inputs of nitrogenous and phosphatic fertilizers. Soils in many parts of the Sahel are so deficient in these plant nutrients that, even in years with low rainfall, grain yields of pearl millet and sorghum can be limited more by the small supplies of nitrogen and phosphate in the soil than they are by the drought. For example, analyses by William Payne of data obtained at the

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* Lewis Ziska had been a graduate student with me and as part of his M.S. degree had developed improved methods for managing the irrigation of cowpea.\(^7\)\(^\text{Chap. 2}\) After leaving UCR, L. H. Ziska obtained his Ph.D. at UC Davis. Dr. Ziska then worked at IRRI in the Philippines conducting research on the effects of elevated carbon dioxide concentration on rice. Subsequently, Dr. Ziska worked as a Plant Physiologist studying mechanisms of plant responses to increasing atmospheric carbon dioxide for USDA, ARS at Beltsville, MD.
ICRISAT Sahelian Center near Niamey, Niger indicate that grain yields of pearl millet would have been increased by moderate applications of fertilizer (20 kg/ha N plus 9 kg/ha P) without risking early depletion of soil water even in the dry year of 1984 when rainfall was only 262mm.\(^{25}\)

In years and locations in the Sahel with rainfall less than about 260 mm, however, grain yields of the most effective pearl millet varieties grown with moderate applications of fertilizer are not as high as the grain yields of the most effective short-cycle cowpea varieties, even when little or no fertilizer is applied to the cowpea. For example, in years in the Sahelian zone of Senegal when rainfall was less than 260 mm, cowpea variety ‘Bambey 21’ which has a cycle length of about 70 days had grain yields that were much greater than those of pearl millet variety ‘Souna III’ which has a cycle length of about 95 days.\(^{26}\)

Cowpea is less dependent on nitrogenous nutrients in the soil than cereal crops due to a symbiotic interaction with \textit{Rhizobium} bacteria that results in fixation of atmospheric nitrogen. The symbiotic system of nitrogen fixation by cowpea and bacteria can be very effective. Studies at UCR by graduate student Hassan Elowad (later he changed his name to Hassan Elawad) \(^*\) indicated that cowpea can fix about 200 kg/ha of atmospheric nitrogen,\(^{27}\) which is enough to supply the needs of a productive crop of cowpea and leave some in the soil for the following cereal crop. Project research by ISRA scientist Dr. Mamadou Ndiaye indicated that cowpea exhibited substantial nitrogen fixation in several field sites in Senegal.

One reason for this is that the \textit{Rhizobia} and cowpea system responsible for nitrogen fixation is described as being ‘promiscuous’. This esoteric scientific term means that there are many species and strains of \textit{Rhizobium} that are able to initiate nodulation with cowpea. Fortunately, the nodules often are effective such that cowpea and the associated bacteria fix substantial quantities of nitrogen in most soils. Cowpea is normally sown without applying \textit{Rhizobium} inoculum to the seed. We did not apply inoculum in our field studies and whenever we examined roots of plants, which were more than one month old, we found nodules that were pink inside and probably were effective.

\(^*\) Dr. H. O. A. Elawad returned to work for the Agricultural Research Corporation at El Obeid in the Sudan and made important contributions to the development and extension of new cowpea varieties.\(^{23}\) Chap. 2
There are other reasons why cowpea is more productive in infertile soils than some other crop species. Graduate student Moses Kwapata* showed that associations with mycorrhizal fungi can enhance uptake of phosphate by cowpea, and graduate student Rommel Mesquita de Faria from Brazil continued this work while studying for his Ph.D. at UCR. The mycorrhizal association probably makes cowpea more effective than some other crop species at obtaining phosphate from infertile soils that have low levels of available phosphate. Mycorrhizal fungi are present in most soils and I have not seen a case where roots of cowpea did not become mycorrhizal in the field.

Moses Kwapata also studied the effects of canopy architecture on the productivity of cowpea. He showed that varieties that have many pods displayed above the canopy have a major disadvantage, they have less ability to produce biomass than varieties with few pods displayed above the canopy. The reduced ability to produce biomass is caused by the shading of leaves by pods, because green pods are much less effective in photosynthesis than are leaves.

This presents a dilemma for cowpea breeders developing varieties for use in the wetter Savanna zones of Africa. Pods displayed above the canopy are useful in this environment because they are easy to pick, and the pods suffer less damage from Maruca pod boring insects and ‘wet’ and ‘dry’ pod rots. The adult female Maruca insect prefers to lay eggs in places where pods touch leaves. Where pods are displayed above the canopy they rarely touch the leaves. Also, pods displayed above the canopy dry out quickly after the rain has stopped falling and thus do not suffer from pod rots. But, varieties with pods displayed above the canopy will have less photosynthesis and less potential grain yield.

For California there is no dilemma for plant breeders. We have bred varieties with pods hidden within the canopy which take advantage of the higher canopy photosynthesis and higher potential grain yield. The crop is mechanically harvested and hidden pods do not impede the process, there are none of the Maruca pod boring insects in California, and usually little rain occurs during pod development thus there are few problems from pod rots.

* After leaving UCR, Dr. Kwapata returned to Bunda College, University of Malawi, Lilongwe where he has been a Professor for many years.
It should be noted that farmers sometimes prefer varieties that have pods displayed above the canopy because they think they have higher yields. This results from the farmers seeing many pods on these varieties; however, in some cases it is the varieties with pods hidden within the canopy that have the highest yields. This illustrates how farmer perceptions of which varieties might be superior sometimes are not reliable.

In recent years, I have seen technical assistance projects in Africa where expatriates have gone to villagers and asked them what they feel should be studied. The projects then designed on-farm experiments based on this advice. Some care coupled with application of agronomic expertise is needed when taking this approach. Over the years we have conducted surveys among farmers in both Senegal and California to obtain opinions concerning the traits that should be bred into cowpea varieties and the approaches to crop management that should be studied. We have found that it is necessary to carefully evaluate the results of these surveys. Even though some farmers provided valuable advice, including insights that we have not thought of, many farmers provided recommendations that were not sound from an agronomic standpoint.

The project has developed complementary improvements in crop management methods for cowpea. In Senegal, the new and old varieties benefit from denser plant spacing than was used in the past when the crop was sown by hand. A simple horse-drawn planter used by farmers to sow peanut seed was modified by the project so that it would sow cowpea seed at an optimal density. The modification consisted of providing farmers with a metal disc for the planter that had holes of the right size and placement to accommodate one cowpea seed and provide an appropriate seed spacing in the row. Using a planter has the additional advantage of sowing the seed in rows that are straight enough to facilitate subsequent use of horse-drawn cultivators to control weeds.

Labor shortages for weeding can be a major bottleneck to farming operations early in the growing season in Senegal. I have seen fields of peanut that have been abandoned for the current year because of weeds becoming too large and smothering the crops. These abandoned fields produced virtually no yield of peanuts and often were not harvested. Weeding with a horse-drawn cultivator requires less labor than hand weeding, and enables farmers to overcome the shortage of labor that often occurs during the early part of the growing season when removal of weeds is critical.
I had wondered why farmers in the Sahel often grew cowpeas at wide spacing, sometimes with 1 to 2 m (39 to 79 inches) between individual plants in both directions. I have concluded that this could have been due to either a shortage of cowpea seed caused by weevil attacks during storage or a lack of mechanization and shortage of labor during planting. Typically there are only a few days that are optimal for sowing. In the Sahel, sole-crop cowpea usually is most productive if it is sown during a short period just after the first major rain storm. A substantial area of cowpea must be sown during a few days. When the supply of cowpea seed or labor is limiting, the most effective method for hand sowing is to use a spreading variety and place seed at a spacing of about 100 cm by 100 cm (39 by 39 inches). But with increased supplies of seed, and animal-draft planting methods that require less labor, the highest grain yields can be obtained by using the new semi-erect varieties and sowing them in rows spaced about 50 cm (20 inches) apart with about 33 cm between individual seeds in the row.

Time and labor limitations, also partially account for the wide spacings often used for pearl millet and sorghum in the Sahel, which can be planted as much as 200 cm by 200 cm apart (79 by 79 inches). But other factors are important. It had been suggested that the wide spacing represented an adaptation to the droughts that often occurred, but I made an observation that suggested something else may be more important.

In 1984 I visited farmers fields in the Nuba mountains in the Sudan. I saw an on-farm experiment where sorghum had been planted at two spacings: traditional sparse spacing of 200 cm x 200 cm, and very dense spacing typical of California of 50 cm x 20 cm. Also, either no fertilizer or a moderate amount of nitrogenous fertilizer had been applied to different plots of plants. The plants had reached the middle stage of their vegetative growth and those under dense spacing with no fertilizer had yellow leaves, indicating a nitrogen deficiency. In contrast, the plants grown at wide spacing either with or without fertilizer and the plants grown at dense spacing with fertilizer had leaves that appeared green and healthy.

I concluded that the sparse planting used by farmers is an adaptation to infertile soil. Farmers in this zone had very little manure and virtually no chemical fertilizer with which to enrich the soil. With wide spacing, roots would continually access sufficient soil nutrients from the infertile soil, as they grew, to meet the needs of the plant as determined by the growth rate of the
shoots. In contrast, with the dense spacing, roots of adjacent plants would begin to compete after the seedling stage, and consequently would not access sufficient nutrients from the infertile soil to meet the needs of the growing shoots. Early shoot growth would have been much greater per unit area of land with the dense spacing since there were 40 more plants per unit land area than at the wide spacing.

The analyses of William Payne indicate that high grain yields of pearl millet can be achieved in the Sahel by using moderate plant spacings of about 1m x 1m coupled with moderate fertilizer applications of about 20 kg/ha N plus 9 kg/ha P. Clearly, if farmers growing sorghum and pearl millet are to benefit from closer plant spacing, they must either have access to more manure and chemical fertilizer for enriching the soil or grow cowpea in rotation to enhance the soil fertility through biological fixation of atmospheric nitrogen and the activities of mycorrhizae in their root systems which enhance phosphate uptake.

Pearl millet seed often is sown into dry soil at the beginning of the rainy season. This is a risky procedure because a small rainfall event will germinate the seed, and the seedlings can die if further rain does not occur and there is a prolonged drought. Death of pearl millet seedlings is a common occurrence in the Sahel and farmers often have to replant parts or all of their pearl millet fields with either pearl millet or cowpea seed. Why do farmers take the risk of sowing pearl millet seed into dry soil, why don’t they wait and sow into moist soil?

A simple answer to this question is that agronomic trials have shown that dry-sown pearl millet usually produces more grain than pearl millet that is sown later after a substantial rain event has occurred. A partial explanation for this phenomenon is that during the dry season, mineralization processes occur in the soil, so that at the beginning of the rainy season there is a flush of nitrate. This nitrate is more completely exploited by the dry sown pearl millet than crops that are sown later when some leaching has moved the nitrate below the crop root zone. Greater exploitation of soil nitrate provides a large advantage to cereal plants in the nitrogen-limited conditions typical of the Sahelian zone. Dry-sown pearl millet also has more chance of completing its life cycle earlier and escaping late-season drought, than pearl millet that is sown later after the rainy season has begun. From a seed-supply standpoint having to replant pearl millet fields is not a major problem since only a small amount is needed (about 80 g seed/ha = 1 ounce seed/acre).
Sole-cropping versus inter-cropping with different species

People have asked me why our project has emphasized sole-cropping when most cowpea production in Africa involves the use of inter-cropping of cowpea with other crop species. A simple answer to this question is that the project has been most active in Senegal. Since 1980 virtually all of the crop production in the Sahelian zone of Senegal was by large sole-cropped fields of pearl millet and peanut, and small sole-cropped fields of cowpea. Subsequently, we saw no reason to recommend a change to intercropping because our research in the Sahelian zone of Senegal showed no advantages from inter-cropping cowpea and pearl millet, and some advantages from rotations of sole-crops. Intercropping peanut with other crop species is not effective in Senegal because most farmers use horse-drawn equipment to lift the peanut pods out of the ground and this mechanical harvest would disrupt any associated crop species or be disrupted by their roots.

A more complex answer is that it is not clear for different parts of the Sahelian and Savanna zones whether there are regions where cowpea inter-cropping with pearl millet has sufficient advantages that it is superior to sole-crops grown in annual rotations. There are some indications that damage to cowpea caused by flower thrips may be less, in some parts of the Savanna zone, when the cowpea is inter-cropped with a cereal crop. In the Nuba mountains in the Sudan, I observed less damage from flower thrips on cowpea grown in intercrops with sorghum than on adjacent sole crops of cowpea. The development of cowpea varieties with strong resistance to flower thrips would eliminate this problem and this advantage from species inter-cropping. However, to-date, strong resistance to flower thrips has not been discovered in cowpea germplasm.

The partial resistance to flower thrips exhibited by the variety ‘Melakh’ is useful but not strong enough for this variety to be grown without using insecticides in the wetter Savanna zones where many flower thrips can occur. Flower thrips are a major constraint to cowpea production in many parts of the wetter Savanna zones of Sub-Saharan Africa but they are not as prevalent in the Sahelian zone. Relay cropping where cowpea is planted late into pearl millet crops that have just begun flowering can be effective in the wetter Savanna zones because the cowpea plants produce flowers late during the beginning of the dry season when there are few flower thrips present.
Value of crop rotations of sole crops in the Sahelian zone and California

Advantages of sole-crops over species intercrops are that animal-draft planting, cultivation and harvest, and the application of pesticides can be more effective. The annual rotations that should be practiced with sole-crops have additional advantages: fertilizers and manures can be applied to the crop species, such as the cereals, that have the greatest need and give the greatest responses to them.

Prior crops of one crop species can have beneficial effects on another crop species grown on the same land the following year. For example, ISRA scientist Mbaye Ndiaye demonstrated that pearl millet can suppress the fungus responsible for the ashy stem blight disease of cowpea; although two years of pearl millet crops may be needed to substantially suppress the fungus. In addition, ISRA scientist, Moctar Wade has shown that prior crops of some cowpea varieties can cause suicidal germination of seeds of the species of the parasitic weed Striga (*Striga hermonthica*) that attacks pearl millet and sorghum but not cowpea. This Striga species can devastate pearl millet and sorghum and other control measures available to farmers as of 2006 were not very effective, especially for pearl millet. Due to the presence of numerous Striga plants, some fields of sorghum in the Sudan look like flower gardens and produce very little sorghum grain. Sorghum lines now have been bred by Dr. Gebisa Ejeta at Purdue University that have some resistance to Striga and provide a useful partial solution to this problem.

ISRA scientists, Ndiaga Cisse and Mame Birame have shown that crops of certain varieties of cowpea may suppress reproduction of the nematode *Scutellonema cavenessi*. This plant-parasitic nematode is a major pest of peanut, pearl millet and sorghum in West Africa and, therefore, rotations of nematode-resistance cowpea varieties may provide a partial solution to this problem.

These research findings concerning possible beneficial rotation effects on ashy stem blight disease, pearl millet Striga and the plant-parasitic nematode should be considered as being preliminary. There has not been sufficient field research to determine the effectiveness of these rotations in managing these pests and diseases.

In other cases the beneficial rotational effects of cowpea have been established. The new California cowpea variety, ‘CB27’ was bred in collaboration with Professor P. A. Roberts and W. C. Matthews of the Nematology Department at UCR and has broad-based resistance to various
root-knot nematodes. The many crops that are susceptible to these plant-parasitic nematodes, including major varieties of cotton and carrot, grow well on land previously used to grow ‘CB27’ due to the low levels of nematodes in the soil. This type of rotation decreases the need to use nematicides which are chemicals with substantial potential to harm humans and ecosystems.

The value of crop rotation is that the growing conditions of individual crop species can be optimized, and that when one crop species is grown on a piece of land it can make this land more favorable for different crop species that will be grown in subsequent years.

**Proposed advantages to species inter-cropping**

Some people have said that intercropping provides insurance for the farmer against the risk of losing a single crop but this argument is not valid. The farmer who grows sole crops can still maintain diverse production of several crops by having several small fields of cowpea, peanut, and pearl millet or sorghum in every year. These crops would be growing as sole-crops at different stages in the rotation of specific fields. For example, an annual rotation of pearl millet followed by cowpea, followed by pearl millet and then peanut, which is then repeated, would enable the farmer to have four fields of these crops - - pearl millet, cowpea, pearl millet and peanut - - each year. Each crop would be grown in different years in the rotation of a particular field. In this way, each year, the farmer would devote 50% of the cultivated land to the production of pearl millet, the staple food crop, and 25% each to the production of cowpea and peanut.

Another argument that has been raised is that species intercropping exploits environmental resources more completely than sole crops. While this argument appears valid from a theoretical standpoint, it does not appear to be relevant in some cropping systems and when effects of rotation also are considered. Proper choice of plant spacing and arrangement can enable sole crops to exploit solar radiation just as well as intercrops. With sole crops grown in rotation one can more efficiently manage the soil environment as it relates to optimizing applications of manure and fertilizer to specific crop species and taking advantage of the beneficial effects that one crop species may have on a subsequent crop species grown in the same soil environment. Also, when crops are growing on current season rainfall that is of limited quantity a species intercrop will not necessarily access any more of this water than would a solecrop.
Non-scientific polarization of opinions

One disturbing feature of the controversy concerning rotational sole-cropping versus species inter-cropping is that a certain degree of non-scientific polarization of opinions has occurred among the protagonists. Some supporters of sole-cropping and rotations say that this is the way it is done in more developed countries and thus it represents the best future option for Africa. In contrast, some supporters of species inter-cropping say that this is the way it has been done for many years in Africa and is elegantly diverse and, therefore, must be the most effective system for the prevailing conditions. Neither of these arguments has much scientific merit.

The development of improved cropping systems should be based on carefully designed and executed scientific experiments. Results should be subjected to rational and objective analyses. Projections should be made concerning future needs for agricultural products and consider future conditions that would influence the success of agriculture.

Varietal intercrops

Specific types of diversity can be advantageous in cropping systems. While visiting fields in northern Kordofan in the Sudan in 1984, I observed that farmers were growing different cowpea varieties with different dates of first flowering in a mixture. These farmers were from the ‘Barno’ tribe which is thought to have originated in northern Nigeria where there has been much cowpea production for hundreds of years. It occurred to me that the stability of cowpea production in the Sahelian zone might be enhanced by growing intercrops of different cowpea varieties that have contrasting morphology and phenology.

We had learned from project research in Senegal that early erect cowpea varieties could be very effective when the growing season was short with a regular distribution of rain. But we also had learned that early erect cowpeas were very sensitive to mid-season stresses due to drought or other factors such as insect pests. In contrast, cowpea varieties with later more sequential flowering and more spreading plant habit were less effective when the rainy season was short. But they were more effective than early erect varieties when the rainy season was longer and when droughts and other stresses occurred in mid-season, and they produced more hay. Clearly, farmers would benefit from growing both types of cowpea varieties but what was the best way for growing them?
Samba Thiaw tested the hypothesis that varietal intercrops consisting of alternating rows of early erect and medium-cycle spreading varieties of cowpea would have more stable production of grain and hay over years than the best varieties grown as sole-crops. These experiments were conducted over several locations and years in the Sahelian zone of Senegal. For locations with low rainfall and poor soil fertility that are typical of much of the Sahelian zone the results were encouraging and surprising. In addition to having more stable yields of grain and hay in different locations and years, the varietal intercrops also had greater yields of both grain and hay than the best sole crops at each location in every year.\(^2\) Chap. 4

Partial explanations for these results are that when a mid-season drought occurs that causes the early erect variety to senesce, the spreading variety compensates by growing into the space that would have been occupied during podding by the early erect variety. In contrast, with a late-season drought, the spreading variety is damaged such that it does not compete as well in terms of grain production with the early erect variety but produces substantial hay instead.

The varietal intercropping research was conducted with older varieties and exploiting this research finding requires that it now be tested with the more advanced varieties that have become available. ‘Melakh’ is an effective early erect variety but a new medium-cycle spreading variety is needed for this research that is well adapted to the Sahel, including having resistance to major diseases and pests.

Further studies would be needed to compare varietal intercrops of these new varieties with sole-crops of the best sole-crop varieties, such as the broadly adapted variety ‘Mouride’, in areas with low rainfall and infertile soil under farm conditions. Conducting these experiments will require considerable skill and take several years for the results to provide reliable predictions.

It also is necessary to determine whether varietal intercrops can be sown, cultivated and harvested in an effective manner by farmers. It should be noted that sowing will require the coordinated use of two single-row seeders, one for each variety. Also, during harvest, grain of the two varieties should not be mixed because this will reduce its value as either food or seed.

* These studies comprised the thesis for which Samba Thiaw obtained a masters degree from UCR.
Obtaining farmer opinions on these sowing and harvesting issues is critical. The overall strategy would be to grow varietal intercrops of cowpea in annual rotation with sole crops of pearl millet and peanut.

For varietal or species intercrops to be more productive than sole crops, they must in some way exploit the soil or aerial environments more completely or more effectively than do sole crops. For example, the relay cropping of the ‘Ndout’ variety of cowpea planted late into the ‘Souna III’ variety of pearl millet practiced by the Sérére people in the Savanna zone in Senegal can result in more complete utilization of soil moisture in wetter years than can be achieved by sole crops of the ‘Souna III’ pearl millet. However, a variety of pearl millet with a longer cycle than ‘Souna III’, such as the ‘Sanyo’ variety also would exploit as much soil moisture as the relay intercrop in wetter years. Growing the ‘Sanyo’ variety is not the optimal solution, however, in that in drier years with shorter growing seasons the ‘Sanyo’ variety would suffer from late-season drought and produce less grain than the ‘Souna III’ variety.

Consequently, the relay intercrop practiced by the Sérére is more reliable for producing pearl millet than sole crops of ‘Sanyo’ pearl millet and produces a bonus yield of cowpea in wet years. As was mentioned earlier, there have been too few wet years since 1969 to make this system effective in the Sérére area.

In some cases a species intercrop might more completely intercept solar radiation than a specific sole crop but the same high level of interception of solar radiation might be achieved with the sole crop by sowing seed at a narrower row width or closer spacing in the row. With closer plant spacings, however, it might be necessary to provide cereal crops with more fertilizer or manure.

It should be apparent that the relative productivities of intercrops versus sole crops is influenced by other aspects of crop management and is a complex issue.

Variatel or species intercrops may have more stable production over years than sole crops if individual component varieties have the ability to compensate by being more productive when the productivity of another component variety is reduced by stress. For example, when an early erect variety of cowpea is damaged by a mid-season stress and senesces, a prostrate variety of cowpea grown with it in alternating rows can have the ability to grow into the area that would in less stressful years have been occupied by the early erect cowpea. In contrast, if the prostrate
variety is damaged by a disease or insect pest, the erect variety may not have the ability to use the extra space that is made available. The presence of the other crop species may result in a decrease in levels of certain insect pests on the other species, but cases also have been observed where intercropping enhanced the levels of certain insect pests.

It should be clear that the relative stabilities of intercrops versus sole crops can depend on many factors and also is a complex issue.

**Improved varieties of pearl millet and peanut for the Sahelian zone**

By the 1990s, scientists had developed new varieties of pearl millet and peanut that are better suited to the harsh Sahelian climate than traditional varieties. The main feature contributing to the improved adaptation of the new varieties is the same as it was for cowpea -- they begin flowering earlier and are ready for harvest at an earlier date than the current varieties. For example, as of 2004, the main pearl millet variety grown in the Sahelian zone of Senegal was the traditional variety ‘Souna III’ which requires a season length of 95 days. In contrast, the new pearl millet varieties require a season length of only 85 days and are better adapted to short rainy seasons.

Unfortunately, a problem has occurred in extending the new pearl millet varieties to farmers. If only one farmer in an area plants a new pearl millet variety that produces seed early in the season, it becomes a focal point for attacks by seed-eating weaver birds since other sources of food are not available. Weaver birds including the notorious *Quelea quelea* are the scourge of pearl millet and sorghum farmers in some parts of Africa. The solution to this problem is to have a program where there is a massive distribution of the seeds of the new variety of pearl millet so that many farmers sow them at a similar time and the attacks by the weaver birds are spread over many fields. A method for achieving a large-scale diffusion of technology is described in the next chapter on “Diffusion of Cowpea Technology in the Sahel: 1992-2001”.

The shortest cycle peanut varieties that now are available require a growing season of about 85 days, similar to the new pearl millet varieties. But they also are not as well adapted to extreme droughts in the Sahel as the 60-day and 70-day cowpea varieties.

Impending famine in 1993 and the World Vision International/ISRA cowpea campaign

While working in Senegal in the fall of 1992, I predicted to administrators of ISRA and the USAID mission in Dakar that a famine could begin in the Sahelian zone north of a line from Mékhé to Thilmakha starting early in 1993. My prediction was based on the assumption that three years of low crop production are enough to eliminate the reserves of food stored in most villages in the Sahel.

The badly droughted crops that I saw led me to conclude that 1992 was the worst year for crop and food production in the Louga region that I had seen during working visits to the region over the previous 17 years. As of October 7, the annual rainfall at Louga was only 184 mm, the rain showers had been badly distributed, and it was unlikely that more rain would fall that year. Later, when government estimates of production were compiled, they indicated that the Louga and St Louis regions had only produced 3,033 tons of cowpea in 1992, compared with the average from 1970 to 1979 of 11,004 tons, and a peak value of 49,803 tons obtained in 1985 (Table 1 in Chapter 4).

Average grain yield per area for cowpea in the Louga and St Louis regions reached a record low in 1992 of only 72 kg/ha compared with the average from 1970 to 1979 of 291 kg/ha and a peak value of 726 kg/ha obtained in 1985 (Table 1 in Chapter 4). I also had estimated that production of other crops such as pearl millet and peanut would be negligible in the Louga and St Louis regions in 1992. In addition, in both preceding years, production of cowpeas and other food crops had been very low in these regions due to low rainfall (Figure 3 in Chapter 1 and Table 1 in Chapter 4) and other factors.

What could our project do to help people overcome the harsh year anticipated for 1993? Importation of ‘CB5’ seed from California was not a reasonable option as it was in 1985. Little seed of ‘CB5’ was available in California because to a major extent it had been replaced by a new more compact variety, ‘CB46’, that is not as effective in Senegal as ‘CB5’.

ISRA now had two new cowpea varieties that were much more effective in Senegal than either ‘CB5’ or ‘CB46’ but the Government of Senegal did not have much seed of them. Consequently, we searched for a way whereby the seed of ‘Mouride’ and ‘Melakh’ could be rapidly
multiplied and delivered to farmers together with advice on the most effective methods for growing
and storing cowpea. The national seed service and extension agencies, however, were severely
constrained by shortages of funds, trained people, vehicles, and other resources.

Fortunately, a few years earlier we had begun working on a new approach to extending
varieties and information that would complement the approaches being taken by the government
agencies. Since 1986, World Vision International (WVI)* had been conducting an integrated rural
development program in the regions of Louga and Thies. During the late 1980s, WVI had installed
boreholes (average depth 62 m = 203 feet) and hand pumps to supply water for people and livestock
in about 400 villages in the Louga and Thies regions. WVI also had initiated an agricultural
development project. There was insufficient water in the aquifers to support much irrigated
agriculture, so WVI was interested in promoting rainfed cropping.

The manager of the WVI agricultural development project, Mansour Fall, was a Senegalese
who had worked for a government extension agency in earlier years and had collaborated with our
on-farm research project. He appreciated the importance of cowpea to the Louga region, and we had
enjoyed working with him. Mansour Fall recommended that WVI collaborate with our cowpea
project.

However, ISRA and WVI had to learn the best ways to collaborate. The ISRA/UCR cowpea
research team felt that WVI had a comparative advantage in extending new materials and
information to farmers in that they had already established good relationships with people in many
villages, and they had the ability to provide materials on credit. WVI, however, also was interested
in conducting research to develop improved technologies. We felt that ISRA had the comparative
advantage for conducting research. But, for the first three years, 1990, 1991 and 1992, ISRA and
WVI cooperated in research on cowpea agronomy. This enabled the WVI staff to gain experience
in the most effective ways to grow cowpea and to learn about the new cowpea varieties and
management and storage methods being developed by our project.

* WVI is a Christian, humanitarian, non-profit, non-governmental, relief and development assistance organization with
its head office in Monrovia, California.
In the fall of 1992, I visited the National Director of WVI in Senegal, Al Johnson, and explained that I was worried that a famine might occur in the Louga region in the following year. He said that WVI had similar concerns and would conduct surveys to determine the severity of the problem. Subsequently, WVI personnel observed several signs of impending famine: an increase in the price of pearl millet grain at a time when a normal harvest would have resulted in a decrease in price; a substantial decrease in the price of livestock indicating people were selling an unusually large number of animals to get cash to buy grain and other foods; and a larger than normal number of family heads leaving villages in search of work to get cash to help to support their families.

In the fall of 1992, I had proposed that WVI should launch a cowpea campaign with the new cowpea varieties together with the improved management and storage methods developed by ISRA. I had convinced ISRA to make available both ‘Mouride’ and ‘Melakh’, even though ‘Melakh’ had not been officially released for use by farmers. Project research had shown that ‘Melakh’ complemented ‘Mouride’ such that if the patterns of drought and other stresses damaged one variety, then there was a reasonable chance the other variety would be effective. I felt that it would enhance food security considerably if farmers grew both varieties.

I explained to WVI that our project could produce several tons of seed of the new cowpea varieties for them during the dry season by using irrigation, providing they were willing to buy the seed from our project. Our project was funded for doing research not extension, and we needed a reimbursement of our seed-production expenses to enable ISRA to pay for research expenses of the project that would be incurred later in the year. I also recommended that WVI should try to obtain additional cowpea seed to increase the scope of their campaign during the 1993 summer growing season.

WVI agreed with this proposal and obtained a grant from their headquarters in Monrovia, California to support the project. Using irrigation during the dry season, Samba Thiaw of ISRA produced about 5 tons of seed of the new varieties, ‘Mouride’ and ‘Melakh’. The WVI obtained an additional 3 tons of seed of other varieties in a cooperative project with the National Seed Service of Senegal.

For the main growing season in 1993, WVI provided about 1,400 farmers in 380 villages with cowpea seed on a credit basis. After the harvest, farmers were supposed to reimburse WVI with
the same quantity of cowpea seed as that they had received. WVI also provided information on management and storage methods.

The National Seed Service in Senegal could not have conducted this project because they did not have the financial resources to either buy the seed of the new cowpea varieties from ISRA or provide them to farmers on a credit basis. With an impending famine on the horizon, it was not prudent to expect farmers to buy the seed.

There was adequate rainfall in 1993 with 342 mm falling at Louga. The new cowpea varieties were very successful producing extremely large yields. The average yield estimated by WVI for their project was 1,280 kg/ha, which is about four times national average yields for the base-line period from 1960 through 1979 (Table 1 in Chapter 4). The WVI reported a 100% return on the credit they had extended to farmers. After the harvest, farmers gave WVI sufficient cowpea grain to pay off their loans. The cowpea grain provided by farmers to repay their loans, and grain purchased by WVI were stored in good conditions and in 1994 they were loaned as seed to interested farmers.

National production of cowpea in 1993 was very high at 55,854 tons, which is much greater than the average national production for the base-line period from 1960 through 1979 of 17,862 tons (Table 1 in Chapter 4). Also, average yield per area was 472 kg/ha in 1993, which is 167% greater than the average yield during the base-line period from 1960 though 1979 (Table 1 in Chapter 4).

Government extension agencies and WVI continued to promote cowpea production in subsequent years. For the nine-year period from 1993 through 2001, yield/area increased by 19% compared with the base-line period (Table 1 in Chapter 4). The increases in yield probably resulted in increased profits to farmers since costs of production would not have increased appreciably.

Increases in profits together with improved storage methods and other factors would have encouraged farmers to plant larger areas of cowpea and this occurred. The area of cowpea planted per year was 84% greater in 1993 through 2001 than the base-line period (Table 1 in Chapter 4). As a consequence of the increase in yield per area and the larger area planted, average national cowpea production for 1993 through 2001 was 39,341 tons per year which is more than double that of the base-line period (Table 1 in Chapter 4).

This large increase in national production provided a much greater supply of cowpea for food for people in Senegal and encouraged export of cowpea grain. The increases in yield/area and total
production that occurred also may have indirectly benefited consumers. Increases in potential profit margins make possible decreases in prices for cowpea grain that are likely to occur when national production also is increased.

The large increase in national cowpea production from 1993 through 2001 could have been partially due to other factors. Agriculture often is influenced by governmental policies. In early 1994 a major devaluation of the local currency occurred in Senegal causing the prices of imported foods to increase. This probably encouraged Senegalese farmers to grow greater quantities of local food crops. Value of the CFA had been linked to the French franc and had been 50 CFA per franc for many years, but after the 1994 devaluation it became 100 CFA per franc.

People who bought significant quantities of imported products were detrimentally affected by the devaluation of the local currency. I have the impression, however, that the devaluation was beneficial to the many people in Senegal whose livelihoods depended on producing and selling local food products, such as most farmers and herders.

**Longer-term consequences of the World Vision International cowpea campaign**

A very important outcome of the WVI project was that the two new cowpea varieties became widely distributed to farmers in northern Senegal which should continue to produce beneficial effects for many years. It became clear after two years of the WVI project that ‘Melakh’ was the favorite variety because of its earliness and large seed, but that ‘Mouride’ was appreciated by farmers for its ability to withstand stresses.

WVI also initiated projects on cowpea storage and processing and the role of cowpea in nutrition. Too many people did not understand the main role of cowpea as a food. People have said to me - - why should I buy cowpea when rice is cheaper? The answer is that cowpea mainly should be considered as being a cheap form of protein to substitute for meat and fish, which are much more expensive than cowpea. Rice, in contrast, is mainly a source of starch and calories, and should be considered as being an alternative to pearl millet. When cowpea grain is combined with a cereal grain such as pearl millet or rice, they can provide tasty foods that meet virtually all nutritional requirements.

In addition to the cowpea and well-construction projects, WVI had comprehensive health and
nutrition programs and was making substantial contributions to the development of women in Senegal. We were very fortunate to have the opportunity to cooperate with the dedicated people working for World Vision International.

In subsequent years, World Vision International and the Belgian non-governmental relief organization, Aquadev, extended ‘Melakh’ in northern Senegal. Also WVI began organizing farmer-based cowpea seed production cooperatives that are affiliated with the national union of personnel involved in seed production in Senegal (UNIS) and hopefully will continue to function for many years. An Austrian non-governmental relief organization, Entwicklungswerkstatt Austria (EWA), began working with farmers in Senegal with the objectives of increasing production of ‘Melakh’, building cowpea storage facilities, and promoting cowpea export to neighboring countries. A few years earlier, a factory in Mauritania had begun using flour from grain of ‘Melakh’ to make an African ‘biscuit’ that was very popular.

**Extension of project cowpea varieties to other African countries**

After 1992, cowpea varieties developed by the project began to be disseminated to farmers in other countries. In 1993, ‘Mouride’ was released as a new variety in the neighboring country of Guinea-Bissau.

In 1996 through 2001, ‘Mouride’ and ‘Melakh’ were evaluated in Chad, Niger and Ghana by a collaborative project involving WVI, the Bean/Cowpea CRSP, and a similar CRSP project emphasizing pearl millet and sorghum (INTSORMIL). ‘Mouride’ and ‘Melakh’ were very effective in trials in the Sahelian zone of Niger, and they were being adopted by some farmers in this country. There were several reports from Niger that farmer appreciation was so high that seeds of ‘Melakh’ and ‘Mouride’ were being ‘borrowed’ from experimental plots by farmers who wanted them for their next years’ plantings.

In the fall of 1995, while participating in an international cowpea research conference at Accra in Ghana, I met one of my students who had gone back to the Sudan some 11 years earlier. Dr. Hassan Elawad told me that he had followed the plan for enhancing cowpea production in the Sudan that I had developed as a consequence of my visit there some 11 years ago, and that it had been very successful.
Over a period of eight years he had conducted varietal trials on research stations and farms in northern Kordofan with early flowering cowpea lines that I had developed, and lines from Senegal and IITA that I and IITA had provided to him. His research had been funded by the Food and Agricultural Organization of the United Nations and the Government of the Sudan.

With no applications of pesticides or fertilizers, the best of my 60-day cowpea lines had produced an average grain yield of 596 kg/ha compared with yields of only 215 kg/ha obtained with local landraces. He stated that in 1994 the government of the Sudan had pre-released one of my lines, 1-12-3, as the variety ‘Ein El Gazal’ (this line has a blackeye, which accounts for the name "Eye of the Gazelle"). He also had recommended release of two land races from Senegal as the varieties ‘Haydoob’ and ‘Gamar Dorein’, and a breeding line from IITA as the variety ‘Dahab Elgoz’.

He said that the development organization, CARE International, and the Organization of Agricultural Engineers in the Sudan had been multiplying seed of the new varieties. By 1995, about 500 farmers in the El Obeid area had obtained seed of the new cowpea varieties from these organizations and now were selling them to other farmers. He said that there had been a substantial increase in cowpea production in northwestern Sudan, in the area where I had proposed a large increase was possible some 11 years earlier.

He invited me to visit the Sudan. I accepted the invitation, because I wanted to see the results of their efforts and help the government of the Sudan to develop a plan for the next phase of cowpea research. Unfortunately, I have not been able to make this visit. In early 1996, personnel in the US Embassy in the Sudan were withdrawn from the country which made it more difficult to travel there. In 1998, the United States bombed a factory in Khartoum, which further strained relations between the US and the Sudan.

In 2000 the Government of Sudan officially released ‘Ein El Gazal’ and the other varieties. By 2001 about 500,000 farmers in northern Sudan had received seed of ‘Ein El Gazal’ and 600,000 farmers had received seed of ‘Dahab Elgoz’. In response to requests from farmers, the Farmers’ Union in Kordofan and non-governmental organizations, the Arabian Sudanese Seed Company began multiplying seed of the new cowpea varieties for large-scale distribution to farmers.

Also, during the late 1990s, Dr. Elawad began evaluating ‘Mouride’ and ‘Melakh’ and some more advanced breeding lines from UCR and IITA. In trials conducted since 1997, ‘Mouride’ and
‘Melakh’ had substantial grain yields such that they may be superior to both ‘Ein El Gazal’ and ‘Dahab Elgoz’ and may deserve being released as new varieties in the Sudan.

While progress was being made in Kordofan, just to the east in Dafur, where these cowpeas could be effective, a civil war was beginning. In the horrific conditions that have occurred, agricultural extension and other types of rural development were not possible.

**Difficulties in extending new crop varieties and management methods in Africa**

I do not want to leave you with the impression that the extension of new varieties or new crop management methods to African farmers is easy. These farmers often have a high degree of conservatism. It is prudent to be conservative when you are living in difficult circumstances and in places where the advice of outsiders has not always been beneficial.

Gaining the trust of these farmers is critical for the success of extension programs. WVI had developed good relations with farmers in northern Senegal partially due to their developing boreholes and wells for the villages during a time of severe water shortage.

While working as an extension officer in Tanzania during 1961 through 1963, I had used several methods to gain the confidence of people in the villages. I will describe some of these methods and difficulties I encountered when conducting extension in Africa.

**Difficulties traveling in rural parts of Africa**

Many problems can arise when traveling in rural parts of Africa. I will describe an incident that occurred in 1962 when I was a Field Officer responsible for agricultural extension in the South Mara District of Tanganyika.

In those years there were only a few miles of hard surface roads in the district of South Mara and none in North Mara where I would subsequently work. We mainly traveled on dirt or mud tracks in desolate areas where there were no gas stations or mechanics. We went as far as we could by Land Rover, in some cases chopping crude roads through gullies and other obstructions using jembes (a strong hoe). We then walked the rest of the way to visit farms often covering many miles through uninhabited bush country.

One day while working in my office in Musoma on the eastern shore of Lake Victoria, I came
to the conclusion that the ministry of agriculture had neglected the bangoreme people who lived in an isolated part of South Mara. The government did not have any extension assistants in that area and as far as I could tell none of my predecessors had visited the ngoreme area. I decided to visit the bangoreme.

We set off early in the morning with a Land Rover and by the afternoon were traveling across a flood plain. Unfortunately, rain was falling and the flood plain became deep in water. We managed to cross the flood plain by driving slowly and having a colleague walk in front to detect any big holes. Eventually we reached the higher dry land on the far side. Relieved by having crossed the flood plain my driver then proceeded to drive at high speed to try and reach the ngoreme area prior to sunset. Mpeho Walyoba was an excellent driver but he then committed the only mistake that he made while working for me. He took a short cut and buried the Land Rover in a swamp.

We then proceeded to try and extricate the Land Rover from the swamp. We had a Tanganyika jack which is useful for getting out of swamps because you can attach it to the outside body of the vehicle and then raise it considerably with a metal screw device. We also carried wooden planks which we placed under the wheels. Mpeho drove forward slowly on the planks and as the Land Rover reached the end of them we placed more in front. Occasionally the planks rotated and the Land Rover slipped off them. We then had to stop and jack it up again and dig out the mud with jembes and replace the planks. But slowly we were making progress towards the edge of the swamp. Then a catastrophe occurred, the drive shaft to the back wheels broke. We had no possibility of getting the Land Rover out of the swamp that day.

It was still raining heavily and approaching nightfall. I decided we should walk out to a Catholic mission I had seen far away in the hills as we traversed the flood plain. While walking I became very sick with malaria and exhausted and it became dark. Fortunately we found the mission but after knocking on the door I collapsed. A few days later I awoke from a coma and found I was in a nice bed.

The man in charge of the mission, Joe Jacobs, had saved my life by nursing me back to good health. Joe had a motorbike that he used when ministering to the people. When I began to feel stronger I went with him on some of his journeys and was impressed by the good work he was doing. When I had recovered enough to return to my duties, he took me and my assistant to a crossroads
where we were able to get a bus ride back to Musoma.

My driver stayed in a village near the swamp so that he could look after the Land Rover. My plan was to order a new drive shaft, which would take a few weeks, and send it to him so he could repair the Land Rover and then return to Musoma. But to my surprise in a few days Mpeho returned to Musoma with the Land Rover.

Mpeho is a Muslim and the bangoreme in the village he was in were mainly animists and he did not want to stay too long in the village. So he had devoted his efforts to trying to fix and extricate the Land Rover. By chance the part of the swamp where the Land Rover was entombed had dried out. Mpeho had raised the vehicle with the Tanganyika jack and removed the parts of the drive shaft that had broken. He then had attached pieces of cardboard to the openings to keep dirt out. Using only front-wheel drive Mpeho had driven out of the swamp, which was now dry, and back to Musoma.

I was not able to work with the bangoreme people because I was soon transferred from South Mara to North Mara. I was chosen for this transfer because I was unmarried and North Mara was viewed as a somewhat wild place and unsuitable for married people and families. I relished the opportunity because I would be on my own and totally responsible for agricultural extension in North Mara.

The Government of Tanzania recruited local drivers for the government vehicles. Officers, such as I, were not supposed to drive the government vehicles because they were not insured. But, soon after my transfer to North Mara I began driving the Land Rover. I was driving because Mpeho had suffered a deep cut to the Achilles tendon in his ankle and could not drive. For several months he had to stay at his home in Tarime while his ankle recovered. He had been recently hired by the government and was not yet on permanent employee status. If I had reported his injury he would have lost his job and his pay.

Except for the incident in the ngoreme area, Mpeho was an excellent driver. He also was a good friend. I did not want to lose his services and was concerned for his well-being and that of his family. I was able to conceal the fact that he had an injury from the upper administration for several months because they rarely came to North Mara. One time the officer in charge of the region came across the Mara river, he wanted to meet with me in a village at the edge of my district. I drove to
see him but hid the Land Rover in some bushes on the outskirts of the village. I then walked to the meeting place because I did not want him to see that I did not have a driver.

Additional problems can occur when traveling in rural parts of Africa. When driving it is necessary to closely watch the road both near, to avoid pot holes that can be very deep, and far, to provide time to stop in case of major impediments. It is not unusual to encounter large trucks or buses coming towards you at high speed in the middle of the road. When working in Senegal I tried to avoid traveling after dusk because it was harder to see and avoid these vehicles when it became dark. Many years earlier in Tanganyika I had been driving a Volkswagen bug at night when I encountered a vehicle coming towards me at high speed that had one poor headlight. I thought it was a motor bike. Too late I discovered it was a large bus taking up the whole road. The bug was severely damaged by the collision whereas the bus only suffered a small dent. By luck I survived only needing some stitches for the place in my chin where it broke the steering wheel.

The traveling problems I like least are the road blocks one can encounter, especially those manned by drunken policemen collecting their monthly tithes or by young men waving AK-47s.

**Gaining the trust of farmers**

For direct extension work with farmers you must gain their trust. They must accept you as being a person who not only wants to help them but also is capable of doing something useful for them. In my experience African and Californian farmers are quite similar in this respect. The problem is how to gain their trust in a reasonably short period of time. I will provide an example of how by chance I gained the trust of a whole village.

One evening in 1962 I drove into a kuria village in the highlands of North Mara in Tanganyika. I made my camp in the storehouse of the local primary school. The government did not have many rest houses at that time. One rest house I had tried was dilapidated and had not been used in recent times. I soon discovered there was a nest of bees in the chimney of the rest house and I immediately left. In contrast, school storehouses usually were in good condition and they were spacious enough to accommodate my camp bed and few belongings.

I cooked my food on a fire outside the storehouse. I was relaxing after eating my evening meal, when two men came to visit me. After some discussion of my health and the health of their
families and the condition of their livestock and crops, they told me about a problem confronting the village. Their posho mill had not been operational for some time. The women had to grind maize by hand to make flour and they were complaining that it was hard work and had been treating the men badly. The men wondered if I could examine the mill and advise them on how to get it repaired.

I agreed to look at the mill and went to the Land Rover to get some tools. I went with the men to examine the posho mill taking some wrenches, screwdrivers and a pressure lamp, which worked on kerosene. The mill was in a shed in the center of the village. First I opened up the grinding area of the mill and found that the hammers appeared to be functional. I then turned the hammer assembly and the bearings appeared to be sound. I would not be able to tell whether the hammers were balanced and the bearings would handle high speed until I could get the engine of the mill started.

It was a gasolene engine and appeared to be very old. I checked and found there was some gasolene in the fuel tank and oil in the crankcase. I removed the fuel filter and found it was completely clogged with dirt – this was the first problem. I cleaned the fuel filter. A filter this dirty might have provided dirty fuel to the carburetor.

I then proceeded to dismantle the carburetor. I was extremely careful because if I broke anything I suspected that it would be very difficult to get replacement parts. I worked under the glaring light of the pressure lamp. Surrounding me were many men from the village, they were sitting on the ground and appeared intensely interested in what I was doing. I took many small pieces out of the carburetor including the float and various jets and carefully cleaned them and then reassembled the carburetor.

I hoped that everything else was working and decided to try and start the engine. I put my tools away and opened all the doors in the shed to reduce the possibility of a dust explosion. The man who owned the posho mill gave me a rope with a large knot on one end and a wooden handle on the other end. I wrapped the rope around the fly wheel on the engine drive shaft and gave it a strong pull. The engine turned over but did not start, however, I heard a cough as if a cylinder had fired once, which meant the ignition plugs might be working.

I then wrapped the rope around the wheel again, and gave it the strongest pull I could muster. With a load roar, some backfiring and smoke, the engine started and the hammer mill began to turn. As the mill built up speed, the turning of the shaft remained smooth with no vibrations, indicating
the hammers were still in balance. In addition, there was no noise from the bearings on the mill shaft and the bearings remained cool. I reached forward to switch off the engine but the men implored me to leave it running.

By now women were converging on the shed from all directions, carrying sacks of maize. The men began emptying the sacks of maize into the hopper of the mill and it was soon ground into flour.

I went back to the school storehouse and laid down on my camp bed because it was now late. While waiting for sleep to come, I could hear the muted roar of the posho mill and I felt very pleased. The posh mill ran most of the night and ground much of the grain that was available in and around the village. The local women were extremely happy and this was appreciated by the men.

I had established a communication link with people in the village. On future occasions while traveling in the area, I would stay over night at the village. In the evening people would bring problems to my attention, some of which I was able to fix. I would also discuss my extension program with them.

The government had a small experimental farm near the town of Tarime that I managed and used for testing new crop varieties. I described the varieties that had performed very well and offered to provide seed. Some people were interested and agreed to test them on their farms in comparison with their local varieties. In this way the extension of new crop varieties was initiated in this village.

**Finding out what people want**

A key step in initiating extension work is to find out something that people want that is reasonable and doable, and then to do it. Often people complained about wild animals that were causing much trouble. The Government of Tanganyika had a division responsible for killing wild animals that caused trouble for people but it did not operate in North Mara.

People considered that the government should control animals that caused trouble and came to me for help. In chapter 3 I mentioned a village in the highlands of North Mara where people had become afraid of a leopard, and how I had solved that problem for them.

On several occasions people complained that baboons were destroying their food crops. People in a luo area asked me to hunt baboons with them and drive them away from their fields. I
visited them and camped overnight. At dawn we left the village. The luo had spears and clubs and I had a Savage 99 rifle. We split into two groups and ran into the rocky hills attempting to trap the baboons in a pincer movement. We ran for several hours and it was incredibly hard work. The baboons were too fast and escaped from us, clearly another approach was needed.

Another village had a terrible problem in that it was next to an escarpment where a large population of baboons lived. The people said they were losing most of their food. They were kuria and they said that they did not want to kill the baboons because they felt the baboons were too much like people. I have a similar impression of baboons. Once I was guiding a family of missionaries into a game reserve in Tanganyika on the northern side of the Mara river. We traveled across the reserve in Land Rovers and made camp next to a group of trees. A pack of baboons had followed us for about an hour while we crossed the reserve and they climbed into the trees next to our tents. The baboons stayed in the trees for the several days that we were in the reserve. The baboons seemed to take as great an interest in watching us as we did in watching them and the other animals.

The kuria farmers asked me to kill some of the baboons and drive them away from their fields but they would not help me. The village was not too far from my headquarters in Tarime. I left my house in the dark and drove to the escarpment. I walked through the bush below the escarpment towards the fields just as dawn was breaking. Several large dog baboons were sitting on rocks on the lower part of the escarpment acting as sentinels while the main pack of baboons was beginning to raid the fields. I managed to get within about 150 yards of the dog baboons. I shot and killed several of them using the Savage 99 with open leaf sights. I was hoping that leopards would now do a better job of controlling the population of the baboons. Leopards are very fond of eating baboons but just one or two of the large dog baboons can drive leopards away.

In one case I had shot too low. The baboon was hurt but had begun climbing back up the escarpment to the caves where they lived. I had to track the wounded dog baboon up into the escarpment to put him out of his pain. While climbing a rock face, I made the mistake of grasping a branch of what turned out to be a nettle tree that was growing next to the rock face. I immediately felt substantial pain in my hand. But I was able to crawl on top of the rock using my good hand. I then heard a noise and looked up. Also on top of the same rock and less than two paces away was the wounded baboon and he was coming towards me showing large fangs. Fortunately, while pulling
myself up with my good left hand, I had put my rifle in my inflamed right hand and it was pointing forward. I immediately shot and killed the baboon.

**Being useful and being used**

In one Luo village in North Mara some of the fields became flooded when heavy rains occurred. The headman of the village told me that they were going to dig a cut-off drain to divert surface run-off away from these fields. He invited me to attend a wedding on Saturday evening in which he was gaining another wife. He said that during the same visit I might help with installing the drainage ditch. I accepted the invitation and one Friday afternoon I took a leveling device (a theodolite), a measuring tape, some stakes and a hammer and drove to the village. A new clean hut was made available for my stay in the village.

Early on Saturday morning, I determined the most effective site for the cut-off drain and the depths it should be dug to give it a slope that would carry off the water without it running too fast and causing gully erosion. I hammered in stakes to indicate where the drain should be dug with a note on each stake indicating how deep it should be dug at that point. A large group of men began the digging while I used the tape measure to guide them on how deep to dig the drain.

By late afternoon the drainage ditch was completed. The wedding began that evening and we drank much beer and ate beef roasted over a fire. The celebrations lasted throughout the night and much of the following day with continuous drumming. Late in the afternoon on Sunday I drove back to my house in Tarime.

I was in a fine mood because I had established a good link with the people in the village and enjoyed the festivities. I was, however, intrigued by one aspect of the weekend. The new wife was from the town of Tarime. She was very young and vivacious and had some formal education. The first and eldest and most senior of the headman's wives appeared to have some reservations about whether the new wife from the town was a good addition to their community. The tradition, as I understood it, was that new wives, since they were younger, were supposed to do more of the hard tasks associated with women's work. But it was not clear whether this new wife was willing to accept this role.

The headman was a judge who officiated at the main local court in Tarime and was very wise.
I suspected he had invited me to the wedding as a diversion to prevent a minor ‘war’ starting between his new wife and his most senior wife. I think he was trying to create a period of peace during which an accommodation might develop among his wives. My guess was that the new wife had a ‘modern’ view of things and that the headman would need the wisdom of Solomon if he was to achieve an amicable household.

**Final thoughts concerning the diffusion of technology**

The types of methods that I used in the 1960s to establish communication links with farmers clearly are not relevant to the Africa of the 21st Century but the principle is still valid. The development and extension of appropriate technologies requires the establishment of strong communication links among farmers, extension agents and scientists. As the scientific technologies become more esoteric, communication becomes more difficult and the establishment of effective linkages with farmers becomes even more necessary.

In rural development it is critical to find out what the people need and want, and, where possible and appropriate, to help them to get it. Much progress has been made by beginning with small steps while many grandiose schemes have not been effective in Africa.
The future needs of the Sahel are very complex. I will simply provide a general assessment which indicates that there are many parts of Sub-Saharan Africa where there is little chance that an adequate quality of life can be achieved by many of the people unless there are some radical changes. My projections concerning the future opportunities in the Sahel focus on what can be done to improve cowpea production and utilization. I feel there is an opportunity for a true ‘Green Revolution’ with cowpea that could have beneficial impacts on many people. In addition, I will provide some general comments on education because this represents an opportunity that could provide a foundation for many aspects of rural development.

**The human population problem**

Comprehensive, reliable data are not available concerning the human population and food production in the Sahel. However, using estimates that are available, a conclusion can be drawn that is sound. An estimate of the population of the Sahel indicated that, even with significant out migration, it grew at a rate of 2.8% per year during the period from 1980 to 1992, due to high birth rates. It should be noted that if this rate of increase were to be maintained, it would result in a doubling of the human population within 25 years. Consequently, just maintaining the present inadequate standard of living would require, in this same time period, a doubling of the production of food, availability of jobs, educational opportunities and health care facilities. This would not have been possible.

What did happen to food production in the Sahel? For the period from 1961 to 1992, food production in the Sahel was estimated as having increased at a rate of 1.8% per year. The estimated increase in food production is much less than the estimated increase in human population. Consequently, it is highly likely that, on average, the amount of locally grown food that was available per person was less in 1992 than in 1961. Despite the localized successes achieved by our project and other projects, by 2006, the production of food per person in the Sahel as a whole
probably had decreased compared with 1961. In addition, deterioration of the environment and natural resource base would have accelerated with the increases in the human population, making it even more difficult to increase food production in the future. Clearly, without a stabilization of the human population the future is bleak for the Sahel. The same conclusion may be drawn for many other parts of Africa.

In some countries in Sub-Saharan Africa, the human population may stabilize in the future due to catastrophic increases in rates of death from AIDS. A greater proportion of the population is infected with AIDS in parts of central, eastern and southern Africa than in West Africa. Fortunately, the proportion of infected people is particularly low in Senegal and some other parts of the Sahel. Where it is present, this disease will only add more dimensions to the problems confronting the people of Africa. AIDS often kills people in their middle years who in normal circumstances are the most productive members of society. In addition, the human and monetary costs of taking care of the sick is placing a crushing burden on the people.

Outbreaks of civil war continue to occur in several parts of Sub-Saharan Africa, including the Sahelian zone of the Sudan (Dafur) and Chad. Rural development cannot take place under these conditions and the destruction of infrastructure that is occurring will delay recovery.

Where rural development is possible agricultural development is one of the fundamental solutions. In addition to contributing more food and better livelihoods, it also can contribute to the stabilization of the human population. In some societies, it has been shown that parents who have farming systems that are more effective and more reliable tend to have fewer children. They have less need for more children to provide labor on the farm and to look after them when they become old. When women have fewer children they are provided with the opportunity to contribute to societal development in many other ways. The emancipation and empowerment of women can strongly contribute to this type of rural development and stabilization of the human population.

**Agronomic developments that are needed**

Predicting the agronomic developments that are needed is difficult because of uncertainty concerning future rainfall. Will the droughts experienced at Louga, Senegal from 1968 to 1998 continue or will the more favorable rains experienced from 1918 to 1967 return (Figure 3 in Chapter
1)? For the central and eastern part of the Sahel in Niger, Chad and the Sudan, some substantial rains occurred in the 1990s indicating a possible return to wetter conditions in this area. The Sahelian zone of Senegal experienced substantial rains in 1999 and 2000 but not in 2001, 2002 or 2003 (Table 1 in Chapter 4). It is extremely difficult to predict the future rainfall in the Sahel judging by what happened in the twentieth century.

The major opportunity for enhancing the efficiency of crop and animal production in the semi-arid 200 to 400 mm rainfall zone will come from the extension to more farmers of short-cycle erect cowpea varieties, such as ‘Mouride’, ‘Melakh’ and ‘Ein El Gazal’, together with improved medium-cycle spreading cowpea varieties. The effective methods for managing and storing cowpea we have developed should be extended as well. Ideally cowpea should be grown in rotation with sole crops of pearl millet, sorghum and peanut using animal-draft mechanization.

In the future, even better short-cycle erect and medium-cycle spreading cowpea varieties should be developed that have stronger resistance to the various pests and diseases that are present. The new varieties should have the resistances to pests and diseases that were discovered by our cowpea breeding programs and others, such as the one at IITA, Kano. Importantly, resistances are needed to additional major pests. This will require discovering genes for these resistances and then combining them with the many useful genes already discovered.

Much of this work can be done by main-stream plant breeders. They would screen diverse cowpea germplasm in field nurseries to select parents, conduct conventional hybridization and then screen and thus select promising lines. Much of this work should be done under the careful control of conditions possible in experiment stations. Final selection should be based on trials in farmers fields where the promising lines are evaluated in collaboration with farmers and consumers. This process will ensure that the new varieties are both more effective from an agronomic standpoint and in addition more desirable to farmers and consumers than current varieties.

What may genetic engineering contribute? Research in genetic engineering has identified genes from the soil bacterium *Bacillus thuringiensis* that confer resistance to an insect pest called the pod borer. These genes are particularly useful because other sources of resistance to pod borer have not been discovered. The *Bt* genes would be most useful in the sub-humid Savanna zones where major attacks from pod borer can occur. The use of exotic genes requires the development of
efficient, reliable and reproducible transformation systems to enable their transfer into cowpea varieties. It also requires the enactment of the various laws needed to permit the use of this type of technology. As of 2006 these tasks had not been accomplished. But, some progress with transformation of cowpea had been made. In the future, effective transformation systems and enabling laws could be available to permit incorporation of additional genes for resistance to insect pests into cowpea and the widespread use of genetically engineered cowpea varieties.

Strong resistance is needed to certain important pests of the Sahelian and subhumid Savanna zones, such as flower thrips and pod bugs, and has not yet been discovered in either cowpea or in gene products obtained from other species. If this resistance is not found these pests will continue to severely limit cowpea production, especially in the subhumid Savanna zones of Africa.

Some progress might be made by crossing cowpea with those wild relatives that have useful resistance to insect pests. An advantage to this technology for developing varieties is that it does not require new enabling laws, as does genetic engineering. Varieties can be released as soon as it has been clearly established that they are suitable and safe for use by humans and livestock. But as of 2006 useful cowpea varieties had not yet been developed based on wide-crossing. Possibly genetic engineering could be used to transfer the genes conferring insect resistance from the wild relatives to cowpea but this would require new enabling laws.

**An international collaborative cowpea breeding project is needed**

Incorporating all of the necessary resistance genes into the wide range of genetic backgrounds needed for the plants to be effective as cowpea varieties in the different production zones of Africa is a daunting task. But it could be done if the scientists, funds and programs are available to make possible an international collaborative cowpea breeding project.

This project would enlist the efforts of main-stream cowpea breeders, genetic engineers, entomologists, plant pathologists, nematologists and other scientists from national programs in African countries and other organizations with cowpea research programs or advanced technologies. Finding people with the necessary expertise is a major constraint to a project of this type. As of 2006, there were only about a dozen active cowpea breeders in the world, whereas other major crop species have hundreds of plant breeders devoted to them. Also, cowpea is susceptible to many diseases,
some of which are seed-borne and can cause considerable damage and severely complicate seed service activities. Unfortunately, as of 2006, there were only a few plant pathologists in the world with practical expertise on working with the many pathogens that cause diseases in cowpea.

Our project contributed to the development of a new breeding technology for cowpea that could make the pyramiding of resistance genes much more efficient. Indirect marker-assisted selection, based on DNA polymorphisms, makes it possible to efficiently select for many genes at the same time on the same individual plant. A cowpea genetic-linkage map was needed if we were to use this technology. This map would identify the associations on chromosomes of DNA polymorphisms and genes conferring resistances to the different pests and diseases. Graduate student Cristina Menéndez* and I in collaboration with Professor Paul Gepts at the University of California at Davis developed an initial DNA-based linkage map for cowpea.¹ For this work we used a set of recombinant inbred lines obtained by crossing a California cowpea with an African cowpea that had contrasting genetic background. Both parents had many different useful traits.

Subsequently, I encouraged several other scientists to screen our set of recombinant inbred lines for resistance to different cowpea diseases and pests. A large collaborating group of scientists now has obtained additional data associating resistances to several pests and diseases with DNA markers,² thereby making it possible to begin conducting indirect marker-assisted selection.

The set of recombinant inbred cowpea lines on which both of these maps were based was developed by a graduate student from the Sudan who worked with me, Mubarak ElKhidir Abdalla. Dr. M. E. Abdalla also initiated the research at UCR on breeding cowpea for resistance to cowpea aphid. He then worked in Saudi Arabia until his untimely death there in 2000.

**Effective seed service and extension agencies are also needed**

Developing improved cowpea varieties is a necessary first step, but additional steps must be taken. Effective seed-service and extension agencies are needed to deliver appropriate current and new cowpea varieties to farmers with advice on the most appropriate management and storage

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* After leaving UCR Dr. C. M. Menéndez obtained a position as a Professor at the Universidad de La Rioja, Logroño, Spain.
practices for their area, and this must be done on a continuing basis. In 2006, governmental seed-service and extension agencies of cowpea-producing countries in Africa still were not very effective, in many cases. Externally directed and funded non-governmental organizations can be effective in producing and extending seed and advice, in the short term, but they are not the most effective solution for the long term, if their efforts cannot be sustained. Locally funded governmental or private seed-service and extension agencies may be more sustainable. Ideally, the seed-service organizations would be financially self-supporting, and have the ability to provide seed to farmers on a credit basis.

Prospects for a true ‘Green Revolution’ in Africa

If robust cowpea varieties can be developed with resistances to drought, heat, pests and diseases, if all of the other necessary steps can be accomplished in a coordinated manner, and if African women can achieve much greater emancipation and empowerment, there could be a true ‘Green Revolution’. It would result in massive increases in the efficiency and magnitude of cowpea production and utilization in Africa, enhanced fertility of the soil, and increases in productivity of cereal crops grown in rotation.

Much of the potential for increasing cowpea production in a sustainable and environmentally friendly manner is present in the Sahel. There are fewer insect pests and diseases of cowpea in this zone than in the subhumid Savanna zones and humid zones of Africa. The Sahel also could be a major zone for cereal production if shorter cycle and more effective pearl millet and sorghum varieties could be developed.

There are major problems of poverty, hunger, disease and malnutrition in the Sahel. One option for overcoming these problems is the development of improved farming systems that integrate rotations of cowpea, pearl millet, sorghum and peanut with livestock production.

The increased cowpea production should be coordinated with the development and use of more effective food-processing methods and cowpea marketing systems. In this way more cowpea grain and value-added products can be exported from the Sahelian zone to other regions of Africa bringing cash to the Sahel and reducing poverty.

Achieving a ‘Green Revolution’ in cowpea production in the Sub-Saharan Africa will require
some investment. There are indications these funds may be available. The Bill & Melinda Gates Foundation and the Rockefeller Foundation announced in September 2006 that they will form an alliance to contribute to a ‘Green Revolution’ in Africa. They will provide funds to promote the production and dissemination of new crop varieties and management methods by African scientists and extension agents. They will support the establishment of effective seed service industries. They will educate African scientists and extension agents at universities in Africa. These foundations have large financial resources and thus will be able to launch massive programs. I have reviewed two of their research proposals and they have some merit. I am hoping that these foundations will consider the programs and approaches I have recommended in this memoir.

Comprehensive educational programs are needed

For development to be accelerated in Africa, greater education is needed at all levels and especially for women. There is a strong desire for education among many young people in Africa, all that they require is an opportunity to achieve it. The following stories illustrate this issue.

I was the last British colonial officer to serve in the district of North Mara in Tanganyika. North Mara was isolated from the center of government in Dar es Salaam and the outside world when I worked there. The British District Commissioner who I had worked with in North Mara, prior to independence, was married to the daughter of a Goanese man who owned a book store in Dar es Salaam. As a wedding present he had given the couple an extensive collection of Penguin paperback books that I greatly admired. While working in Tanganyika I spent much time on my own and during the evenings I read many books.

When visiting villages I was impressed by the desire for education of many young Africans. I remember one young man who lived on the escarpment near Tarime who took me into his small grass hut. The hut was remarkably clean given the local conditions and his few possessions were well organized. He showed me with pride a paper pad and ball-point pen, which clearly were precious possessions. He wrote a complete sentence in English on the pad. I noticed, however, that there were no books in his room. I hope that since then he has been able to get some to read.

On another occasion a local teacher came to see me during the evening to talk. I had set up a temporary camp on the side of a river. Intense rains had caused the river to flow high and had
prevented us from fording it with the government Land Rover. He said he had been teaching students how to use logarithm tables to do multiplications and divisions but that he and they wanted to know how the logarithm tables were developed. A mathematical text would have helped with this problem but he did not have one. I did my best to explain the theory of base-10 logarithms to him.

**What is involved in education!**

A decade later when I became a Professor at the University of California, Riverside I devoted much thought to the general process of education. My own experiences did not provide a good guide to formal educational processes. Much of what I had learned I had taught myself by reading and thinking. I always questioned and tested, where I could, the validity of what I read.

My thoughts on education led me to five main conclusions. 1) Education is having a clear understanding of the extent of your own knowledge. 2) The main role of teachers is to encourage students to educate themselves. 3) Students must have a desire to teach themselves to understand what they do not know and to learn more. 4) Voracious reading coupled with careful evaluation and analysis, and some guidance from a teacher, when needed, provide a way to accomplish this. 5) Some things are more easily learned by doing them rather than by reading about them. Laboratories and practical classes under the guidance of a skilled person can provide valuable opportunities for learning by doing.

My view of what is involved in education probably was influenced by my own experiences in life. I suppose, I expected students to be like I was and want to educate themselves. I taught advanced undergraduate and graduate courses where I have the impression that I was very effective with good students but hopeless with the other students. Maybe I needed to devote more effort to point 2 -- encouraging students to educate themselves. I suspect, however, that the students with mediocre performance already had been spoiled by being told that teachers were supposed to educate them. The poor students also had a tendency to try to memorize facts which did not help them in taking the exams I gave, which tested for understanding of concepts.

Too many people think that an educated person is someone who knows many facts. Nothing could be further from the truth: an educated person is someone who understands the limits of their knowledge --- they know what they know and importantly, what they do not know. This principle
is valid for all levels of education. For people who mainly work with their hands, such as carpenters, being educated means knowing the limits of both their knowledge and their physical capabilities. I am not suggesting that people should not try to do new things but that when they do it they should know that it is new and are careful.

I have seen very few books while traveling in Africa, which is unfortunate because many Africans have a strong desire for learning. The little library of Penguin paperback books in the District Commissioners house in Tarime, North Mara in 1962 was indeed a valuable resource for me. After I retired in 2003, I donated several thousand issues of scientific journals that I had accumulated during my many years as a scientist to a research station of the national agricultural research service of Burkina Faso which did not have a library.

Making more books available to people in Africa could enhance rural development. Many types of books are needed including practical works on how to repair bicycles, water pumps, small engines and grinding mills, human health and disease, human nutrition, agriculture and how to build irrigation and drainage canals, houses and stoves, text books and scientific works, non-fiction treatments and literary works. These books could be made available by having central libraries supporting fleets of mobile libraries that visit villages on a weekly basis. When I was growing up in a small village in Yorkshire, England one of the highlights of the week for me was the visit of a mobile library which came to the parking lot of our local tavern. The books in this library brought the ‘world’ to the many young people and others who took advantage of it.

Many people think that one answer to educational needs is to spread computers that have access to the internet to the far reaches of the world. For rural areas with little contact with the outside world I favor libraries of books as being a more robust technology with fewer potential bad side-effects. Maybe the most effective progression would be to first provide books and then to provide computers because they are complementary.

The essence of being a scientist

Public perceptions of scientists typically involve regarding them as knowing many facts and being able to develop technologies. This is not the essence of being a scientist.

I have served on committees giving written and oral Qualifying Examinations to Ph.D.
students. The objective of these examinations is to determine the students potential for becoming a competent research scientist. Students who failed my part of the oral examination typically did so because they did not understand the limits of their knowledge. I deliberately asked them some questions that I was sure they could not answer (because no one I knew could answer them). If they had said “I do not know the answer” this would have been adequate for me. If they had said “I do not know the answer but I will speculate as follows” this would have been even better if the speculation had some merit. If, however, they proceeded with providing what they felt was a clear answer, but which I felt was not sound in relation to theory and previous empirical studies, they risked failing the examination.

Once while working as an administrator, I had to evaluate whether a person should continue to lead a particular scientific project. I asked the person to explain what the project should do in the future. The person had worked on the project for many years and had much experience and knew many facts. The person had developed many ideas about how the project should proceed, some were innovative and sound but some were clearly not valid. Overstated and inadequately justified claims led me to conclude that a new leader was needed for the project. Inadequately educated people have a tendency to think they know more than they do which can result in unwise decisions and impede development. This is why it is prudent when electing a President of a country to choose one who has an adequate level of ‘true’ education whether gained formally or informally.

On written qualifying examinations for Ph.D. students I often included the following question. “Describe the general responsibilities that scientists have towards other people?” I believe that scientists are privileged and as such do have a responsibility to serve society. I have received diverse responses to this question. Students have often said “Develop new knowledge.” or “Develop new useful technologies.” My current preferred answer is “When asked, provide a rational, honest and objective analysis.” A reputation and ability for doing this is the essence of being a scientist. During the subsequent oral qualifying examination of Ph.D. students I often would ask questions on this topic that were designed to determine how well they appreciated the difficulty of being objective.

Where there is political interference with science it becomes more difficult for scientists to be objective and execute their responsibilities to society. By late 2006, more than 10,000 United States scientists, including 52 Nobel Laureates, 62 National Medal of Science winners, 194 members
of the National Academies of Science, and science advisors to Republican and Democratic Presidents dating back to President Eisenhower had signed a statement strongly condemning the politicization of science by the administration of President George W. Bush. In my opinion, the development and future progress of any country requires the active involvement of an effective, objective scientific community that is not politicized.
Chapter 10. Epilogue

Administrative disturbances of the project in Africa and the United States

The project experienced a series of catastrophic events in Senegal in 1995. A new Director General of ISRA was appointed and major changes began to take place in the organization of agricultural research in Senegal that were detrimental to the cowpea program. By the end of 1996 the cowpea research team in Senegal had lost four experienced scientists. Dr. Ndiaga Cisse who had just returned from his Ph.D. studies in the United States had been assigned to cotton breeding, and Samba Thiaw had been assigned to cotton agronomy. They were supposed to work in a remote ISRA station at Tambacounda located in eastern Senegal. Samba moved to Tambacounda but Ndiaga questioned the value of his transfer since he had been trained in breeding cowpea and sorghum, which was needed in Senegal. Subsequently, Ndiaga was assigned to sorghum breeding based at the Bambey station. Plant pathologist Mbaye Ndiaye had been so discouraged by the ISRA administration that he left Senegal and accepted a job as a teacher with the Agrhymet project in Niamey, Niger. In addition, the ISRA research station at Louga had been closed, and the head of the station Moustapha Diop had been transferred to St Louis, Senegal. Cowpea research in Senegal essentially came to a halt.

At the same time changes were occurring in the operation of the Bean/Cowpea CRSP that brought both new opportunities and problems. The program had been extended by USAID for five more years starting in April, 1997. But with a regional disciplinary approach rather than the bilateral holistic approach we had used in earlier years. Bilateral approaches are easier to administrate and historically have been more effective in international development than regional programs. But they have less potential impact than regional approaches which have the chance to promote rural development in several countries.

I was now responsible, together with a cowpea breeder from Africa, Dr. K. O. Marfo, for coordinating cowpea breeding activities by the CRSP. This involved coordinating activities in several U.S. universities and national cowpea breeding programs in Cameroon, Ghana and Senegal, and with other organizations such as IITA and WVI.

Early in 1997, another new Director General was appointed to ISRA and I hoped that
conditions would improve for cowpea research in Senegal, but no significant changes were made in the cowpea team during 1997. Since there was no significant cowpea breeding activity by ISRA in 1996 or 1997, I did not visit Senegal during these years. I did this to provide to ISRA an indication of my dissatisfaction with the changes that had taken place. Prior to this I had visited and worked in Senegal virtually every year since 1976.

Changes also were occurring at UCR. From July 1994 through June 1997, I had been Chair of a large department at UCR and this had constrained my ability to conduct collaborative research in Africa. During this period there was considerable administrative turmoil at UCR mainly generated by the desire of the administration to make major changes in the College of Natural and Agricultural Sciences. As Chair I had spent considerable time trying to protect the faculty from the disruptive effects of the decisions made by the upper level administration. My intent was to help the faculty to devote at least some of their time to the important tasks of conducting research, teaching, and the extension of information to farm advisers and growers.

During the 1990s there had been increases in the number of professors at UCR who were conducting either basic molecular research on plants, which was assumed to be of benefit to agriculture some time in the future, or studies of environmental problems and natural systems. In addition there had been substantial decreases in the numbers of people actually working on aspects of crop production. The new structure has been very effective in enabling UCR personnel to obtain substantial federal grant funding but it is not clear whether it will be of much value to agriculture.

The broad approach that I had taken to plant breeding and agronomy was not consistent with the new long-term plans of UCR. I am glad, however, that I was privileged to work for UCR and the California Agricultural Experiment Station during a time when they were making major contributions to agriculture. I appreciated the fact that UCR had given me the freedom to work on those applied and more basic research problems that I felt were important.

**Project recovery**

In the fall of 1997, I visited Ghana to initiate collaborative research in cowpea breeding for the Savanna zones of Africa with Dr. K.O. Marfo who had collaborated with me on breeding for heat tolerance while conducting his dissertation research at UCR a few years earlier. I thoroughly enjoyed
the opportunity to meet K.O. again and have him show me what to me was a ‘new’ country. I was impressed by the diverse and generally good conditions for agriculture that I saw in Ghana, and the substantial opportunities for making progress in research and development. My deputy, Dr. Jeff Ehlers visited Ghana in the fall of 1998 to strengthen our collaboration in cowpea breeding. In addition, Jeff, K.O., Ndiaga and I continued to plan the development of improved cowpea cultivars for the Sahelian and Savanna zones during a Bean/Cowpea CRSP meeting in Michigan in the spring of 2000. Unfortunately, shortly after this meeting Dr. K.O. Marfo died in an airplane crash that occurred in Ghana on June 5th, 2000. This was a terrible blow both personally and professionally. Jeff, Ndiaga and I had to try to design other ways to make K.O.’s and our dreams for the improvement of cowpea become a reality.

Early in 1998, I had participated in an administrative meeting of the Bean/Cowpea CRSP in Dakar, Senegal. At this meeting, the new Director General stated that the collaborative project between ISRA and UCR had been very effective and was being used as a model for collaboration between the various research programs of ISRA and external organizations. He also informed us that Dr. Ndiaga Cisse, the experienced cowpea breeder who had developed ‘Mouride’ and ‘Melakh’, had been reappointed to the cowpea team (but also still with responsibility for breeding sorghum). I visited Senegal again in the fall of 1998 and was impressed by the progress Ndiaga had made in reinvigorating the cowpea breeding program. In the fall of 1998, Samba Thiaw was permitted by ISRA to come to UCR to study for a Ph.D. under my direction which he completed in the winter of 2003. He then returned to Senegal to work on the agronomy of various crops at Bambey.

**Recognition of the accomplishments of the project**

Dr. Ndiaga Cisse received a prestigious Senegalese Presidential Award for Science from President Abdou Diouf on July 14th, 1999 for developing cowpea varieties ‘Mouride’ and ‘Melakh’. The cowpea project in Senegal is now in a position where it can have some chance of making additional progress in solving the major problems that confront rural development in the Sahel.

I received the Chair’s Award for Scientific Excellence from the Board for International Food and Agricultural Development (BIFAD) on September 28th, 2000. BIFAD is a Presidentially appointed board that provides scientific, professional and intellectual guidance to the United States
Agency for International Development. The reason for the award was stated as follows: “For outstanding research on plant responses to environmental stresses and plant breeding, and advising and collaborating with African scientists; thus contributing significantly to the development and extension of cowpea varieties that have provided millions of poor people with more food.”

I also received a United States Department of Agriculture, Secretary’s Honor Award from the Secretary of Agriculture, Ann Veneman in Washington, D.C. on June 4th, 2001. The reason for the award was “For breeding disease-resistant and early-flowering varieties of black-eyed pea (cowpea) that have become reliable sources of nutritious food in drought-ridden West Africa.”

My awards honor the contributions of many people, as I said in my presentation at the BIFAD/USAID awards ceremony in Washington D.C. in March 2001: this project “took many years and a collaborative effort involving many people. This is their story as well as mine.” * A story I have tried to tell within the pages of this memoir.

A short while after receiving the 2001 award, an official from the USDA contacted me. They wanted to use my story as an example to encourage young people to get involved in international development. I declined their kind offer to make me a ‘poster boy’ even though I certainly encourage young people to be involved in international development. I explained to the person who contacted me that it now would be difficult for young people from the US or Europe to do the things in Africa that I had done in the past. As an example, the areas that I have walked through in the Kordofan region of the Sudan have been impacted by armed rebels coming from the south. Even though as of 2006 the civil war in the Sudan has officially ended, to the west of Kordofan in the neighboring Dafur region unspeakable atrocities are being imposed upon the Sudanese people by armed militia. There even has been reluctance among several governments and organizations to put non-African troops in this region. It has become difficult for outsiders to work effectively in some parts of Africa. The development of this continent mainly should be done by Africans and many are stepping forward to meet the challenge.

* A complete version of my presentation at the awards ceremony -- “Cowpea Varieties Provide a Partial Solution to Sahelian Droughts” -- may be found in Annex Two of “Agriculture in the New Century”, Title XII Report to Congress, Fiscal Year 2000, USAID.
Planning for the future

My role as director of the USAID project over many years in Africa and California ended on July 31st, 2002. I had been seriously ill too many times while working in West Africa, and discouraged by the death of friends. In addition, changes had occurred at UCR that I felt were detrimental to agricultural research and education. More importantly, I had come to recognize that some younger scientists with different expertise could more effectively execute this difficult work than I could. I stayed one more year at UCR to facilitate the transfer of leadership of the USAID project and the Agricultural Experiment Station cowpea breeding project.

A new phase of the USAID project began late in 2002 under the joint leadership of my UCR colleagues Dr. Jeff Ehlers in the Department of Botany & Plant Sciences and Professor Phil Roberts in the Department of Nematology. Dr. Ehlers had substantial experience working on breeding cowpea for pest resistance and improved grain quality in Africa and California. As my Deputy he already had become responsible for the cowpea breeding project of the Agricultural Experiment Station. The expertise of Professor Roberts in plant resistance to plant parasitic nematodes should continue to be very valuable to the UCR cowpea breeding project and collaborative projects of the Bean/Cowpea CRSP, especially in the Sahel. The projects are now in a good position to make substantial progress breeding cowpea varieties for Africa and the United States that have increased pest resistance, improved grain quality and many other desirable traits.

With the help of many colleagues I wrote a review of the accomplishments in breeding and developing cowpea cultivars of the 20-year Bean/Cowpea Collaborative Research Support Program for a Special Issue of Field Crops Research. This Special Issue, for which I was a co-editor, also includes reviews by other CRSP scientists of their accomplishments in the management of insects pests of cowpea during storage, cowpea processing and cowpea marketing, and research on common beans.

I also wrote a short final chapter for the Special Issue that provides advice on “Future Directions of the Bean/Cowpea Collaborative Research Support Program”. My intent, although I did not explicitly state this in the article, was to provide my recommended future directions for all of the CRSP projects and all of the International Agricultural Research Centers (IARCs).

I feel that the CRSPs and IARCs should focus on plant breeding but in a broad sense that
includes associated studies on crop management, quality and nutrition, and food processing and marketing. The most successful CRSPs and IARCs, such as the wheat and maize center, CIMMYT, and the rice center, IRRI, did this in the past. The ‘Green Revolution’ in wheat and rice production resulted from these efforts at CIMMYT and IRRI. Unfortunately, in recent years CRSPs and IARCs have been initiated that did not have any plant breeding and focused on other topics. Also, the CRSPs and IARCs that had strong plant breeding programs, in the past, have been modified by adding many other projects that do not contribute to plant breeding but compete for resources that have become scarce due to funding constraints. These other projects tend to be site specific without general value on an international scale and do not represent areas where the IARCs and CRSPs have a comparative advantage compared with other research organizations.

But why should the CRSPs and IARCs focus on and emphasize plant breeding? There are two main reasons for this recommendation.

1) New crop varieties can in principle be adopted by many farmers, including those who are poor, in all countries where the crop can be grown. New varieties can enhance profits and decrease poverty thereby indirectly contributing to reductions in human birth rates. They can require less use of pesticides thereby enhancing the environment. They can increase the supplies and quality of food for people. Overall the use of new varieties can enhance human health and well being.

2) Plant breeding benefits, much more than many other technologies, from collaborative efforts across many ecological zones and disciplines which is a major strength of the approaches taken by the CRSPs and IARCs.

The world needs international collaboration in plant breeding to 1) overcome plant diseases and pests because they do not respect national boundaries, and to 2) enable many people to benefit from the new technologies and varieties. The world can benefit from international collaboration in plant breeding by developing comprehensive strategies for plant-gene deployment to overcome plant disease organisms and pests that continue to evolve and produce biotypes that overcome the resistance genes present in current varieties. Varieties with new sources of resistance to diseases and pests need to be tested on an international scale to determine where they are and are not effective. When important genes are discovered that enhance varietal value in many target production environments, they should be bred into many different types of varieties so that the many farmers
in these different environments and countries can make use of them.

Plant breeding can benefit from the contributions of scientists from many disciplines including plant pathologists, nematologists, entomologists, weed scientists, plant physiologists, microbiologists, molecular geneticists, agronomists, soil scientists, biochemists, food scientists, socio-economists etc. But, their input must be collaborative, the scientists must work together with the common goal of developing new varieties. CRSPs and IARCs can be organized so that scientists are encouraged to work together as a collaborative team, whereas universities and some other organizations can have difficulty doing this due to the degree of independence granted and required of individual scientists. Some independence is desirable since it can lead to creativity. An important goal of research organizations should be to enable individual scientists to achieve an optimal balance in the extent of collaboration and independence in their research activities. Unfortunately, as of 2006, universities in the United States were losing much of their previous strength in research and education in main-stream plant breeding.³

In the article on “Future Directions of the Bean/Cowpea Collaborative Research Support Program” I made a closing statement which I will present here with some minor changes. International collaboration in research can provide an excellent opportunity to develop long-term friendships that are of immeasurable value, enhancing personal well-being and mutual understanding among people from diverse cultures. When scientists with similar applied goals gain mutual scientific and personal benefits from collaborative efforts, bonds are created that provide a sense of community that can last a lifetime. Agricultural scientists can and should play a key role in enhancing mutual understanding on an international scale because this could make major contributions to world peace.
References

Preface


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Chapter 5. Cowpea and the “Hungry Period” in the Sahel


Chapter 6. On-Farm Experiments and Progress for Women


4 Recipes provided by Kay McWatters, Department of Food Science and Technology, University of Georgia, Griffin, GA 30223, USA.

5 Recipe provided by Ngoye Samb, who is the wife of Samba Thiaw, CNRA, Bambey, Senegal.


References


Chapter 7. Improved Cowpea Production Systems for the Sahel and California


References


Chapter 9. Future Needs and Opportunities for Agricultural Research in the Sahel


Chapter 10. Epilogue


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