Appraisal of the Potential for Dry Season Vegetable Irrigation, Particularly Drip Irrigation, in Zaire Province of Angola

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Appraisal of the Potential for Dry Season Vegetable Irrigation, Particularly Drip Irrigation, in Zaire Province of Angola

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Executive Summary

A proposed training program on drip irrigation was fortunately shifted to appraisal for dry season irrigation of vegetable in and around the community of Kuimba, Zaire Province, Angola. While the appraisal looked at various forms of irrigation, the emphasis was on the prospects for using drip irrigation. This was done during September, which is towards the end of the dry season when stream flow as the source of irrigation water would be at the lowest. The appraisal concentrated on:

- The amount of water available, relative to the area planned for irrigation,
- The ease of access between the available water and areas to be irrigated,
- The quality of water particularly regarding the potential for plugging drip emitters,
- The estimated cost for irrigation systems, particularly drip, relative to value of the anticipated produce to assure the investment is recoverable, and
- The ease with which the system could be operated.

There were four farms visited in detail each interested in developing vegetable irrigation on several hectares in some lower lying areas near perennial streams. In most cases the stream had adequate water to accommodate the area planned for irrigation, and for which any excess applied water would quickly return to the stream and be available to a downstream users. One of the four farmers was already involved in a very simple but effective form of vegetable irrigation, for which there was little to offer as improvements. Some of the areas were still being acquired by the farmers. Thus it is highly realistic for all host farmers to develop dry season irrigation of vegetable, and it is possible to use drip irrigation. However, the question is rather drip irrigation is the most appropriate or not. Since only one host farmer was involved in a very causal but effective form of vegetable irrigation and since there was no drip material or equipment identified in Angola, the appraisal also include a quick review of basic irrigation including an initial estimate of daily crop water requirements 86 m3/ha for full canopy low altitudes tropics. This is a substantial amount of water, and usually much more than most people conceptualize at. Also, since no drip material was located in Angola it was impossible to provide any hands on experience to the hosts and all information had to be handle with photos.

Thus while drip irrigations does substantially reduce the irrigation water needed for incomplete canopy crops like vegetables, and is heavily promoted for it water saving potential, it is also substantially more expensive to purchase, more sensitive to maintenance problems, and economic returns. Thus it is most effective in areas where water is locally in very short supply or very expensive, or it was needed for humidity induced fungus control, such as with grapes or squash. The biggest concerns for drip irrigation, particularly at the scale envisioned by the host farmers is:

- The total cost of all the drip lines, connectors etc needed for a full hectare of irrigated vegetables,
- The need for clean water that will not plug the pressure compensating drip emitters,
- Thus the need for filters to make certain the water is clean,
- The extra labor needed to work around the drip lines in weeding fields and managing crops,
- The potential damage done by animals biting emitters to access the water,
- The potential damage from careless workers, and
- The frequent need to replace the entire drip system after only one or two year as ultra violet light renders the plastic lines brittle.

With all that additional expense the question is can the cost be recovered in an environment in which the consumer prices of vegetable intended to produce are only 1/3rd to 1/5th that of the USA, severely restricting the profit margins for the vegetables produced and considerable reducing the relative amount farmers can invest in irrigation. These are all the production economic conditions the host must each address individually before making a final commitment to drip irrigation.

In addition to discussion on irrigation a couple non-irrigations issue were discussed and are commented on in the Appendix. These include soybean production and the need for a specific rhizobium for N-fixation and the viability of seed held over the dry season. Plus, aquaculture for which the hosts had done a commendable effort at developing. However they might consider the possible importance of inducing all male fish to prevent too many generation in a confined pond, and the potential for poultry and pig production in conjunction with the aquaculture.

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Introduction

As originally written the Scope of Work (SOW) for this F2F assignment was to provide training in the use of drip irrigation for the Chalom farm near Kuimba, in Zaire Province of Angola for vegetable production during the dry season. However once the SOW was reviewed by the volunteer and in response to questions raise, the emphasis was shifted to being an appraisal assignment of the potential for irrigation in the area, with an emphasis on drip technology. Also, once on the ground three additional farms were added providing a more comprehensive analysis of the irrigation potential for the area. The four farms were organized into an association to explore the potential for irrigation in the area. In reviewing the irrigation potential of the area several concerns were taken into consideration. These were:

- The amount of water available, relative to the area planned for irrigation,
- The ease of access between the available water and areas to be irrigated,
- The quality of water particularly regarding the potential for using drip irrigation,
- The estimated cost for irrigation systems, particularly drip, relative to value of the anticipated produce to assure the investment is recoverable, and
- The ease with which the system could be operated.

This was all done in the overall context that irrigation technology has become far more precise than most farmers are able to take full advantage of, as most delivery systems just cannot deliver water at the research level of accuracy. Also, given the soil water holding capacity's potential to buffer small weather induced changes in crop water needs, is it really necessary to deliver water at the accuracy of available irrigation research? Is it even possible in Angola to access the necessary climatic parameters needed to make daily adjustments in plant water requirements. This is true even in the USA where most farmers are familiar with crop water requirement, have ready internet access to all the climatic parameters needed to accurately estimate crop water requirements, are knowledgeable of all the various irrigation technologies, so they can carefully select what is most suitable for their particular condition. The concern for irrigation research technologies exceeding the capacity of virtually all delivery systems and farmers to utilized can be summarized in a couple comments opening the irrigation chapter of the volunteers book "Developing Smallholder Agriculture: A Global Perspective". These comments are:

- In response to an internet inquire seeking details on a water requirement constant, and my questioning the need for the level of accuracy requested, the comment was "measure it with a micrometer, mark it with a grease pencil, cut it with a chain saw."
- A comment of my own: "More combined research and extension time, effort, and money has been spent on irrigation and related issues by engineers, agronomists, economists,

and sociologists for less user-acceptance by farmers than any other crop production activity!"

This all implies that the guiding principles in developing on-farm irrigations systems is simplicity and convenience.

Agronomic Description of Area

The Zaire Providence of Angola is in the Northeastern portion of the country neighboring the Democratic Republic of Congo (Fig. 1). The Provencal capital is M'Banza-Kongo which is about 70 km southeast of town of Kuimba where Chalom farm is located and the appraisal was conducted. The area appeared mostly to be rolling hills with some steep V-shaped valleys going down to perennial streams and rivers. There are only limited low lying flat areas suitable for dry season irrigation of vegetables, with simple low lift pumps and hoses for distributing water. Areas that were so suited, were effectively being irrigated by simple but effective means. The rainfall distribution followed the typical southern hemisphere tropics with a rainy season from October or November to April and a dry season from May to October (Table 1).

Fig. 1. Map of Angola Showing Zaire Province with captial M'Banza-Kongo in North West.

Table 1. Ave. Rainfall (mm), Max. & Min. Temperature (°C) for M'Banza Kongo, Angola

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Prec.	115	125	170	250	100	1	0	1	9	75	200	155
Min. Temp	21	21	21	21	20	17	16	18	20	20	20	21
Max. Temp	29	30	30	30	29	27	25	26	27	29	29	29

However, if you assume an Evapotranspiration (ET) rate of 6.0 mm/day[1] or 180 mm/month most months during the rainy season the rains would be at a deficit to the ET requirements. This would typically put most crops under some moisture stress during the rainy season resulting in some yield loss, but would not result in full crop failure. It would be expected to have the typical variation in the monthly mean of 100% for the on-setting and decline months of October and May, and nearly 50% for the midseason months of November through April. The elevation at Kuimba is some 300 – 400 m above sea level which is enough to reduce the temperature slightly compared to lower elevation. The temperature is fairly uniform through the year, but with the lowest temperatures during the dry season (Table 1). This could be important for retaining soybean seed, as discussed in the Appendix A.

The volunteer assignment came in September at the end of the dry season. Thus the rivers and streams were at their lowest flows, but with the minimum about of particulate or biological

[1] To be discussed in detail later.

contamination that would interfere with drip irrigation emitters. However, the streams and rivers are continuously use for various domestic activities like, fermenting cassava to remove the cyanide, washing clothes, bathing, washing vehicle, etc. All of which can either generate some slime or stir up sediment that would be picked up by any irrigation pumps and have to be carefully removed for use in drip irrigation. Earlier in the dry season the stream flows would be higher allowing more areas to be irrigated, but the water would most likely be more turbid with suspended matter that would need to be removed for drip applications to avoid extensive plugging of emitters. This is something the hosts will have to evaluate on their own.

Most of the cropping appears based on cassava with a mixture of other intercropped such as groundnuts, beans and soybeans. All of these were mostly likely planted starting last November during the early part of the rainy season. Thus, at the time of the visit all the potential intercrops had already been harvested, with only cassava remaining and this was in the process of being harvested, fermented, the outer skin removed and dried. Animal enterprises appear mostly goats, chicken with a scattering of pigs and ducks. Only limited number of cattle were noted. There appears to be a tremendous amount of land available for development, and among the assignment hosts some enterprising individuals willing to acquire land and invest in its agricultural development. As most of this looks like land that could have been developed for non-irrigated crops like cassava long ago, this could reflect a change in governmental policy to encourage private development of land that might formally be held by the government.

Field Visits

The assignment was coordinated through the Chalom farm but involved several other farms. The individuals appear to have formed some type of association to develop fairly large areas for irrigated vegetables in the dry season near some perennial streams and rivers. However, some of the land for the planned irrigation has yet to be formally acquired by the hosts and was mostly in native vegetation that would have to be cleared and graded before becoming suitable for irrigation. The individuals have only limited experience in irrigation of any type, with only one actually involved in limited but effective small scale irrigation. However, the hosts are computer literate, familiar with seeking information from the internet and adapting it to their situation as needed and they did for the fish ponds and aquaculture enterprises. They have been recommended to consider drip irrigation, because of its potential to save water, but do not appear well versed on what drip irrigation entails. It has to be noted that drip is highly promoted by the development community for its potential to save water, without considering some of the economic and operational difficulties associated with it, or the relative economics of drip compared to other forms of irrigation.

Also, most of the irrigation association members appeared to also be the permanent president of a “farmer’s association” that appeared more like landlord – sharecropping tenant relationship, in which the farmer/tenants were required to work 2 of the 6 day work week for the association president/landlord. Initially this appears to be an interesting twist on the usual standard nearly worldwide 30-70 sharecropping based on yield sharing instead of labor sharing, with the 30% representing the value of land. However, it is also reminiscent of feudal lord and serf system that was based on mandatory labor obligations.

Fig. 2. Cassava Production at Chalom Farm with Intercrops Already Harvested

Chalom Farm: The main Chalom farm is a 200 ha farm about 15 km from Kuimba. It is owned and managed by Mr. Kakuvutuka Nfuavata, who was the primary host for the F2F assignment. This appeared to be a direct owner/manager and not the tenant relationship described above. He is also involved in multiple other farm and non-farm enterprises and appears to have the financial resources to acquire and develop additional irrigated land. The main farm is used mostly for rainfed cassava (Fig. 2). Which is often intercropped with groundnuts, soybeans, common beans, etc. Since he was producing soybeans time was diverted to discuss some of the concerns of soybean production (Appendix A) Since it was September and the cassava was mostly planted 11 months earlier the only crop remaining was cassava with all intercrop having already been harvested. The main farm contains a small natural pond. It was reasonable size but at the bottom of a steep V-shaped valley. While there was some irrigation potential from the pond, and it would most likely represent a water table that could quickly recharge the pond if water was withdrawn for irrigation. However, it would require a 30 m lift to get the water to a land suitable level to easily irrigate (Fig. 3). This would require a high pressure pump capable of developing 4 bars (60 psi) of lift. That might be too expensive to purchase and operate. There was a small plot of land being used for irrigated vegetables from a seepage well below the pond. It occupied all the level ground in the immediate area (Fig.4).

Fig. 3. Natural Pond on Chalom Farm but Needing 30 m Lift to Reach Irrigable Land

On a second visit we were shown 5 small fishpond the owner had develop after getting ideas from the Internet (Fig.5). They were actually well designed and regulated with gravity access from a nearby stream, and pipe links to equilibrate the water between ponds. This represented a commendable effort. He was thinking of placing a piggery on a raised

Fig. 4. Small Area of Irrigated Vegetables Below Chalom Farm Pond

Fig. 5. Fish Ponds Recently Built on the Chalom Farm

bit of land with the waste from the piggery feeding the fish or fertilizing the pond to promote algae growth to feed herbivore fish like tilapia being raised. This is a well promoted concept in Asia, where they also suspend poultry enterprises over fishponds. Since the ponds are at stream level of a reasonable steep sided valley there was no interest in irrigating crops from the ponds as implied in the original SOW. While observing the pond the discussion was diverted to some observation on fish farming (Appendix A).

A third visit did get to the area being acquired and far more suitable for irrigation from a stream (Fig.6). However, the flow was minimal at about 2 l/sec. and thus most likely he would not be able to develop the entire 9 ha he was hoping to or at least not this late in the dry season. The current flow would only accommodate 2 to 4 ha of irrigated vegetables even with drip irrigation. This may be the most appropriate area to consider drip irrigation at some time in the not too distant future, but perhaps not initially.

Fig. 6. Mr. Nfuavata Overlooking the Chalom Farm Expansion for Irrigation of Vegetables.

Simon Diangani: The second farm was owned and managed by Simon Diangani. It was about 400 ha. farm located 10 km on the other side of Kuimbe from the Chalom farm. The farm appears to be a hybrid of direct management and leased land, with the lease agreement being 2 day of labor each week as described earlier. The area was primarily in cassava that could have been intercropped previously with all the intercropped already harvested. Currently a group of women, who could have been tenant farmers cum laborers were harvesting and processing cassava after allowing it to ferment in the stream for 2 days (Fig. 7). A process that eliminates the naturally occurring cyanide in cassava, but also results in some scum forming in the surface of the water in the stream that could

Fig. 7. Women Processing Cassava After Fermenting in Stream for 2 Days to Eliminate the Cyanide

be sucked up in a pump and easily plug drip emitters. If these women were actually farmers or tenant it was not mentioned nor did they participate in the visit and discussions.

Fig. 8. Mr. Simon beside His Irrigated Tomatoes and Onions with Cabbages along Border.

His land included a perennial stream with a flow of about 20 l/sec. This he and some of his neighbors on the other side of the stream were actively lifting water about 3 meters to irrigate vegetables such as tomatoes, onions, cabbage and eggplants and was the only active organized irrigation seen during the assignment (Fig. 8). The typical situation was a small diesel pump with about 3 m of lift, going into a large 10 cm hose similar to what is used for fire engines, then splitting the outflow into 2 standard size hoses for distribution to small basins and furrows (Fig. 9, 10). A very simple and effective means of irrigating small areas of up to 2 ha adjacent to a reliable water source. The practice was widely used under similar conditions in Zambia as noted in a previous F2F assignment[2]. Given the land readily available for irrigation and stream flow, it would really be difficult to provide a better system for simplicity and convenience. You could use drip irrigation but it most like would be too much effort as the water supply was more than adequate even late in the dry season with any surplus water would simple and rather quickly return to the stream and be available for re-pumping, perhaps with some minor loss from soil surface evaporation. The diesel fuel needed to pump any extra water would most likely be cheaper than the cost of installing and maintaining a drip irrigation system with all the accessories and extra effort the drip systems might require. He might consider placing some fairly large

Fig. 9. Small Diesel Pump Used to Lift Water from Small Stream to Irrigate Adjacent Land Planted to Vegetables.

Fig. 10. The Main Hose from the Pump being Split into 2 Hoses for Distribution to Vegetables.

[2] http://webdoc.agsci.colostate.edu/smallholderagriculture/SMC-RLT-Report.pdf

rocks, which will not wash away during the larger mid-rainy season flows, across the stream just downstream of his pump. While not fully blocking the stream or consuming any water, it would serve to lift the water and make it easier to pump water and keep the intake hose off the bottom. This would reduce the amount of particulate material like sand and small gravel being sucked into the pump and abrasive to the impellers, etc. The biggest concern is that, as people upstream also undertake similar irrigation practices, the water supply could dwindle. If and when this happened drip irrigation could be considered, but not before.

Ntinti Lulendo: Ntiniti Lulendo has a large farm with historic ownership, and appeared to manage the land as president of a farmers' association as mentioned earlier. He was hoping to develop a large low lying area for irrigations. This was again down near river level and even had intermitted flooding on some field for a couple days during major surges in the rains. Much of the area was planted to cassava and other crops including bananas (Fig.11). He claimed to have legally or at least unencumbered unlimited access to the Ambroz River with a flow of some 2 or 3 m^3/s (Fig. 12). This is more than adequate for the area intended with only 4 or 5 m of lift, but a 0.5 km of conveyance distance. The area between the planned pumping station and the fields was in heavy brush so it was not possible to visit the intended pump location. Instead we observed the river from a nearby bridge crossing. Given the amount of water relative to the area, and rapid return of any excess water to the river, the simplest irrigation would be general surface irrigation avoiding the additional cost and complexity of more sophisticated sprinkler or drip irrigation technology.

Fig. 11. The Land Mr. Lulendo Plans to Develop for Irrigated Vegetables

Fig. 12. The Ambroz River Just Upstream from Where Mr. Lulendo Plans to Take Water.

Miguel Mayimonanga: The final farm was about a 2 hr. drive over rough road and near the Congo border. Similar to Mr. Lulendo there was access to the Laungu River with a flow estimate of 3+ m^3/s. (Fig. 13). However, it would require nearly 10 meters of lift to access the more level land suitable for good vegetable irrigation. This is possible but not ideal as it would require lift pumps instead of simple suction pumps. At the time the land was un-acquired and covered with 3 m high natural vegetation making it impossible to fully evaluate the land quality. The land will require some considerable development effort to burn, disc, and grade before it will be ready to irrigate. Again considering the supply of water and ease of returning water to the river, it should initially be developed for surface irrigation before considering shifting to drip depending on the extra fuel costs to pump water relative to the cost of installing a drip system.

Fig. 13. The Laungu River as Source for Irrigation Water

Matondo Magole: Another fish pond site was visited that was owned and managed by a teaching colleague of the interpreter. This was similar to the Chalom farm's fish pond and appears to be part of an association of perhaps 20 members interested in getting into fish farming along with companion enterprises, such as pigs, goats, and possible poultry (Fig. 14). Again there was no real interest in using the fish pond water for irrigation, but there are some discussion and ideas on fishpond management and aquaculture, including the importance of all male fish and combination of fish and other animal enterprises (Appendix A).

Fig. 14. Fish Ponds Developed by Mr. Magole. Stocked with Tilapia Obtained from Congo.

Irrigation Principles

The primary purpose for this consultancy is to look at the irrigation potential of the areas. That basically involved the availability of water and feasibility of the water being distributed to the plants in sufficient quantity, reasonably conveniently, and economically for the plants' benefit and make a sustainable and profitable vegetable production enterprise. The problem is that too often people greatly underestimate the water requirements for plants and conversely overestimate the amount of water available for irrigation.

Basic Physics: The basic physics of plant water requirements are to allow plants to transpire as a means to cool the plant. Transpiration is identical to evaporation except it is done through the plant's stomata instead of a soil or water surface. For this reason and the difficulty separating transpiration from soil surface evaporation the two are combined into the term Evapotranspiration or ET. It is the process of converting water from a liquid to a vapor state. This requires a large amount of energy that is usually referred to as the "Latent Heat of Vaporization" and is typically some 540 cal/cm^3. That is a lot of energy. Since the process of vaporization has a cooling effect the purpose of transpiration is to cool the plant similar to sweat cooling a person. Since the plant does not have the energy to vaporize this amount of water, the energy is external to the plant and comes primarily from the solar radiation of the sun. Without the ability to transpire water the plant will overheat, wither, and die. Prior to this plants will undergo moisture stress that will proportionally impact growth and crop yield, particularly those crops needing to go to seed maturity such as maize, soybean and beans. Less affected are those crops produced for vegetative products such as cassava, sweet potatoes or yams. The ultimate result is that the water requirements of plants has little to with the plant. Instead it is mostly associated with the weather, particularly the amount of solar radiation the plant is subject to with some minor adjustments for wind, relative humidity, etc. These weather variables are uniform over any area for all plants. Thus, while there is a lot of information about the difference in water requirements for different crops, a closer analysis will show that early in the season the difference is related to the percent of the canopy coverage, and once the canopy is fully covered and all radiation is intercepted, almost all crops transpire water at nearly the same rate so the difference between crops is mostly the duration or maturity of the crop. This is also true for the physiological water needed for rice. The excess water requirements for rice represent the water needed to accommodate the deep percolation to keep the paddies flooded. The excess water applied to rice usually will eventually return to the surface water resources and be available for reallocation. In total plant transpiration consume most of the fresh water across the globe, and irrigation consumes most of the developed water, particularly in arid areas.

Plant Water Requirements: Because of the large volume of water required for irrigation and the numerous large scale irrigation schemes a tremendous amount of research has gone into irrigation technology, mostly with a concern on minimizing the water requirements. The result is irrigation science has developed to at least an order of magnitude beyond what most delivery system can respond to. Consistent with uniform radiation load on plants the easiest mean of estimating the changing water requirement is observe the daily evaporation from a pan of water, even if it is not a standard meteorological evaporation pan found in most agricultural weather station. The same energy that is evaporating the water from a pan, is transpiring water from plants at approximately the same rate, unless the plant is under moisture stress and losing potential yield. It would be difficult to find an irrigation water delivery system, even a drip system, which can respond with greater accuracy. It is also unlikely in Angola you can access reliable real time metrological information to consider any daily adjustments. In most tropical areas with uniform day length and temperature throughout the year, a rule of thumb in the absence of detailed reliable weather data, would be an evaporation rate of 6 mm/day which is approximately l lit/s/ha of continuous flow. That would amount to: 86,000 lit/day or 86 m^3/day. Thus the guiding principal for developing and operating an irrigation system, particularly in a country like Angola, is keep it simple and convenient and allow the normal soil moisture holding capacity to buffer the daily fluctuation in transpiration.

Types of Irrigation

There are three basic types of irrigation. They are surface, sprinkler and now drip. Of these the oldest and normally the cheapest is surface irrigation in which water is diverted or lifted from the source, conveyed to the field via canals, and distributed to crops via basins or furrows. It is typically not the most efficient method of irrigation, often only about 30%. However, if water is plentiful and excess water easily returned to the source where it is available for reuse, it will normally be the most economic form of irrigation, and with multiple diversion of the return flow become reasonable efficient. For example 4 diversions at 30% efficiency with have a total system efficiency of 75%, which is the case for the South Platte River in Colorado. The second type of irrigation is sprinkler which now is probable the most common for large farms in the USA. This is pressured system which basically mimic natural rainfall. It is commonly used for full canopy field crops and less so for limited canopy horticulture or vegetable crops. In the USA the most common type of sprinkler is the center pivot, which is a water source, either from a well or canal, in the middle of a square, usually 65 ha. and irrigating 48 ha. It is then self-propelled around the field, usually making a full circle once a day and often runs continuously from planting to harvest (Fig. 15). These systems are clearly visible form the air as large green circles (Fig. 16). With the low pressure drop nozzles center pivots can have up to 95% application efficiency. The third is drip which will be discussed extensively below.

Fig. 15. Self-Propelled Center Pivot Irrigation System Commonly Use in the USA to Irrigate 48 ha of a 65 ha square. The Field is Cotton

Fig 16. Satellite View of a Mass of Irrigation Center Pivots Over Kansas, USA

It should be noted that changes in irrigation methodology in the western USA from surface, with syphon tubes, to surface with gated pipe, and on to center pivot with some drip has been mostly motived by labor constraints and not water availability. There are large scale farmers in the USA who concurrently use all 3 types. It should also be note that some of the shift to drip is motivated by the opportunity to sell or rent water rights to municipalities for substantial amounts.

Drip Irrigation

The scope of work clearly specify evaluating the potential for drip irrigation by the host farmers. Drip or micro irrigation includes a large variety of irrigation techniques the most common of which are drip emitters, micro sprinklers and bubblers. Drip technology is heavily promoted by scientists, extensions, dealers, development professionals, and other promoters for the potential to minimize the water applied. It should be noted they are not necessarily the end users, who have to pay for it, adsorb the extra time and effort in managing it, and still make a profit from the crops produced. The heavy promotions based on water saving imply that the availability of water and water saving are the one and only overriding considerations in irrigation selection decisions. This is rarely the case and despite the promotions irrigation is only one of many crop management components and has to be integrated into the overall farm management and production economics. Thus while drip irrigation can save substantial amounts of water, it can be expensive to install and even more so to maintain, and may have to be frequently replaced if poor quality material is used that degrades when exposed to the ultra violet light of the sun that commonly occurs with commercial open field growing conditions. It is also very sensitive to water quality as any particulate or biological matter in the water can quickly plug the emitters. It tends to be used were water is either in short supply or very expensive, and in economies where the farmers receive sufficient return on their crops to justify the expense. This I reviewed a few years back in a non-F2F consultancy[3].

The use is also concentrated on incomplete canopy crops such as vegetables where other forms of irrigation will allow considerable evaporation from the soil surface, and used in crops that are sensitive to fungal attacks such as downy mildew associated with canopy humidity as could happen with grapes or squash. In this case the drip allows water to be applied under the canopy, in a limited surface area close where the plant stem enters the soil allowing the water to be quickly adsorbed by the soil so the canopy remains dry (Fig. 17). It can also be used for tree crops in sloping lands like coffee where other types of irrigation would lead to excessive runoff and erosion, or other plantation crops where there is only limited need for soil disturbing mechanized such as bananas in Zambia (Fig. 18). Drip irrigation is not a particularly new techniques as it has been used for about 40 years originating in Israel which remains a major user and provider of quality materials, as well as advancing the technology.

Fig. 17. Drip Irrigation Being Used for Grapes to Minimize Mildew Infestation by Applying Water Directly to Soil and Minimizing the Wetted Surface.

[3] http://webdoc.agsci.colostate.edu/smallholderagriculture/DripIrrigationInma.pdf

Fig. 18. Micro Sprinkler Drip Emitter Being Used for Bananas in Zambia

There appears to be a very limited supply of drip equipment available in Angola, as a search of agriculture suppliers in Luanda found none, there was none in Kuimbe, and most people did not understand the request. Thus it was impossible to show the host farmers what drip materials really looks like or provide any relevant hands-on training. It is understood that USAID has initiate drip projects in a dryer area of Southern Angola, which might be worth some of the host farmers visiting, perhaps spontaneously to allow candid discussion with the farmers in the absent of any facilitators or promoters. It appears these systems are based on the iDE design for very inexpensive mini-drip systems covering about at most 100 m^2, and well below the multi-hectare systems envisioned by hosts and they may not be economically viable in producing a marketable surplus of produce to justify the marketing costs.

Fig. 19. Soaker Hose Not to be Confused with Drip System. This Represents Simple Small Holes in A Hose, and Not Pressure Compensating Drip Emitters

Emitters: The key to drip irrigation are the emitters. They are **not a simple hole in the tube**, and thus should not be confused with soaker hoses, commonly used in the USA for watering odd shaped lawns. Soaker hoses have many very small, nearly invisible holes, in the hose and depending on the line pressure, typically about 4 or 5 bars, spray water up to 2 meters in the air, instead of as continuous drops directly on the soil in a highly confined area (Fig. 19). Instead emitters are primarily pressure compensators and thus force the water through what is referred to as a "torturous" track that enhance the friction lose and so the emitters end up releasing the same amount of drip as a continuous stream of individual drops to individual plants at negligible pressure regardless of distance from the source or undulations in the field (Fig.20). This tortuous track can become easily plugged by any particulate matter or algae that gets in the system. Thus most commercial drip systems have sand or other filters to make certain the water that enters the system is clean enough to flow through the emitters unimpeded

Fig. 20. Example of Commercial Embedded Emitters Including Transparent Sample Showing Torturous Track the Water Must Cover Before Exiting the Emitter. All This to Reduce Pressure and Allow Dripping Instead of Spraying.

Fig. 21. Bank of Sand Filters Used in Large (20 ha) Commercial Drip Operation to Make Certain no Particulate Material will Plug Emmiters

(Fig.21). This adds to the overall expense and maintenance of the system. There are many manufactures of emitters and all work equally well. Typically they can be divided into two types, individual emitters and drip tape. Individual emitters are used mostly in gardens where there are a variety of different plants at different spacing and thus individual emitters are placed next to each plant, often connected to the 2 cm. dia. main drip line with a small 0.6 cm dia. capillary line. If there is a concentration of plants like in strawberry productions that vegetatively multiple during the season making individual placement impractical micro-sprinklers can be used.

However for most commercial crop production for vegetable and similar crops at the scale envisioned by the hosts drip tape is used. This is a plastic tube about 2 cm in diameter in which the emitter are imbedded in the tape, at specified distances such as every 30 cm. and with specified flow rates, typically 1 or 2 liters/hour (Fig. 22). However, they all work on the same tortuous track principle. It is also possible to make our own emitter as was the case in Zambia and Iraq. For example the Zambian emitter is simple a very fine capillary tube with a knot twisted in it that can be pulled as tight as needed to control the flow (Fig. 23). Similar the Iraq emitter is a very curly capillary tube with the length of curled tube controlling the flow (Fig. 24).

25 Mil Drip Tape - Heavy Duty - 12" Spacing

7 gpm per 1,000' (0.42 GPH per Emitter) This Tape uses Standard 5/8" Drip Tape Fittings!

Each Roll is 1,000 Feet

DripNet PC is the only true pressure compensating thinwall dripperline available. All drippers deliver precise and equal water applications anywhere in the field irrigating longer runs (up to a quarter-mile long) and undulating fields with high uniformity. Retrievable and reusable, DripNet PC is available at Berry Hill Irrigation today in 25 mil wall thickness, inside tubing diameter of 0.636.

- **Wide regulation pressure range 6 to 30 psi operating range**
- **Sub-Surface or Surface installations**
-
- **Multi Season uses**
- **Inside Tubing diameter .636"**
-
- **Made in the USA**

Excellent for a wide aray of crops including raspberries, strawberries, boysenberries, blueberries, artichokes, hops, alfalfa, potatoes, lettuce, sugar beets, onions and tobacco.
MAXIMUM OPERATING PRESSURE: .636 ID; 30 PSI

Fig. 22. Specifications for Commercial Drip Tape. Metric Conversions are: 1000 feet = 305 m, 12" = 30 cm, 7 gpm = 26 l/min, 0.42 GPH = 1.6 l/hr, quarter mile = 402 m, 0.636" = 1.6 cm, 6 to 30 psi = 0.4 to 2.0 bar (column of water 4 to 20 m high)

Advantages of Drip: The advantages of drip systems are:

1. They can substantially reduce the amount of water applied on incomplete canopy crops by eliminating soil evaporation while still meeting crop water requirements,
2. If water is limited, they can allow additional areas to be irrigated with the available water,
3. It can also increase access to the crops needing frequent harvests, as only a fraction of the in-row surface is wetted leaving the inter-row area dry enough to access. This is good for vegetables like cucumbers that need to be harvested every couple days, and if surface irrigated it would take several days for the soil to dry sufficiency to access the rows.
4. Similarly, they will reduce the canopy humidity and any humidity stimulated fungal diseases that may occur such as downy mildew on grapes or squash (Fig. 17).
5. It is also very useful for tree crops such as coffee on sloping land where other forms of irrigation would result in excessive runoff, and soil erosion as well as other plantation type crops such as bananas in Zambia (Fig. 18).
6. Finally, 100% soluble fertilizer or systemic pesticides can be applied through the drip system, but it has to be 100% soluble or undissolved or partially dissolved fertilizer granules could plug the emitters. Except for urea this would be difficult to find in countries like Angola. In reality there is no other way to incorporate fertilizer, any mid-season applications need to go through the drip system, or it will just sit on the surface undissolved and never reaching the plant roots.

Fig. 23. Simple Capillary Emitter Developed in Zambia, by Knotting the Capillary.

Fig. 24. Simple Drip Emitter Used in Iraq by Make Tight Curls of the Capillary tubing.

Disadvantages of Drip: Some of the disadvantages of drip systems include:

1. Difficult to work around emitters for weeding or other cultural practices, which can substantially increase labor costs (Fig. 25) as well as the opportunity for careless laborers to damage the drip line.

2. Major restriction on mechanization access, as the drip tape has to be completely removed to get any soil disturbing equipment onto the field. It is possible to drive over a drip line, but not use any implements that will cut into the soil.
3. Subject to animal damages such as goats or rats biting off the emitters to get water. This would including those large rodents often hunted for bush meat in Angola.
4. Fixed planting locations. You have to adjust your planting to where the emitters are. This would take priority over any recommended plant spacing.
5. Replacement of drip tapes. Typically in the open sun the tapes are only good for a couple years. Those locally manufactured in Iraq were only good for one season.
6. Major environmental problem disposing of massive amounts of used drip tape that is rarely biodegradable.

Fig. 25. Capillary Tubing Serving Vegetables in Zambia. How Much Additional Time Will be Needed To Weed These Vegetables?

Fig. 26. My Home in Fort Collins Where I Maintain A Drip Irrigations System Starting on the Front Porch and Extending All Around the Back Yard,

Personal Use: I do have small drip irrigation system at my house to irrigate my garden that surrounds the back yard and the front of the house. It is directly connected to city water supply (Fig. 26). While not on the scale the hosts are considering it can illustrate what drip equipment is and some of the concerns with using drip irrigation. My use of drip irrigation became essential when 35 years ago they installed the main lawn sprinkler system and left out the gardens. The system is automatic operating off a battery powered timer on the front porch. This also includes a legally mandated backflow prevention value, filter and pressure compensator reducing the line pressure to something safe for the drip line (Fig. 27). The main drip line is 2 cm dia. flexible PVC plastic tube extending all the

Fig. 27. Timer Controlling the Drip System Connected Directly to the Outdoor Hose Connection for City Water. Directly Below the Timer is Back Flow Prevention Value, Followed by Filter and Pressure Compensator to Reduce City Water Pressure to Level Suitable for the Drip System.

Fig. 28. Main 2 cm Drip Line With T Junction to Another Section Plus Capillary Line Going to Individual Roses.

way around to the back gate some 100 m with couple splits and various capillary tube leading to individual emitters (Fig 28). I operate it for a half hour 5 days a week. I make no attempt to adjust for variation is ET as the fixed timing is just too convenient. I use a combination of individual button emitters for irrigating individual plants like roses, tomatoes, and cucumbers often connected to the main tube with a 0.6 cm capillary tube (Fig. 29), and quarter circle (moon) micro-sprinklers for groups of plant like strawberries and flowers (Fig. 30). I very carefully have the main line tucked under the fence to keep it out of the sun and so far it has lasted 17 years with only some minor annual adjustments of emitters to keep up with evolving crop usage and spacing, but mostly I adjust the planting to the available emitters. In the middle there is a small birdbath (Fig. 31), which serves to protect the drip line from animal like squirrels from biting off the emitters. Before I added the birdbath, each year several emitters would be bitten off by various animals, but now the animals take water from the birdbath and leave the emitters alone. What are the prospects for various wild or domestic animals getting into drip systems in Angola?

Fig. 29. Individual Button Emitter for Water Individual Plants.

Fig. 30. Micro-Sprinkler Used on Cluster of Plants Like Strawberries.

I had one freak accident when a neighbor tossed a lighted cigarette butt at the fence, it went through the fence landed on the drip line and melted a hole in the line (Fig.32). Again, what are the prospects that careless laborers will inadvertently damage a drip line? The main part of the yard with full canopy coverage is irrigated with buried sprinklers that I operate twice a week for 0.5 or 0.75 hour depending on the type of sprinkler head being used for different part of the yard (Fig. 33). I make no effort to adjust for any daily temperature or other fluctuations in ET during the irrigation season from 1 May to 1 October, even if I wanted to and I do have ready internet access to the necessary data, or for some $300 I could purchase and install a soil moisture meter to operate the irrigation system. I just like the convenience of the simple timed setup. If I did opt for the automated soil moisture meter to control the sprinklers, it would most like take more water as the overall system runs several centimeters below the official ET estimates over the

Fig. 31. *Birdbath in Middle of Drip System to Provide Animals a Place to Drink so As Not to Bite Off Emitters. Also note Main Drip Line Tucked Under Fence to Avoid Direct Exposure to Sun.*

course of the irrigation season depending on how much rain we receive. I think most farmers in the USA and Angola like, even with limited economic opportunity in the dry season would opt for this level of convenience rather than fine tuning the irrigations to daily fluctuations in water demand.

Fig. 32. Freak Accident Of Cigarette Butt Melted Hole In Drip Line Highlighting Potential for Careless Laborers Damaging Line.

Fig. 33. Sprinkler Irrigation for Full Canopy Main Lawn.

<u>Components of Drip System:</u> In the context of Angola and the hosts interest in drip irrigation for several hectares of irrigated vegetables the following items would be needed. Most of these are simple 2 cm PVC plastic held together with simple one-way friction coupling sleeves that are not designed to handle high pressure (Fig. 22). The items are:

1. Sufficient drip tape with imbedded emitters to cover the planned irrigated area,
2. Additional drip line (same as drip tape but without the imbedded emitters to connect the central water storage tank to the various drip sets, and between different rows.
3. Extra individual emitters to replace any plugged emitters as they occur.
4. Assorted connectors for T-junctions, elbows, straight connectors and plugs as needed to complete the set layout.
5. A large storage tank to hold water prior to distribution to the drip lines. This would also serve as a settling basin to allow any particulate material that could plug emitters to settle out and make certain no excessive pressure is put on the drip lines. The capacity of the tank should be able to hold enough water to irrigate 1/4th the irrigated area. That would be approximately 40 m^3/per ha assuming 50% canopy coverage and a full canopy ET rate of 86 m^3/day as discussed earlier. The tank could be brick and concrete like the one in Zambia (Fig. 34) or plastic or even a recycled fuel storage tank depending on what is available in country or can be constructed as well as the cost of providing it. The storage

tank should be 4 m above the highest drip line. The 4 meters will generate the minimum 0.4 bars of pressure needed to operate commercial drip emitters.

6. A pump with capacity to lift water from the source to the storage tank
7. Hoses or pipes sufficient to deliver water from the source at the stream or river to the storage tank. This could be 5 cm or larger diameter pipe/hose that can easily fit the pump. This is basically what is readily available.
8. Additional 5 cm pipe to distribute water from the storage to the different drip sets, with associated values to release water from the pipe to individual drip sets.
9. A filter connect to the distribution line near the storage tank. This has to be sufficient capacity to filter water and remove any remaining particulate material.
10. Wire staples to hold the drip lines in place and prevent them from being disturbed particularly while crops are being established and there is a lot of activity at each emitter (Fig. 35).

Fig. 34.Water Storage Built to Hold Irrigation Water for Use On Vegetables in Zambia. Note the Farmer Filled It With Small Diesel Pump Similar to that Used By Mr. Simon, and Not the Treadle Pump

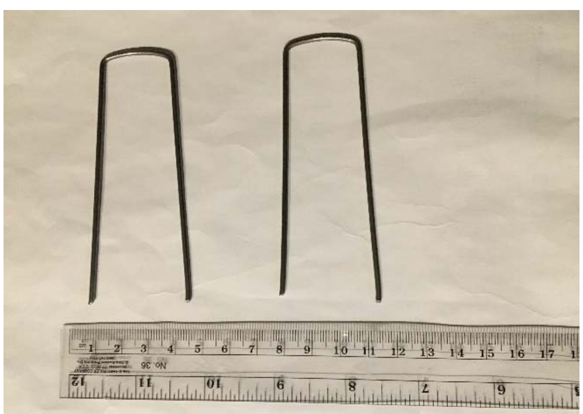

Fig. 35. Simple Wire Staples Easily Made From Local Wire Used to Hold Drip Lines/Tape in Place While Crops Are Established.

<u>Drip Layout and Operation</u>: The basic layout of a drip system is fairly straight forward, but the details have to be worked out on an individual farm or host basis for which I can only provide some guidance. First you need to have your storage tank located high enough to provide a minimum of 4 m of head to the nearest and highest drip set. That would provide the minimum operating pressure of 0.4 bars. Be careful in trying to make a direct connection from the water source to the drip lines. As mentioned previously these are low pressure operations usually 0.4 and 3 bars of pressure, going through 2 cm dia. PVC tube with no outlet other than the emitters. Pushing more water than can be readily distributed could severally damage the drip lines, so it would require some form of manifold to distribute the water to several 2 cm drip lines to irrigate directly from pump to drip lines. This is very different from what Mr. Simon was doing, as his hoses were wide open, so any buildup of pressure could vent through the open end rather than being forced through a pressure compensating emitter.

The irrigation sets are typically laid outs in reasonable square or rectangular sections and the actual water application rotated between sets (Fig. 36). The size of set would be determined by how much water you have available when operating. While in the USA drip sets can be several hectares with individual drip runs of 400 m (Fig. 22), I would recommend that initially start with something smaller depending on the water available in the storage tank. Using the 500 m drip tape as an example it could be set up as 10 lines of 50 m each, with a 0.75m row spacing and would cover a total area of 50 x (0.75 x 10) = 375 m^2. (0.04 ha) With 30 cm spacing and 2 lit/hr flow a 0.04 ha set will consume nearly 3,400 l/hr. (3.4 m^3). This should provide enough water for several days and thus only needs to be applied twice a week. Depending on the available water several of these small sections could be irrigated concurrently, or the water shut off after only a half hour operation.

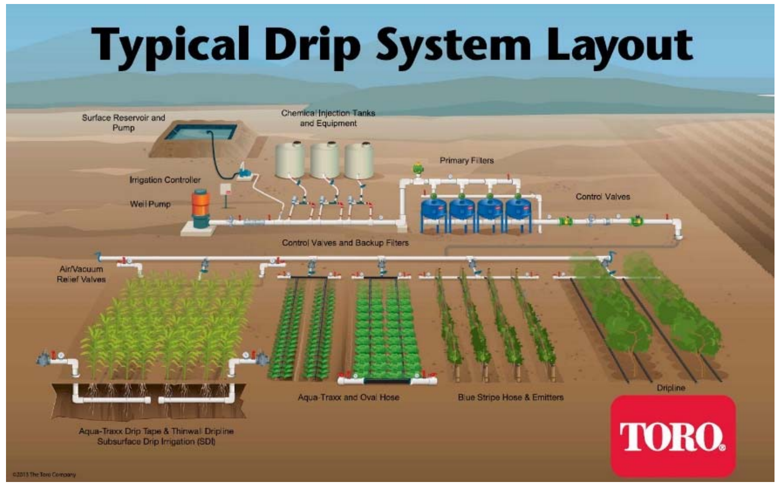

Fig. 36. Schematic Layout for Commercial Drip System

All sets do not need to be the same spacing. You can adjust row spacing according to the crops you anticipate planting and available land. However, once in place the rows are fixed at least until the tape is replaced. Each time you start irrigating a set, the whole set being irrigated must be inspected for damage to the line and emitters. When the line is damaged it will be clearly apparent as water will gush out at full pressure. When an emitter is plugged the wetting front where the emitter is dripping will not be visible.

Initial Cost of Drip Systems: As mentioned previously, despite individual items being fairly cheap the total requirements could result in the cost of drip systems being quite high compared to other forms of irrigation, particularly as there does not appear to be any drip supplies available in country and it may have to be imported directly. This needs some additional internet search. The only data I could easily obtain what that 300 m of drip tape with emitters imbedded costs approximately US$ 100. For a square hectare of 100 x 100 m with rows 1 m apart, it would consume 100 tapes of 100 m = 10,000 m total and cost US$ 3,300 (660,000 KZ) just for the tape. One meter row spacing is normally fairly wide. More typical would be 0.75 m. This would require an extra 30 drip tapes and run the cost up over US$ 4,000 (800,000 KZ). In addition filters, storage tank, pump to lift water to storage system, pipes to distribute water to various drip set, etc. would have to be purchased and installed or constructed. The total cost would approximate US$ 10,000 (2,000,000 KZ) for the first hectare and somewhat less for the additional hectares as additional pumps conveying material would not have to be procured.

Maintenance of Drip Systems: In addition to the initial costs, the maintenance costs have to be considered. Often maintenance costs are difficult to estimate as it is difficult to know in advance what will breakdown and need servicing and how frequently this will be. Most of this is associated with replacing emitters as they get plugged and filtering the water. If there is a high potential for emitters to get plugged it might be better to use individual emitters rather than imbedded emitters within a drip tape. The reason being that replacing an individual emitter is fairly easy and does not involve cutting and splicing the main drip tape, while repairing an imbedded drip tape will require cutting the tape and splicing in a new section. However, it might be possible to plug in an individual emitter to replace a plugged imbedded emitter. Other maintenance concerns are replacing damage areas from animal or careless individuals, and maintaining filter systems. Occasionally it might be necessary to replace the entire drip line if over exposure to the sun resulting in the tubing becoming brittle and crack. For incomplete canopy vegetable production this can be considerable as there will always be substantial percent of the soil surface exposed to the sun. Also, when the drip line needs to be replaced it has to be done before the season in anticipation it will not last for the entire season, as replacing the tape in mid-season with crops in the ground will be very difficult and result in considerable damage to the crops. In Iraq the drip tapes for Tomatoes in the Basra area had to be replaced every year.

Cost Recovery of Drip: Since drip irrigation has a higher capital and operational cost then other types of irrigation, before getting overly committed to drip it is important the estimate if the additional cost can be recovered. In this regard I tend to look at the overall economy of Angola compared to the USA as it would reflect on the ability of farmers to recover their investment in drip irrigation. In this regard I consider Angola to have be a financially suppressed economy[4] in which consumer prices including the vegetables the hosts expect to produce may be 1/3rd to 1/5th the USA prices (Table 2), but wages are only about 1/12th the USA wages or perhaps even less[5]. This forces the bulk of the population to spend up to 80% of their income on food just to feed their families, and consumer prices can only reflect this limited purchasing power. The result is tremendous downward pressure on consumer prices to what people can afford with their very marginal wages and purchasing power.

Table 2. Comparison of Select Consumer Prices Between Angola and USA

Commodity	Angola Price (Kwanzas)		US Price (US$)		Adjusted to US$ & Common Unit			Ratio
	Price	Unit	Price	Unit	Angola	USA	Unit	An/US
Rice	200	kg	1.00	lbs	0.61	3.17	kg	0.19
Maize Meal	200	kg	1.13	lbs	1.21	2.49	kg	0.49
Squash Seed	600	kg	4.99	lbs	3.64	10.98	kg	0.33
Cassava	75	kg	1.99	lbs	0.45	4.38	kg	0.10
Tomatoes	75	kg	0.99	lbs	0.45	2.18	kg	0.21
Onions	75	kg	0.79	lbs	0.45	1.74	Kg	0.26
Eggplant	100	kg	2.12	lbs	0.61	4.66	kg	0.13
Green Peppers	75	kg	1.05	lbs	0.45	2.32	kg	0.20
Mangos	100	kg	1.43	lbs	0.61	3.14	kg	0.19

Exchange rate US$ = 165 Kz

This in turn quickly reduces what farmers can receive for their crops and still have a living profit margin. This then reduces what they can invest to improve their farms including investing in the more expensive drip irrigation. Thus an urgent question is can the host farmers, with the limited returns they receive for their crops including vegetable crops, afford drip irrigation relative to what the USA farmers can afford. Note the drip equipment most likely has to be purchased on

[4] http://smallholderagriculture.agsci.colostate.edu/financially-stalled-governments/

[5] The established agriculture wage in Angola is US$2.50/day compared to the minimum wage is the USA of US$10/hr or US$80/day.

the international market the same as the USA farmers, plus possible being subject to some potentially high import and value added taxes typically levied by countries like Angola. This is a question that each individual host has to determine for himself.

USAID's Interest in Mini-Drip Systems: USAID and perhaps other donors have been heavily promoting a Mini-Drip irrigation system as an inexpensive drip system with a presumed potential for poverty alleviation. Again this assumes saving water is the most critical if not only consideration initiating an irrigation project. Also, this may be what those initially recommending drip irrigation to the hosts were thinking. But the scale is way too small relative to what the hosts are considering unless the intentions were for this to be part of the tenant system with each tenant having a small system like this. However, no mention of tenant involvement in the drip system was mentioned during the discussions.

The USAID promoted mini-drip system was basically designed by iDE, (International Development Enterprises), an American NGO that originally was exclusively promoting the highly labor intensive treadle pump, which was extensively distributed by various NGOs, but had virtually no open market sales, and I feel that most were accepted as part of a larger development package and quickly set aside because too much energy as noted by those in the briefing in Kuimba and Fig. 34 where the farmer was more than happy to demonstrate the treadle pump for my benefit, but relied on diesel pump to fill his storage tank. More to the point, iDE tends to overlook labor requirements, assuming it is not a problem, when there often are severe dietary limits on labor that restrict the work day to only a few hours, and reduce the diligence of labor, including the heavy demands of manually moving water[6]. IDE has since shifted away from its interest in treadle pumps and is now concentrating on the mini-drip system. The Mini-Drip system demonstrated by iDE was originally based on a standard 55 gallon (208 liter) water barrel placed on a platform 2 or 3 meters above the ground to generate the operating pressure. This has to be manually filled with water requiring some 10 trips with a typical 20 lit. jerry can. Depending on how far they had to carry the water this could take several hours each day of heavy manual effort, just to get the water. If you applied 1 lit/day/plant you could only irrigate 200 plants, which with a 30 cm in-row emitter spacing and 75 cm row spacing would irrigate and area of 42 m^2 or 0.0042 ha. (Fig. 37). This is well below the scale envisioned by the hosts for this assignment. The basic emitters are similar to those I first observed in Iraq, basically a curled capillary tube.

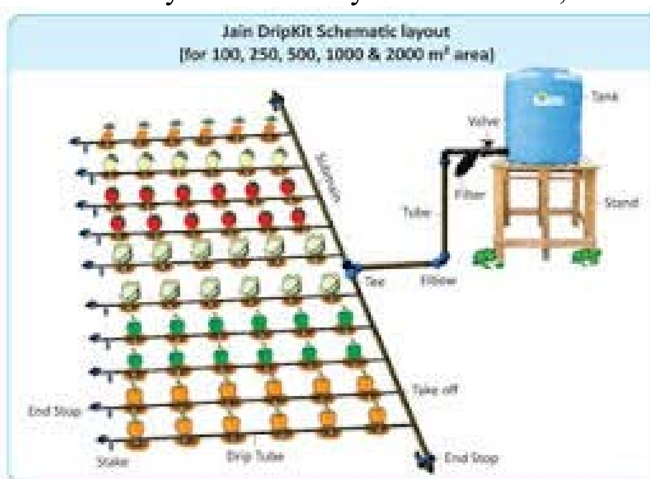

Fig. 37. Small Mini-Drip System Based On Standard Water Barrel or Similar Tank.

[6] http://smallholderagriculture.agsci.colostate.edu/calorie-energy-balance-risk-averse-or-hunger-exhasution/

With this much effort to get water to the system, and commanding this limited area one has to wonder if it wouldn't be easier to simple apply the water directly from a jerry can or watering can to the plants. It would also be difficult to use a small pump to fill a tank of this size, and then move to another similar tank a 100 m away, too much water would be lost moving the hose from tank to tank. Also, with this small an operation in terms of both the irrigated area and number of plants, one has to wonder if the production can routinely, throughout the harvest period, generate enough surplus production to justify the marketing costs including lost opportunity for doing other economic activities. Thus the question what is the minimum amount of surplus production needed to justify marketing, below this it is better to simply discard the produce.

I understand USAID with the help of CNFA as established some of these systems in a dryer part of Angola, I believe operating from wells. They might be worth visiting before initiating any drip systems.

Implications for Angola: As for the potential in Angola and Zaire Province, the question can you install drip irrigation, for which the answer is definitely yes, it is possible to install a drip irrigation systems. Will it require any extensive external technical support? Mostly likely not beyond what can be determined from the internet in a manner similar to what the hosts learned about fish ponds and fish culture and make appropriate adjustment to their individual situation. The more critical question is, is it appropriate to do so, for which the answer is probable not. There are several reasons for this:

1. Is access to water sufficiently limited to justify the use of drip?
2. Can it be easily operated and maintained?
    a. Can you assure the sufficiently water quality to protect the emitters?
    b. Can you prevent animals like goats or rats from biting off emitters?
    c. Or, can you prevent careless laborers from occasionally damaging the drip lines?
3. Will it be economic viable?
    a. The basic cost and continuous maintenance costs can be substantial?
    b. Do your farmers get sufficient return to afford drip system?
4. How readily available is the drip equipment and what variation in specifications? So far none has been found in agriculture dealers and thus any that may in used must have been directly imported or developed by individuals.

General Recommendations to Hosts

1. There is considerable potential to develop dry season irrigation for vegetable crops on the hosts' farms.
2. Thus the host should continue to acquire and develop the land for vegetable irrigation.
3. Once the land is acquired the hosts should initiate irrigated vegetable production initially using a variation of the simple means currently being used by Mr. Simon.
4. Continue reviewing the potential of drip irrigation and if it is consider feasible proceed to gradually introduce it to the farms.
5. As part of reviewing the potential for drip irrigation arrange to visit areas in Angola which have tried using drip irrigation, including those using the USAID promoted min-

drip system. If at all possible this should be done through direct contact with the farmers and avoid any individuals facilitating the use of drip, and whose effort to continue promoting the mini-drip system could interfere with the candid discussion. This will allow the most candid answers to any questions arising. At this point it has to be recognized that virtually all development project reports are written by the promoters and not the end-users, and the promoters have a massive vested interest in appeasing the donor and can spin reports to appear successful when they are not, but the donor all very much appreciate the spun reports. Because of this any visits should be done with a specific list of comprehensive questions to be asked. Such questions should include:

a. How large an areas does each system command, and how many individual plants are produced?
b. What was the initial cost for the system, and how what are the maintenance costs? Were there any subsidies in these initial costs?
c. How does this compare with what the host are anticipating in their vegetable irrigation plans?
d. How many of the individual units are operating and how many appear abandoned?
e. If the farmers have to manually carry water from source to the drip system, how much time is this taking, and how often are the farmers simply manual distributing the water to the individual plants, by-passing the drip system?
f. If using wells as the water source do the well have sufficient daily yield to provide adequate water for the area developed?
g. How many season can they use a drip line before it has to be replaced?
h. What do the emitters look like and how frequently are they getting plugged and need to be serviced?
i. How often do wild or domestic animals bite off an emitter resulting in water loss and need to replace or splice the drip line?
j. How often do careless workers damage the drip line resulting in repair costs and disrupting irrigation schedules?
k. How much extra time is required to work around the emitters compared to an open unencumbered field?
l. How accessible are the drip fields to soil disturbing mechanization?

Specific Recommendations of each Host

In addition to the general recommendations listed above there some specific recommendations for the different hosts. These are:

Chalom Farm: The main Chalom farm has a natural pond that has sufficient water to irrigate a couple hectares of vegetables. The problem is the water is about 30 m below the land most suitable for irrigation. This requires a substantial lift of about 4 bars (60 psi). That would be an expensive pump. If the decision is made to develop and irrigation system the most suitable means would be to pump the water into some form of storage tank similar to that used in Zambia (Fig. 34) capable of holding 40 m^3 for each hectare to be irrigated, and then distribute the water from there. The recommendation would be to fill the storage tank during the day and allow the water to sit overnight so most of the sediment can settle out. The water than could be distributed through a tap and simple hoses to the fields. It would be possible to use drip, but first the water need to be carefully check to make certain there is not an accumulation of algae from the pond. While it might be possible to put a sand filter in line, it would be very difficult to occasionally back flush it as needed to remove accumulated debris and renovate it. The simple hose distribution system could result in some wasted water, but it still could remain more cost effective and cheaper than a drip system.

The potential for irrigation is considerable greater in the new land being acquired. This is reasonable level and closer to a perennial stream. The intention is to irrigate some 9 ha. However, the flow in the stream is too low to support that large area, at least this late in the dry season when it was observed. It might be possible to irrigate a larger area earlier in the dry season and the real challenge is to balance the declining available water with the plant needs, removing crops to reduce the irrigated areas to coincide with the declining water. The land is partly cultivated to unirrigated crops, and needs some development to become more suitable irrigation. This would basically be a good agricultural discing followed by road grader to smooth it out. Given the limited water there may be some potential for drip, but don't necessarily rush in. It might be best to start with something simple as on Mr. Simon's farm then gradually move into drip as you become more familiar with irrigation and expand the land being developed for irrigation as well as the cost and operational needs for drip irrigation. Since the stream does not have adequate flow to irrigate the entire area he is planning to irrigate he needs to consider building a small dam to hold as much water as possible and minimize that flowing down stream. This could be similar to the weir farmers in Tanzania built to informally and perhaps illegally divert water to their rice paddies (Fig. 38).

Fig. 38. A Farmer Built Diversion Structure to Divert Water To Their Unofficial Rice Irrigation Scheme

Simon's Farm: For Mr. Simon there is really nothing to recommend. He has spontaneously got what is a basic simple, reliable, and low maintenance irrigation system, with the low lift pump and hoses to distribute the water. This is ideal for the size area he is irrigating which is all the land readily available. This is also very similar to what I have observed in Zambia by famers with access to wet lands or streams from which they can easily pump water. Yes, it would be possible to put in a drip system but I don't see the rational, and doubt if it would be cost effective. He might be applying excessive water, but it will quickly seep back into the stream and be available for pumping again. He might consider placing some large rocks in the stream immediately downstream from his pump. This will partially block the flow, raise the water and make it easier to pump water without sucking up sediment from the stream bottom. In the future if his upstream neighbors expand their irrigation efforts and this starts limiting the supply of water, it might be desirable to consider drip, but not until that occurs.

Ntinti Lulendo's Farm: Mr. Lulendo has the most advantageous prospects for irrigation. He as access to more water then he can possible use for the area available to irrigate. The area is also too large to follow Mr. Simon's example. The need here is to proceed to develop the land with a good discing and grading with a road grader for a basic surface irrigation system. Then construct a suitable storage tank at the high point in the developed land, with a series of small canals to convey water to the different irrigation basins and furrows. He needs to be careful so the irrigation furrows are not too steep resulting in soil erosion. That would be less than 1% grade. He could also run irrigation furrow back toward the river so any excess water simple and quickly returns to the river, either directly as return flow or subsurface seepage. He might consider a small weir or barrage to assist in pumping water, similar to what was observed constructed by farmers in Madibira, Tanzania for an informal rice irrigation (Fig. 38).

It would still benefit from a storage tank at the high point and a small system of conveyance canals or pipes to the various sub-divisions to be irrigated in sequence once or twice a week during the vegetable season. This would be similar to the storage tank observed in Zambia (Fig. 34). If the conveyance system could handle the full pump discharge, he could go directly from source to furrow without the storage tank. The land would have to be carefully graded and appropriate furrows and bed constructed to convey and apply water without being erosive. During any grading it would be appropriate to drain the area subject to flooding during the rainy season. While with rather weak water laws in Angola I don't see a problem in his initially taking the water he needs, but in the future if Angola tightens it water rights laws and has the means to enforce the laws, downstream urban areas might seek to deny him access. He also might profit from a check structure in the stream at the point he inserts his pump similar to farmer created diversion noted in Tanzania (Fig. 38)

Miguel Mayimonanga: Miguel Mayimonanga farm was similar to Mr. Lulendo's but not as advantageous. He had good access to a river with a flow estimated in excess of 3 m^3/s. However he would have to contend with about 10 m of lift to reach the area suitable for irrigation. This would add additional pumping costs. However, the recommendation would still be to initially look at surface irrigation as any surplus water would quickly return to the river. Since the land has not been acquired he will have considerable land development requirements to clear and grade the land. Currently it is in 3 m high natural vegetation making it difficult to clearly see what the details are. He might eventually shift to drip irrigation once he become more knowledge about his particular irrigation situation and costs, and economics of pumping the water consistent with drip irrigation.

That is about all I can formally recommend, I hope this is all helpful to the hosts and they can proceed as appropriate to develop their vegetable irrigation program. If I can be of further assistance in the future please feel free to contact me.

Appendix A

Non Irrigation Interests

During the field visits and discussions on various farming activities, there were discussions on farm management not related to irrigation for which I thought I might add some commentary and references.

Soybeans

There is a major interest, particularly by USAID, to promote soybeans as a new crop in many warm tropical countries. This is done primarily because of the nutritional quality of the beans. However, soybeans are also often also promoted as a legume crop that has the potential to fix nitrogen leading to increased soil fertility. As an N-fixing grain legume soybeans can be effective and provide up to 50 kg/ha N or about half the N requirements for most grain crops. However, I have a couple concerns with soybean production particularly in the low elevation tropics such as Angola. These are:

1. Unlike most legumes produced in the tropics, the nitrogen fixing bacteria is specific to soybeans. Thus unlike ground nuts or common bean that will nodulate and fix nitrogen from the native rhizobium bacteria found in the soil, soybeans require a specific rhizobium bacteria and thus have to be inoculate when introduced to a field or not grown for 5 or more years. This is not difficult but sensitive as it involves working with a live bacteria that, if not handled carefully, will quickly die. Thus those who encouraged you to produce soybeans should have careful mentioned and made certain you had reasonable and reliable access to the inoculant. It is easy to see if your soybeans are fixing nitrogen, just dig up a couple plants and look for the nodules (Fig. A1). In soybeans they are substantially large than what we observed in at Chalom farm on some beans and wild legumes. It should also be noted that when a nodule is pinched or cut in half the inside should be distinctively pink in color. This indicates active N-fixation with a non-pink color showing no N-fixation. If the soybeans have been promoted for their N-fixing potential, but no mention is made of the need to inoculate with the specific rhizobium and no reliable source of inoculant is readily available, or the recommendation is for approximately 50 kg N fertilizer, you have been promised something with zero probability of being achieved. Thus you should discuss this with your attorney and seek compensation for the misrepresentation. It should also be noted that N-fixation is a high energy consuming process for which it is estimated that it takes some 10 kg of photosynthate to fix 1 kg of N. Thus you can always get a higher soybean or other legume yield applying N-

Fig. A1. Soybean Nodules for Fixing Nitrogen. Note: These Are Considerable Larger Than Most Common Legumes.

fertilizer than relying on N-fixation. However, once the N-fertilizer is applied the N-fixation will stop and the soil improvement benefit of a legume will be negated.

2. My second concern is seed viability. With soybeans in warm climate the seed viability can quickly decline after harvest when retained seeds are stored at ambient temperatures over a dry off season of 4 to 6 months. In Thailand at low altitudes such as near Bangkok, the viability would decline to unacceptable low levels within 6 weeks after harvest. Also during an earlier F2F assignment in Ghana a simple rag-doll germination test of seed recently removed from cold storage was only a marginal 65%. If and when soybeans become an established crop in Angola, it is highly unlikely that the seed industry, even combining both public and private seed sources will be able to meet all the demand. Typically in countries like Angola the seed industry only meets a small percent of the demand so over 90% of the seed planted is to retained or local "market" seed. Thus, for soybeans to be sustainable crop in Angola the seed must be readily available either through direct retaining by farmers or in the local market that would require storage for up to 6 months at ambient temperature. Since soybeans are self-pollenated there should be little genetic variation for several generations of retained/market seed. For this reason I normally recommend that soybean production, at least initially, be concentrated above 1200 m, where the off season temperature is cooler and the seed will remain viable over most 6 month dry seasons. The 1200 m altitude is where Malawi produces most of their soybean as defined as the top of the Rift Valley Escarpment and not along the lake shore or Shire Valley. Similarly in Kenya it is concentrated at higher elevation as with Nigeria in the area around Jos. The alternative is to obtain expensive certified seed each year which is normally in short supply or produce a small irrigated seed crop over the dry season. However in Zaire Province of Angola with the coolest temperatures in the off-season and a 400 m altitude, this may not be a problem, but needs to be carefully observed (Table 1).

There are four F2F reports on soybeans posted on my website that can be readily accessed[7].

Fishponds and Aquaculture

While I am not really an expert on fishponds and aquaculture, when I was on the faculty of the Asian Institute of Technology outside of Bangkok, Thailand I worked closely with the aquaculture program, which is one of the best in the world for small scale fish farming. While there I learned a few things that might be useful.

With so many fish confined to such a small area it is highly desirable to keep them all approximately the same size and not have multiple generations in the pond at one time. If there are different generations of fish the large ones will start consuming the smaller ones. This problem can easily be address by stocking all male fish that will not be able to reproduce resulting in a mass of small fish fry in the ponds. Getting all male fish is easily done in

[7] http://webdoc.agsci.colostate.edu/smallholderagriculture/ValueChainAnalysisSoybeansMalawi.pdf; http://webdoc.agsci.colostate.edu/smallholderagriculture/SoybeanKenya.pdf; http://webdoc.agsci.colostate.edu/smallholderagriculture/SoybeansGhana.pdf

commercial hatcheries by introducing a specific testosterone based chemical hormone into the water shortly after the fish hatch.

There is interest in some complimentary enterprises to fish farming. These include pig production next to the pond or poultry production suspended above the ponded above the pond (Fig A2, A3). In both cases the waste from the pigs or chickens will fertilize the pond to promote algae production that is consumed by herbivore fish like tilapia. This idea is well promoted and implemented in Thailand and other parts of Southeast Asia. However, this was largely accept only after the rice farmers shifted from water buffalo to power tillers which halved crop establishment time for rice. With rice production and food security under control the farmers were able to diversify into the fish ponds and complimentary animal enterprises. Will the same be necessary in Angola?

Fig. A2. Pig Production in Viet Nam with Waste Going Directly Into Fish Pond to Fertilize the Pond and Promote Algae Growth for Herbivore Fish Like Tilapia.

Fig. A3. Poultry Operation Suspended Above Fish Pond in Thailand, with Poultry Waste Fertilizing the Pond.

The management of fish ponds might make for a good F2F volunteer assignment to advise on good pond management, If USAID would agree the most appropriate place to get a volunteer would be either the Asian Institute of Technology outside Bangkok, which was established by USAID nearly 70 years ago, but has not received recent support from the USA in recent years, or World Fish outside Penang, Malaysia. This is the CGIAR (Consultative Group for International Agriculture Research) Institute responsible for fish with an emphasis on small scale production as you would find in Angola. As a CGIAR institute they receive substantial support from USAID. It should also have USA staff or retiree who could be interested in an F2F assignment. If restricted to the USA the University of Arkansas has the best warm water aquaculture program. Going further north in the USA much of the fishery work is cold water trout hatcheries for sport fishing.

Appendix B

Angola Daily Log

7 Sept.	Departed home at 7:00 am for Denver International Airport, proceeded to Detroit connecting to Amsterdam.
8 Sept.	Arrived Amsterdam at 7:30 with time to visit the Amsterdam Flower Auction, rather fascinating. Got some sleep in Day Room at Sheraton, before proceeding to Luanda

9 Sept.	Arrived Luanda at 6:30 am, was taken to Villa Alice Hotel, check-in, cleanup and headed into Luanda to look for irrigation equipment particularly drip. Found none, except for small pumps and hoses. Obtained ticket for M'Banco-Congo, for which flights were only available on Sunday.
10 Sept.	Took flight to M'Banco-Congo and got settled into the hotel.
11 Sept.	Received briefing from CNFA staff and proceeded to Kumbia as final destination. Meet with translator Mr Diavova Lumbu and planned next day's activity.
12 Sept.	Had initial field visit to 2 farms. The first was large farm Chalom Farm managed by Mr. Kakuvutuka Nfuavata as listed in the Scope of Work. He was the owner and operator working with hired labors. which may have been landlord tenant association in which the rent was paid as 2 days labor each week, representing modification of share-cropping to be labor conscription at same ratio The main crop standing was cassava (manioc) but we were informed it had been intercropped with beans and soybeans as well as pineapple with the annual intercrops already having been harvested. We were shown a nice natural pond with some potential to

irrigate, but would require 30 meter lift to get to an appropriate level for easy irrigation. That would be a high pressure pump lifting 4 atmospheres.

The second farm owned by Simon Diangani It was estimated to be about 400 ha. This would officially be outside the Scope of Work for the assignment. Some of this was rented out to tenants on a share labor charge. That is the tenants were required to work for the owner 2 of 6 days a week. It appears an interesting adaption to the typical share crop relationship of 30% of the crop to the landlord. Also the land was mostly in cassava that was being harvested and processed into dried cassava after soaking in the stream for a couple days that would ferment out the Cyanide. In this case there was some flat land in proximity to stream and it was being irrigated similar to what was observed in Zambia. Basically a low lift pump with distribution by hose for several hectares of vegetable, tomatoes, onions, cabbage, eggplant, etc. This would represent the simplest and most convenient means of irrigation for the area. In addition they were attempting to dig a couple very small fish ponds that were extending into the water table as shown by the stream.

That concluded the field visits for the day.

13 Sept. Remained at the hotel to digest material and plan what is the best irrigation for the area. Limited computer time as power is off most of the day. Thus have to work largely at night. Met with the translator to get some background information on the assignment and help them with the technical terminology they were really not that familiar with, resulting in considerable discussion getting lost in translation. They were insisting of the third visit that would be outside the scope of work.

14 Sept. Big mix up, someone without my knowledge and approval arranged for a group of trainees to train, I don't know about what. I don't really know who they are, I doubt if they were really farmers and suspect they were teacher colleagues of the interpreter. I think the originator of this problem was the "2nd" unhired interpreter, who seems to think he is running the program. I hope he got the message and I won't see him again.

After sorting out the "training" problem we proceeded back to the Chalom farm and visited the fish pond. There were actually 5 well-constructed fish ponds but perhaps small in size from what I had seen in Thailand and other parts of SEA. They were placed at stream level with gravity feed into the ponds then cascade from pond to pond. When asked where he got is information to build the fish ponds, he replied the Internet. If this farmers is this skilled at getting information from the Internet there is little need for a volunteer.

15 Sept.	After a little delay visited another fish pond operations with Matondo Magole. It was similar to the first and showed a lot access to quality information and resourcefulness to get the job done. They were interested in adding pigs and goats to the mix with the refuge going into the pond to fertilize the pond. Again no irrigation potential for the area. Proceeded to M'Banko-Kongo for a long weekend including a national holiday on Monday.
16 Sept.	Mostly took the day off and enjoyed a good book
17 Sept.	Got back to work and drafted several pages of report. Had sufficient internet access to search of additional information. Wasn't able to attend Church.
18 Sept.	National holiday but continued working on report. However in the afternoon meet with Luciano to coordinate the return to Kuamba and more appropriate set of activities
19 Sept.	Returned to Kuamba with Bento who then assumed interpreter role. Arrange for another visit to Chaloma Farm but this time to a lower area more suitable for irrigation. He was interested in 9 ha of irrigation but the stream flow would not support it at this time. It was also mentioned that he had ordered and expected delivery of 500 m of drip tape. If this had imbedded emitters at 30 cm spacing and flow of 2 l/hr the tape would contain some 1,666 emitter and disperse 3,300 l of water and with row spacing on 1 m cover an area of 50 x 10 = 500 m2 or 0.05 ha.
20 Sept.	Arranged for an irrigation briefing for 4 farmers. This was held in the hotel dining room, but without power could only use the computer to show the PowerPoint material. After the briefing proceeded to visit another farm with Ntinti Lulendo. This was again down in a low area that should be easier to irrigate. It was also an area of short term flooding during the rainy season. The water was from a major river with a flow that could be 3 m^3/s, and made me wonder if he could establish right to it, or simply take it without saying anything and any downstream users would have little enforceable recourse. The irrigated command area he was considering was up to 40 ha. Given the amount of water and quick return flow a simple surface irrigations system might be most appropriate. The area is too large for the simple system used by Mr. Simon and neighbors.
21 Sept.	Began the day visiting with the USAID representative for F2F who was visiting volunteers in the field. This was followed by a long bumpy ride to look at another potential irrigated area with Miguel Mayimonanga. This again had potential but the lift would be about 10 m to get to a reasonable level area for irrigation. The stream flow as good at perhaps 4 m^3/s. It

	would also require considerable initial development as the vegetation was over 3 m so impossible to really look at the land.
22 Sept.	Spent the day in Kumbia rapping up the administrative needs of the visit.
23 Sept.	Returned to M'Banza-Kongo
24 Sept.	Mostly in hotel in M'Banza-Kongo working on technical report.
25 Sept.	Continued working on Technical Report from Hotel in M'Banza-Kongo
26 Sept.	Continued working on Technical Report from Hotel in M'Banza-Kongo
27 Sept.	Traveled by road from M'Banza-Kongo to Lunada
28 Sept.	Remained around hotel until departing to Airport for 9:00 PM Flight to Paris
29 Sept.	Extended all day travel with stops in Paris, Salt Lake City before arriving in Denver and taking Shuttle to Fort Collins. Arriving Home 8:00 PM

End Of Daily Log