

***Innovations in dryland farming
techniques***

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1. Introduction

Recent developments in dryland agriculture have made it possible to grow trees in deserts and drylands. Technologies that are geared towards tackling the major production constraints have been developed around the dry parts of the world. These include water harvesting techniques, use of early maturing and drought tolerant species, mulching, manure application, improved agronomic practices, irrigation and so on. The major technological options developed are presented below.

2. Water Harvesting Techniques

In many locations, direct rainfall is insufficient for crop growth, and increasing the amount of water available through water harvesting techniques is the most appropriate way to ensure sustainable production and reverse desertification. Water harvesting concentrates rainfall by encouraging run-off from catchment surfaces in a controlled way and then store the harvested water for subsequent use. Therefore water harvesting is actually the process of concentrating precipitation through runoff and storage for beneficial use. All sorts of water harvesting techniques are innovations in dryland farming.

For detailed information on water harvesting techniques the reader is referred to Sub-report No. 2.

Contour Ridges/Tied Ridges: details and local experiences

Among the different soil water harvesting techniques tied ridges were found to be very effective in soil water conservation and yield increase in many field crops in most Sub-Saharan African countries. I mentioned the research results and local experiences in African countries for the purpose of sharing the lessons learned.

Tied ridge system involves the use of semi-permanent ridges (ideally about 20-25 cm in height). Generally, they are laid in the field at a grade of 0.4-1% across the slope. Cross -ties are put in to a height of 1/2 to 2/3 the height of the ridges at intervals of 1 to 2 meters depending on slope, however in flat topography the interval could be wider up to 5 m interval. The ridges are constructed using an animal-drawn plough or ridger in a deeply ploughed up field (approximately 20 cm). Cross ties are put in after ridging using a cultivator with a worn-out moldboard attached on the rear tine position. For maize and sorghum the standard spacing of 75 cm is used and planting is done into a fully moist ridge. Two hand weeding operation are recommended, the first being 2-3 weeks after germination and the second soon after re-ridging and re-tying when the crop is

about knee high (maize). In the second and subsequent seasons seedbed preparation simply involves reconstructing the ridges and tying specially where mechanized ridging tractor operation is used. This technique applies well under animal drawn based systems.

In Ethiopia tied ridges are traditionally used by small farmers as in situ water harvesting technique in sweet potato production system using hand hoe in the eastern part of the country in Hararghie area. Therefore, it is a traditional practiced and was modified and extended through research to be used for other grain crops such as sorghum and maize.

In other African countries such as Zimbabwe it was first introduced in the early nineteen eighties by the Institute of Agricultural Engineering, and is known as "*marji akasungwa*". In Zimbabwe tied ridges is used as a soil and water conservation technique in areas where the availability of mulch during winter is limited and where water erosion is generally a problem.

The technique has been extensively tested and evaluated with smallholder farmer in Ethiopia, Eritrea, Zimbabwe, Kenya, Uganda, Tanzania Burkina Faso, Nigeria and else where in Africa. However, the technology is not widely used by farmers.

Therefore, technical and socioeconomic problems of technological adoption of tied ridges will be discussed. But, first the experimental evidence of the effectiveness of tied ridges in soil water conservation and its impact in yield increase and water use efficiency will be discussed under different set of conditions.

In soil with low organic matter, fine texture, compacted soil surface with low infiltration rates high runoff and soil loss tied-ridges (ridging with additional cross in the furrow at short intervals) has been found to efficient and effective method for conserving soil moisture. The main reasons for effective soil water conservation through tied ridges include high rates of water penetration into the stirred soil, the action of tied-ridges in preventing run-off from the rain and increasing the opportunity time for infiltration. Thus, it enhances rapid build-up of soil moisture needed for rapid seed germination, and early plant growth.

Dagg and McCartney (1968) in Tanzania conducted several experiments to determine the effect of tied ridges as a soil water harvesting technique on different soil types including red, ash and black soils. The results indicated that on the red soils, only the maize grown on the flat showed signs of moisture stress at tussling. Whereas on the ash soils, despite the early superiority of the crop plants on the ridged plots over the other treatments, moisture stress apparently was severest at the time of tasseling. They concluded that ridges made on black soils conserved the largest amount of moisture followed by those on the red soils. The ridges made on the ash soils conserved the least amount of moisture.

Tied ridges were also found to be effective in controlling runoff and increasing the infiltration opportunity time. These are particularly true on fine-textured soils with low infiltration rates, where temporary surface storage of water can reduce runoff. Jones and Clark, 1987 also observed that tied ridges (known as basing listing in the US) are effective methods for retaining surface water until it can infiltrate. In addition, according to Clark and Jones (1981) tied ridges prevented runoff from a 24-hour, 114-mm storm on a clay loam soil in Texas. Tied ridge were also found to be very effective in controlling runoff from large storm of 70 mm day⁻¹ on clay soil in eastern Kenya. On the other hand, conventional tillage with or without farmyard manure resulted in controlling only about 40% of the runoff loss. Stover mulching was the most effective and was able to control all runoff and resulted in the highest soil water storage (Table 1). But the availability of mulching material is a problem for practical use in dryland areas due to alternative use as animal feed, fuel wood. In these situations tied ridges could be a good alternative to be used for soil and water conservation.

Table 1. Soil moisture and Runoff arising from 122.1 mm rainfall

Treatments	Soil water storage (mm)	Runoff (%)
Stover mulching	128.0	-
Tie-ridging	86.0	13.7
Farmyard manure	69.0	38.0
Conventional tillage	65.8	42.7

Source: (Nijihia 1978)

In Kenya tied ridges were also found to be very effective in soil water conservation and resulted in significantly higher grain and drymatter yield of maize in alfisols.

Table 2 Effect of tillage methods on drymatter production of maize

Period	Crop	Crop yield (kg ha ⁻¹)		
		Minimum Tillage	Conventional Tillage	Tied Ridging
Long rains	Maize (drymatter)	1068	1047	1105
Short rains	Maize (drymatter)	2040	1920	1760
	Maize (grain)	337	221	513

Source: (M'Arimi 1978)

However, for effective use of tied ridges it is very important to understand the conditions when and where tied ridge works. Soil type, fertility status, rainfall amount and distribution are among the major factors, which affect the effectiveness of tied ridges. For instance, tied ridges can cause water logging in

above average rainfall conditions particularly on vertisols. As a result several soil research activities were conducted in order to avoid the problem of water logging. Thus, Lawes (1961, 1963 and 1966) compared the performance of alternative designs with open free-draining furrows, alternate cross-tied furrows, all furrows cross-tied, and all furrows cross-tied with mulch. His results showed that tying of alternate furrows only or the tying of all the furrows in combination with mulching significantly improved yields of cotton over open furrows and over-tied un-mulched furrows both in dry and wet seasons (889 and 1303 mm rainfall). With groundnuts and sorghum these treatments were not significantly different (Table 3). It is recognized that differences among alfisols probably explain many of the diverse reports on the benefits of tied ridging. Unfortunately, few workers gave adequate descriptions of the soils under these studies.

Table 3 Effect of Measures to Increase Infiltration on Crop Yields (Mg ha^{-1}) at Samaru, Nigeria^a

Crop	Year	Rainfall	ODF	ALFCT	AFCT	AFCTM	SE (\pm)
		mm					
Cotton	1958 ^b	889	0.89	1.18	-	1.16	0.05
	1958 ^c	889	0.88	1.03	-	1.04	0.05
	1962	1303	1.74	2.14	1.82	2.19	0.08
Sorghum	1959	1062	2.17	2.33	2.19	-	0.04
	1960 ^b	1092	1.99	2.09	2.00	-	0.06
	1960 ^{c, d}	1092	3.24	3.48	3.37	3.59	-
	1962 ^d	1303	2.40	2.34	2.55	2.30	-
Groundnuts	1959	1062	1.22	1.26	1.24	-	0.04
	1960	1092	1.62	1.53	1.54	1.65	0.04

Source: Jones and Wild (1975), modified

^a Lawes, 1961, 1963, 1966

^b Groundnut shell

^c Grass Mulches

^d Figures are means of two different fertility levels

ODF = open free draining furrows, ALFCT = alternate furrows cross-tied, AFCT = all furrows cross-tied, AFCTM = all furrows cross-tied and mulched

The effect of tied ridges as a soil water harvesting technique is enhanced if used in combination with organic residues. For example, Kilewe and Usaker (1984) reported that tied ridges in combination with stover mulch conserve more water and lead to higher dry matter and grain yields of maize compared to minimum tillage. Maize stover effectively controlled runoff through increased surface water storage, which in turn increased the time available for infiltration and also minimized evaporation, surface sealing and crusting. It was also reported that, when a combination of tied ridges and maize stover mulch were used a crop of maize was realized for a season of extremely low rainfall of 171 mm, whereas no yield was obtained from the conventional tillage plots with or without farmyard manure.

The high degree of efficiency of tie-ridges in controlling runoff and soil erosion was also demonstrated earlier in the late 1960s in the highland areas of Kenya (Periera et al 1967). The soil types were Kikuya red loam latosols on 10-12 percent slope under rainfall intensities often exceeding 2 inches per day and tied-ridges controlled runoff efficiently under continuous arable farming. Keiome *et. al* (1995) also reported that tied-ridges were effective means of controlling soil loss, runoff and improving crop production.

Soil erosion is major problem particularly in sloppy areas leading to low soil fertility and overall land degradation in the dryland areas. Fournier (1967) studied the effect of tied ridges on soil erosion under different degree of slopes in different parts of Africa. And concluded that the less steep the slope the greater the effect of tied ridges in controlling soil erosion. In his studies, erosion was reduced seven-fold at Adispodoume, Ivory Coast on 7% slope, and thirteen-fold at Safa, Senegal (1% slope). Runoff was reduced eight-fold at Bouake but was thirty seven times less at Safa. His conclusion was that ridging was extremely important for the control of runoff and soil erosion. Thus, tied ridges are very effective in natural resource conservation particularly soil and water.

Table 4 Effect of tie ridges, minimum and conventional tillage on soil moisture conservation in the semi-arid of Kenya

Soil depth (cm)	Soil moisture content (% volume)		
	Minimum tillage	Conventional tillage	Tied ridging
0-30	15.7	16.1	17.9
30-60	19.7	19.4	21.9
6-100	19.6	19.0	21.1
100-150	16.3	16.5	16.7

Source: (A'Arimi 1978)

Njihia (1979), working on Alfisol in the same region investigated the effects of tied ridges, conventional tillage, crop residue mulch, and farmyard manure on soil

and water conservation. He found that maize stover effectively controlled runoff through increased surface storage, which in turn increased infiltration opportunity. Maize stover also minimized evaporation, surface sealing and crusting.

2. *Shilshallo*: Inter-row cultivation, a traditional soil and water conservation practice

In Ethiopia farmers usually plant sorghum and maize by broadcasting. They use high seed rates (20-30 kg ha⁻¹ and 60-80 kg ha⁻¹ for sorghum and maize, respectively) to ensure satisfactory seedling establishment. Thereafter, they practice *Shilshallo* (oxen cultivation) at certain intervals (50 -70 cm). This enables them to break the crust, reduce runoff and increase soil infiltration rate. In addition through *Shilshallo* farmers control weeds and thin plant populations to appropriate levels. However, since most farmers do not practice *Shilshallo* at the right time of crop growth stage, substantial plant damage is usually observed on farmers' fields leading to low yield (Tilahun and Teshome 1987).

Experiments were conducted at Nazaret Research Center during 1987-1989 to examine the right time to performe *Shilshallo* for sorghum and maize.

The results of the experiments showed that there were significant differences among the different *Shilshallo* treatments on both sorghum and maize grain yield (Table 5). Generally, growth and yield increased were enhanced when the *Shilshallo* was performed at earlier stages- (4-6 leaf stage for sorghum and 6-8 leaf stages for maize). However, although there was substantial grain yield increase with early *Shilshallo*, tied ridges gave significantly higher yield increase in both crops. The aim of this work is to give option for farmers who could not use tied ridges due to lack of labor or oxen, or the tie ridger implement.

Table 5 Effect of *Shilshallo* on sorghum yield at different growth stages at Melkassa

Treatment	Yield (q/ha ⁻¹)			
	1987	1988	1989	Mean
Shilshallo at				
10 leaf stage (farmers practice)	3.36	28.91	16.51	16.26
8 leaf stage	4.11	26.35	19.54	16.66
6 leaf stage	4.60	30.12	17.31	17.34
4 leaf stage	9.43	31.18	23.04	21.21
Tied ridges	20.39	48.44	44.80	37.27

3 Combining Water Harvesting, Fertilizer Application and Use of Improved Cultivars

The two major biophysical problems of crop production water and low soil fertility should be addressed simultaneously to increase crop production on sustainable basis. There are several experimental evidences, which indicate that, the combined use of soil water conservation through tied ridges and fertilizer application is more effective and resulted in sustainable increase crop production than the use of tied ridges or fertilizer use alone in semi-arid areas of Africa.

For example, in farmer managed trial in Burkina Faso; sorghum grain yield was higher with fertilizer and tied ridges than with either fertilizer or tied ridge alone (Nagy et. al.1990). In Zimbabwe sorghum yields were increased from 118 to 388 kg ha⁻¹.using 1.5-m tied ridges and 1071 kg ha⁻¹ when 50 kg ha⁻¹ N was applied to tied ridges during below average rainfall season (Nyakatawa 1996). Kidane Georgis (1999) also reported similar increase in both grain and biomass yield increases of sorghum and maize when both tied ridges and fertilizer (N and P) were used together.

In the semi-arid areas of Ethiopia tied ridges have been found to be very efficient in storing the rain water and lead to substantial grain yield increases in some of the major dryland crops. Kidane and Rezene (1989) reported that maize, sorghum, wheat and mung bean grain yield was higher when grown with tied ridges regardless of the different planting patterns used, i.e. planting in the furrow or top of the ridge compared to the flat seed-bed(farmers' practice). The average grain yield increase ranges from 75 to > 145% compared to the traditional practice depending on soil type, slope, rainfall and the crop grown in some of the dryland areas of Kobbo in northern and central rift valley areas in Melkassa (Table 6).

Table 6 Effect of tied ridges on grain yield of sorghum, mung bean, and maize in the Semi-arid areas of Ethiopia

Soil conservation method	Average grain yield t ha ⁻¹		
	Kobo	Melkassa	Mean
Sorghum			
Flat planting (farmers practice)	1.6	0.80	1.20
Tied Ridges planting on ridge	2.9	3.0	2.95 (145%)
Maize			
Flat planting (farmers practice)	1.2	-	1.2
Tied Ridges planting in furrow	2.7	-	2.7 (125)
Mung bean			
Flat planting (farmers practice)	0.4	-	0.4
Tied Ridges planting on ridge	0.7	-	0.7 (75%)

Ridge height = 35 cm, Ridge spacing = 40 cm for mung bean, 75 cm for sorghum and maize, Ridges tied at 3 m interval.

Source: (Kidane and Rezene 1989)

There are several experimental evidences, which indicate that added fertilizer is of no use unless sufficient water is available to support a response and increasing plant available water by management practices is futile unless the soil fertility problems are addressed to ensure adequate fertility is available to take advantage of the increased water supply. It is very important to identify, which of these constraints is the limiting constraint and address it initially. Then as the first constraint is alleviated, practices can be put in place to alleviate the second constraint.

Field trials were conducted to determine the effect of moisture conservation of tied ridges on the yield of maize with and without fertilizer application in the Semi-arid areas of eastern Ethiopia. The results of these experiments show that a substantial yield increase was obtained from tied ridges as a water conservation practices (Table 7). On the average yield increase of more than 50% was attributed to the water conservation practices under unfertilized conditions. Under fertilized conditions the overall yield increase was not relatively high (27%). However, in terms of absolute yield, the combination of moisture conservation and use of fertilizer gave the highest attainable yield. The results indicate that fertilizer application gives better yield than either fertilizer or moisture conservation alone.

Table 7 Mean grain yield (t ha⁻¹) of five improved maize varieties grown under unfertilised and fertilised conditions with water conservation and without water conservation Methods in the Semi-arid Eastern Ethiopia

Variety	Grain Yield t ha ⁻¹					
	Without Tied Ridges		Mean	With Tied Ridges		
	- Fertilizer	+ Fertilizer	% Increase	- Fertilizer	+ Fertilizer	% Increase
Alemaya composite	2.8	5.4	70.9	4.8	7.1	33
KCC	2.6	4.7	67.5	4.3	6.6	39
EaH-75	2.6	4.8	38.6	3.6	6.0	25
Ca 5	2.3	3.8	26.4	2.9	4.7	23
Bukri	2.0	3.7	47.6	2.9	4.0	9
Mean	2.5	4.5	51.2	3.7	5.7	27

Source: (Tamire Hawando et al 1984)

There is also substantial evidence, which indicate that when soil fertility limits yield the use of fertilizers will result in more grain and drymatter yield per unit of available water thus increasing water use efficiency (Power 1990). This increase occurs because adequate fertility stimulate early growth, thus increasing leaf area for photosynthesis and increases root development often into deeper soil zones, which increase the supply of water to plants. Also well-fertilized plants with vigorous extensive root system may absorb water from higher tension level and greater depth in soil (Viets 1963). In addition crop canopies develop faster with adequate fertility and this leads to higher infiltration and decreased runoff because the canopy protects the soil surface from raindrop impact. Increased crop canopies can also decrease soil evaporation, thereby increasing the proportion of soil water that is used for transpiration. Proper fertilization can also hasten the maturity of crops thereby shortening the period crops have to draw on limited water supply, which is important in dryland areas with short length of growing period

Itabari and coworkers (J.K Itabari, unpublished data) compared the effect of water harvesting methods with and without fertilizer application on yield and water use efficiency of sorghum in semi-arid Eastern Kenya. He reported that there was substantial increase in grain yield and water use efficiency when fertilizer was applied with water conservation technique such as tied ridges and Zai pitting. The highest grain and water use efficient of about 1 t ha⁻¹ grain yield and 3.4 Kg ha⁻¹ mm⁻¹ of water were obtained when fertilizer was applied with water harvesting technique zai pitting and also tied ridges and fertilizer application (Table 8).

Table 8 Effects of in situ water harvesting and fertilizer on grain yield and water use efficiency of sorghum at Masinga in Kenya.

Treatment	Grain yield (kg ha ⁻¹)	ET (mm)	WUE (kg ha ⁻¹ mm ⁻¹)
A. Short rains			
Flat Cultivation - fertilizer	190	299.0	0.64
Flat cultivation + fertilizer	380	299.2	1.27
Tied ridging - fertilizer	360	297.8	1.21
Tied ridging + fertilizer	820	300.5	2.73
Zai pitting - fertilizer	850	297.9	2.85
Zai pitting + fertilizer	1010	298.8	3.38
B. Long rains			
Flat Cultivation - fertilizer	80	276.09	0.29
Flat cultivation + fertilizer	350	276.86	1.26
Tied ridging - fertilizer	310b	275.53	1.13
Tied ridging + fertilizer	1030	276.97	3.75
Zai pitting - fertilizer	900	275.10	3.27
Zai pitting + fertilizer	780	275.99	2.83

Source: (Itabari et al unpublished)

In water stress areas but fertile soil such as the valley bottoms in the kobbo area use of tied ridges alone result in substantial maize yield increase. In these areas with fertile soils the application of inorganic fertilizer with tied ridges were similar to those of tied ridges alone, since soil fertility is not a problem the response is low. However, the use of inorganic fertilization by itself is risky. Insufficient water at the critical times of plant development results in the lack of response to fertilizer, even in the soils with very low fertility.

There are also several evidences that show that use of fertilizer application and water harvesting techniques are economically sound than the use of tie ridges or fertilizer application alone under many areas in the semi-arid areas in SSA. For example, Sanders et. al. (1990) at Burkina Faso reported that 5 to 56 % of the farms in the field trials would have lost their cash investments had they used inorganic fertilizer alone. However, the use of both tied ridges and fertilization resulted in no loss of money for farmers in five of the village sites in 1984 (Table 9). Moreover, the combined technologies resulted in a substantial decrease in the number of farmers losing money in both years across almost all of the sites, as compared with sites using fertilizer alone.

From the above discussions it is important to note that in all the semi-arid areas characterized by low and unreliable rainfall, the relationship between soil water balance and crop yield plays a major role in the use of fertilizer.

Table 9 Yields and percentages of farmers who took cash losses from fertilization and tied ridges in sorghum production in farm trial villages, 1983 and 1984.

Year/Village	No. of Farmers	Traction Source	Control	Yields (kg/ha)			% of farmers losing cash	
				Tied Ridges	Fertilization	Tied Ridges & Fertilization	Fertilization	Tied ridges & Fertilization
1983								
Nedogo	3	Manual	430	484	547	851	56	0
Nedogo	11	Donkey	444	644	604	962	58	42
Bangasse	12	Manual	406	493	705	690	21	17
Diapangou	24	Manual	563	441	719	753	8	8
Diapangou	25	Donkey	481	552	837	871	12	16
Diapangou	25	Ox	526	578	857	991	20	12
1984								
Nedogo	11	Manual	157	416	431	652	27	9
Nedogo	18	Donkey	173	525	355	773	50	0
Bangasse	12	Manual	293	456	616	944	8	17
Dissankuy	25	Ox	447	588	681	855	28	0
Diapangou	19	Manual	335	571	729	1.006	26	0
Diapangou	19	Donkey	498	688	849	1.133	21	0
Diapangou	19	Ox	466	704	839	1.177	5	0

Source: Sanders, Nagy, and Ramaswamy (1990. p. 10)

Note: Cash expenditures were only for inorganic fertilizer. Tied ridges alone never increased cash expenditures. The only additional input of tied ridges was a substantial increase in the use of family labor

Table 10 Cropping patterns and farm income with hand traction, donkey traction, fertilization, and tied ridge technologies in the central plateau of Burkina Faso.

	Intensive Yield-Increasing Technologies: Hand Traction			Extensive Strategy: Donkey Traction	
	Traditional Management	Maize and Sorghum: Tied Ridges. No Inorganic Fertilizer Available	Maize and sorghum: tied ridges. Inorganic fertilizer available	Maize and sorghum: tied ridges, inorganic fertilizer available. Rental market for donkey traction ^a	Maize and sorghum: tied ridges. Inorganic fertilizer available. No rental market for donkey traction
Total area (ha)	5.84	6.02	6.02	6.48	7.35
Maize (ha)	0.15 CL	0.15 CL, TR	0.15 CL, TR	0.16 ^b CL, TR, DT	0.20 ^b CL, DT, TR
Sorghum (ha)	--	0.73 TR	0.73 TR, F	0.60 TR, F, DT	No sorghum. New activities on high-quality land: Maize: 0.28 DT 0.32 DT, F
Sorghum-Cowpeas (ha)	1.42	0.78	0.78	0.90 HT	0.90 BF, HT
Millet-Cowpeas (ha)	4.00 BF	4.06 BF	4.06 BF	1.20 BF, DT	5.25 BF, DT
Peanuts (ha)	0.27 BF	0.30 BF	0.30 BF	3.20 BF, HT 0.25 BF, DT 0.17 BF, DT	0.40 BF, DT
Urea (kg/farm)	--	--	37.00	30.00	16.00
Cotton fertilizer ^c (kg/farm)	--	--	73.00	60.00	32.00
Net farm income (CFA), including value of home consumption	152,345.00	170,295.00	172,552.00	184,337.00 ^d	178,524.00 ^d
Implicit wage (CFA/adult hr.)	43.00	48.00	49.00	52.00	51.00

Source: Sanders, Nagy, and Ramaswmy (1990, pp. 12, 13).

Note: BF – bush-fallow land; CL-compound land; DT-donkey traction; F-inorganic fertilizer; HT-hand traction; TR-tied ridges. There are variations in the quality of slightly better land where sorghum is grown. These differences and the distinction between red and white sorghum were included in the model and are summarized here. Opportunity cost of agricultural labor was CFA50 per hour (Jaeger, 1987). Currency of Burkina Faso is the CFA franc; exchange rate is CFA301 per U.S. dollar (average for 1987).

^aUse of 23 donkey unit

^bAnimal manure of work animal can be retained to improve soil quality and increase the area of compound land.

^cPredominant fertilizer sold in Burkina Faso with NPK nutrient levels of 14:23:15. ^dThere were three different annualized cost estimates for donkey traction; the total field estimate of CFA17,000 used here was adjusted with a 10 percent cost inflation. Estimate was CFA24,000 in Roth et al. (1986). Estimate was CFA34,000 in Jaeger (1987).

In the second scenario, when inorganic fertilizer is available, sorghum with inorganic fertilizer and tied ridges replaces sorghum with only tied ridges. The increase in income from adding inorganic fertilizer to tied ridges is very small compared with the effect of tied ridges alone. However, this is a more stable, long-term solution, because the soil will not be mined. Soil fertility quickly becomes a limiting constraint on these soils when water availability is assured. Therefore, this solution of tied ridges combined with inorganic fertilization is considered to be a sustainable solution, while the tied ridges alone are not (Sanders et. al. 1996).

The diffusion of results need to be separated by climatic zone. Bangarse is in the far north reaching almost into the Sahelian zone. Since soils there are very sandy, their retention capacity is low and their potential for using tied ridges is limited. Not surprisingly, the introduction of either tied ridges or inorganic fertilizer was minimal. In the two Sudanian sites of Nedogo and Diapangou the diffusion results were consistent with model predictions of simultaneous introduction of fertilizer and tied ridges on small areas. On the average, the areas of the farmers' fields utilizing the new technologies were still approximately one-third of model estimates. This could be due to adjustment costs, as farmers were moving toward the model predictions. In the interviews conducted in the Sudanian villages, farmers identified labor constraints as the principal reason for not further extending the tied ridges. As both Poedogo and Dissankuy are near the isohyet division for the higher-rainfall Guinean zone, soil fertility was the principal constraint in most years. A high percentage of these farmers used inorganic fertilizer on a substantial area of these small farms (3 hectares). There was minimal adoption of tied ridges in these two villages, as there is less need for tied ridges in the higher-rainfall areas.

In summary, the income increases from improved agronomy of the stage 3 type are as yet still small, but there was farmer adoption despite an unfavorable economic environment of low output prices and high labor requirements to make the tied ridges. Both higher cereal prices and the availability of an animal traction ridges are expected to hasten the introduction of the tied ridges.

Table 11 Adoption of tied ridges and fertilizer in farm trial villages of Burkina Faso

Village	Farm trial involvement (years)	Number of farmers	Farmers Adopting (%)		Average Area of Technology Adoption (ha) ^a	
			Tied ridges	Fertilizer	Tied ridges	Fertilizer
Bangasse	3	53	23	0	.03	.01
Nedogo	5	69	25	10	.32	.46
Diapangou	3	61	25	8	.18	.34
Poedogo	2	27	4	33	.11	3.00
Dissankuy	2	60	3	97b	.03	3.00

Source: Sanders, Nagy, and Ramaswamy (1990, P. 15).

*a*Average of the adopters only.

*b*Figures relate only to land sown to cotton. Small amounts of fertilizer were used on cereals.

Thus, it could be observed that ensured soil moisture through the use of tied ridges reduced risk levels sufficiently to make investments in fertilizers, weed control, and improved agronomic practices feasible. Thus, the interaction between the high yielding potential of the cultivars and favorable agronomic conditions was realized, leading to substantial yield increase.

Thus the effectiveness of tied ridges in soil water conservation and yield increase of many field crops including sorghum is appreciated by farmers in many parts of not only Ethiopia in many SSA counties. Although, the adoption rate is very slow, because it is tedious and very time consuming to make them by hand. The Farming System Unit at Melkassa and in Burkina Faso estimated that it would take up nearly 26-30-work days ha^{-1} to construct tie-ridges by hand with a small hand hoe. However, the Agricultural Implement Research and Improvement Center of IAR has developed a simple tie-ridger attachment with an oxen plough implement which enables the farmer to do tie ridging four times faster than making them with hand and it is under verification on farmers field.

There are also other factors, which should be understood by researchers and extension workers for the effective use of tied ridges, technology transfer. Some of these factors include the soil properties (degree of slope, texture and structure), the amount and distribution of rainfall type the crop.

4. Soil water conservation practices with improved agronomic practices

Soil water conservation should also be integrated with other improved agronomic practices so that the soil water retained could be used effectively. Weeds should be controlled as early as possible to avoid completion. Water harvesting techniques should also be used with improved crop management practices to use the harvested water more efficiently.

Table 12 Water harvesting plus improved agronomic practices on Maize Grain Yield

Treatments	Yield
	(t ha^{-1})
Broadcasting, no fertilizer, late weeding 6 weeks after emergence, flat planting (check)	1.3
Row planting, no fertilizer, late weeding 6 weeks after emergence, flat planting	1.7 (37)
No fertilizer, Late weeding 6 weeks after emergence, tied ridges	1.9 (46)
No fertilizer, early weeding 3 weeks after planting, tied ridges	2.3 (73)
40 N 46 P_2O_5 , early weeding 3 weeks after planting, tied ridges	2.9 (117)

Numbers in parenthesis indicate percent of grain yield increase over the check, farmer's practice.

Source: (Kidane and Abuhay 1997)

It is also important to note that the achievements of farm yields much closer to experimental potential is unlikely to result from a single piece of technology in isolation, but it will require an additive approach that builds on the complementarities of improved variety and agronomic practices (Table 12). While this does not mean that progress in raising productivity will not be feasible without applying the whole package, it does imply the need to consider each item as a component of a technology rather than a stand-alone.

Table 13 Summary of Innovations in Maize yield and Their Impact on Grain Yield in Kenya

Component	Content	Yield t ha ⁻¹ (t/ha)
Basic	Local variety	0.6
Improved variety	With a small increase in plant population	0.7
Improved fertility	40 kg N/ha 15 kg P/ha	1.1
Time of planting	Moved to near optimum to the area	1.3
Weeding	A second weeding	1.4
Plant population	Increased from 25,000 to 35,000 plants/ha	1.5
Further improvement to fertility	Fertilizer increased by an additional 50 kg N and 20 Kg P ha ⁻¹	2.1
Changed to hybrid seed improved timing of operations	Use of hybrid planted within two weeks of start of the rains and weeded within one month of planting	2.8
Improved pest control	Appropriate action to control stem borer and other pests	
Additional improvement to fertility	Addition of 50 kg N/ha and 30 kg P/ha	4.0

Source: Carr (1989)

5. Mulching

Most of the soils in the semi-arid areas are highly degraded with poor physical, chemical and biological properties. The soils have problem of shallowness, compaction or surface sealing or crusting which lead to low water infiltration and high runoff (Getachew Alem 1985). In addition to these undesirable soil conditions, high evaporation rates in the account of hot dry climate under

reduced rainfall and short season are the major factors of water loss in these areas. This is continuous process and amount of water is lost through evaporation is usually quite high.

One proven technique for increasing rainwater infiltration is mulching. Mulch absorbs the energy of raindrops and prevents the soil surface from crusting. Thus surface mulching has been proven to be effective in soil water conservation, maintaining favorable temperature conditions and improving soil structure through enhanced biological activity (Lal 1979).

Mulching also increases soil organic matter by improving soil physical conditions as well as nutrient and moisture retention capacity. At the same time it has a distinct advantage of controlling weeds that compete with crop plants for water and nutrients. In the dryland farming research work carried out at Katumani in Kenya, stover mulching was found to be very effective in controlling run-off, reducing evaporation, an increasing infiltration rates, and maize yield was increased by about 100% during a low rainfall season (Nijihia, 1979).

Some preliminary studies were carried out by IAR to select multipurpose leguminous trees and shrubs and to evaluate their suitability in alley cropping systems. The results indicate that *Sesbania sesban*, *Leucaena leucocephala*, and *Cajanus cajan* could be adapted to semiarid conditions of Ethiopia. The results further indicate that sorghum, wheat, faba bean, tef, maize, and haricot bean could be successfully alley cropped with these trees, producing equal or better seed and stover yield in most cases. Haricot bean grain yield, for instance, was increased by 30% when alley cropped with *Cajanus cajan* compared to sole cropping. Substantial amount of dry matter, up to 3 t/(ha/year), was produced by the legume trees such as fuel wood, animal feed, green manure or mulch, etc

In the semi-arid areas at Melkassa research center trials were conducted to evaluate the effect of different rates of two mulching materials tef straw and scoria (red volcanic ash) applied at 3 and 5 tons/ha and 137 and 222 tons/ha respectively were used on maize and sorghum yield. The results (Table 14) show that mulching raised the yield of both crops as compared to the check.

Table 14 the effect of different mulch materials and rates on the yield of maize and sorghum grown at Melkassa.

Treatment	Grain Yield (q/ha)	
	Maize	Sorghum
Control (no mulch)	24.5	36.5
3 tons/ha (tef straw)	35.9	38.3
5 tons/ha (tef straw)	31.6	40.2
137 tons/ha or 3 cm depth of Scoria (red ash)	45.7	38.3
222 tons/ha or 5 cm depth of Scoria (red ash)	35.3	36.5

Source: IAR (1988)

The straw mulch rates increased the yield of maize and sorghum by 29-47% and 147-198% respectively, whereas, scoria mulches increased the yield of maize and sorghum by 44-87 and 170-184% respectively. Comparing the two crops the highest benefit from mulching was obtained from sorghum. As Scoria mulch rates increased a slight reduction in yield was observed. Further studies in this area are in progress at Melkassa Research Center.

Kilewe and Usaker (1984) also reported that tied ridges in combination with stover mulch conserve more water and lead to higher dry matter and grain yields of maize compared to minimum tillage. Maize stover effectively controlled runoff through increased surface water storage, which in turn increased the time available for infiltration and also minimized evaporation, surface sealing and crusting (Table 15). It is also reported that, when a combination of tied ridges and maize stover mulch were used a crop of maize was realized for a season of extremely low rainfall season of 171 mm whereas no yield was obtained from the conventional tillage plots with or without farmyard manure. Lal (1979) also reported the significance of crop mulching in controlling runoff and soil erosion (Table 16).

Table 15 Soil moisture and Runoff arising from 122.1 mm rainfall

Treatments	Soil water storage (mm)	Runoff (%)
Stover mulching	128.0	-
Tie-ridging	86.0	13.7
Farmyard manure	69.0	38.0
Conventional tillage	65.8	42.7

Table 16 The effect of mulching on runoff and soil erosion at different slopes in Nigeria

Mulch rate t ha ⁻¹	Water runoff (mm)				Soil erosion t ha ⁻¹			
	1	5	10	15	1	5	10	15
0	293	396	219	294	8.0	100.0	130.0	80.0
2	6	61	4921	47	0.06	4.0	5.0	6.0
4	4	10	12	20	0.03	0.7	0.5	0.6
6	0	7		12	0.01	0.2	0.1	0.5

Source: Lal (1979)

Table 17 The effect of mulching on soil and water loss through runoff at Nigeria

Slope (%)	Water runoff (mm)		Soil erosion	
	No mulch	Mulch	No mulch	Mulch
1	412	0	9	0.0
5	483	11	134	0.2
10	303	21	137	0.2
15	375	20	96	0.7

Source: Lal (1979)

Crop residue mulch was applied at 6t ha⁻¹ and the rainfall of the season was 1022 mm

Erosion was monitored at field runoff plots with manual slopes. Each slope represent different soil type, soils of 10 and 15% were of coarse texture and suffered less from erosion than 5% slope

Therefore, mulching is a proven technique for improving organic matter content, decreasing water loss leading to soil water conservation and soil fertility improvement in the semi-arid regions. The use is however limited due to lack of mulching material, because crop residues have got alternative uses such as animal feed, fuel wood and other household purposes.

6. Manure Application

In dry areas soil fertility is usually the second most limiting production factor after moisture stress. The improvement in the supply of water available to plants under water harvesting can lead to depletion of soil nutrients. Therefore it is very important to maintain levels of organic matter by adding animal manure or compost to the soil. The recommended amount of manure application is about 10 tones per hectare but this varies from one area to another. Inorganic fertilizers are seldom economic for subsistence crops grown under water harvesting. It is advisable to start with small quantity of manure application and increase the level of application as deemed required. Inorganic fertilizers are seldom economic for subsistence crops grown under water harvesting.

Broadcast application (i.e., spreading thinly across the farm) of manure has to be strictly followed because local concentration of manure has a risk of burning of the crops and unnecessary wastage. Even better is making compost, rather than applying manure directly on farmlands. One difficulty that may be perceived by agropastoralists is transportation of the bulky manure. This could easily be solved by organizing them into groups (*Daboo*) that will work together on their respective farms. Donkeys or camels are available and could be used for transportation.

7. Improved crop varieties

As a result of collaborative research efforts in EARO several varieties were identified and recommended for the drought prone areas. The major crop species and cultivars recommend for the semi-arid areas are presented below. The released crop varieties are specifically indicated for certain areas in the drylands of Ethiopia. Thus, introducing the varieties to new areas requires serious caution and should preferably start with pilot activities.

7.1 Sorghum

Cereals are the major food crops grown in Ethiopia, for example, during the 1996/97 cropping season out of the total cultivated land area of 8.07 million ha about 6.69 million ha (82.86%) were devoted to cereals. Out of the total cereal production area during the same period 2.17 million ha (27%) were allocated to tef (CSA 1997). The other important cereal crops in terms of production area were tef sorghum and maize in that order.

Sorghum is one of the major traditional crops grown mainly in the dry semi-arid areas of Ethiopia. It is the most important crop in the Kobbo-Alamata plain, Shewa Robit area, Chercher highlands and Humera. It is a staple major food crop for millions of people who live in the dryland areas of the country. It grows mainly in the lowlands and medium altitude areas, but also in some highland areas. It is the third most important crop in the country. The area of production covers 1.3 million ha with an annual production of 1.7 million metric tons. Sorghum is indigenous to Ethiopia and thus has tremendous range of genetic variability.

It is used for making injera and preparing local drinks such as *tela* and *areke*. The crop is also consumed as boiled and roasted forms. The stalk is used as a fodder, construction material for housing and fencing.

Sorghum is grown mainly as a rainfed crop in the semi-arid areas. In these areas sorghum production is being limited by water stress due to low and variable rainfall between season and with the seasons. Sorghum yields vary considerably between years and show a close dependence on rainfall. The other major sorghum production constraints in the semi-arid areas include low soil fertility, weeds particularly striga, and stalk borer infestation, poor seedling emergence, birds (Qulea), These production problems have also regional importance in both eastern and southern African countries although their relative importance vary between regions and agroecologies. Moreover, different stresses often occur together, causing severe damage to the sorghum crops. For example, the adverse effects of striga infestation are exacerbated by nitrogen and water stress conditions. As a result of this the national yield average of the crop is less than 1 t ha⁻¹ far below the yield potential of the crop. For instance, research results

conducted in different parts of the country have shown that using improved sorghum varieties and management practices a yield of 4-5 t ha⁻¹ can be achieved.

Climate

The dryland sorghum growing areas of Ethiopia can be characterized as areas receiving low amount of rainfall, mostly with bimodal rainfall pattern. The rainfall is highly variable and erratic. There is high coefficient of variability (usually > 30%) with regard to quantum, onset and cessation of rainfall (Hailu and Kidane 1988).

Sorghum suits to areas receiving an average annual rainfall of about 350-800 mm. Studies done on the effect of rainfall distribution on the yield of rainfed sorghum (crop/weather relationship studies) indicated that

- ◆ About 25-mm rain immediately after seeding helps in satisfactory germination.
- ◆ Rains should coincide with the critical stage of crop growth.
- ◆ Heavy rainfall of 75 to 100 mm in the flowering period is bad for the crop as it washes pollen or makes the stigma less receptive and interferes with grain setting.
- ◆ About 25 to 50 mm rainfall during maturation helps in better grain development.

The results also indicated that crop is able to grow in areas, which are too dry and too hot for other crops. Therefore, it is called the 'camel' of the plant kingdom. Complete failures to moisture scarcity are much less frequent in sorghum than other crops like maize, wheat etc. The drought resistance of sorghum is attributed to its extensive root system and profusion of rootlets as well as to the morphological characteristics of its leaves and stalks which effectively reduce transpiration. The root system is about twice as active as that of maize in taking up water from the soil whereas the leaf area is considerably less. The crop was found not only able to absorb water more effectively than many other crops, but was also able to regulate water-losses to the atmosphere better. With the onset of moisture stress, the crop shows the lowest rate of decrease in relative turgidity and the least diurnal depression as compared to other crops because it reduces its transpiration rate to a much greater extent than the others. In contrast to plants like maize, in which stomata do not recover after a severe drought, sorghum stomata resume their normal behavior even after a severe drought lasting fourteen days. The recovery follows just after the restoration of turgidity to the leaves.

In terms of temperature sorghums performs best when average daily temperatures are from 24 to 26°C. Although, this crop is capable of tolerating excessive heat better than maize, grain yield is often reduced if temperatures exceed 38°C especially during the heading stage. The growth of sorghum plants is reduced appreciably when temperature is less than 16°C. The optimum growth of plants is recorded when temperatures are 27-30°C.

Soils

Sorghum can grow in different soil types from light sands to heavy clays if they are well drained. The pH should be above 5., but it performs best on deep, fertile sandy loams. Good yields are also possible on heavy but well drained soils. In fact, good fertility, drainage and optimum temperature are most important considerations in the successful culture of sorghum. This crop can tolerate considerable quantities of alkali or salts. Under rainfed conditions it performs well in the soils of high water retention capacity.

The Traditional Cropping Systems and Major Constraints of Sorghum Production

The farming systems and growing conditions in the dry areas of Ethiopia vary considerably. In the lowland water stress areas of northern Ethiopia and the rift valley areas cereal-based monocropping is the dominant cropping system. In these areas sorghum monocropping is the usual practice with little use of production inputs such as fertilizer. This practice has led to decline in soil fertility, high pest infestation (particularly striga and stalk borer).

In the highland and mid-altitude areas of Western areas of Hararghie farmers have developed highly diversified cropping systems. Sorghum is either mixed cropped or inter-cropped with grain legumes such as haricot bean, with other cereal crop mainly maize and haricot bean together (maize sorghum-bean associations). The crops may be planted at the same time or usually at different dates adding to the complexity.

These practices are also common in other similar areas with survival oriented agriculture where farmers resort to crop association of varying complexity rather than mono-cropping with a view to minimize risk. Multiple cropping systems usually reflect farmers multiple objectives, including first and foremost their need to survive. In addition, these cropping systems provide a better canopy coverage and conserves both soil and water, protecting the natural resource base and so providing a more sustainable basis for crop production over a long-term. Thus, the complexity of the system both in time and space also confers both biological and social and economic advantages.

Smallholders in dryland sorghum growing areas also practice crop rotation. But the rotation is usually not systematic based on a specific ratio of crops. Usually farmers want to plant much more of one or two favored crops than of the others, and this frequently does not make rotation feasible. Thus from the above discussions the yield might be low but traditional cropping systems are less risky, stable and sustainable.

7.1.1 Improved Sorghum Varieties and Management Practices

Sorghum Varieties

Based on the major sorghum production and farmers and consumers' preference and requirements, several research activities on varietal development, management practices, and crop protection measures have been executed by EARO.

The recommended sorghum varieties for the dryland areas of Ethiopia developed by the National Sorghum Improvement Program, appropriate growing conditions (climate, soils), agronomic management and crop protection control measures for successful, high and stable sorghum production are presented below.

Table 18 Improved Sorghum Varieties and Management Practice for the dryland areas

	Altitude (m)	Rainfall (mm)	Planting date?	Days to maturity	Grain yield q ha ⁻¹	Row spacing cm	Plant spacing Cm
Variety							
G-1107	<1600	335-513	15-30-June	110-130	30-50	50-75	15-30
76-T1-23	<1600	335-513	15-30-June	90-120	25-45	50-75	15-30
Dnkimash	<1600	335-513	15-30-June	90-120	30-50	50-75	15-30
Seredo	<1600	335-513	15-30-June	90-120	30-50	50-75	15-30
Meko-1	<1600	500-600	15-30 June	90-110	30-50	50-75	15-30
Gobiye	<1600	500-700	15-30 June	90-100	30-50	50-75	15-30
Abshir	<1600	500-700	15-30 June	90-100	30-50	50-75	15-30

Source: (IAR, Sorghum Handbook 1995)

Table 19 Candidate Improved Varieties for Borena Area

	Altitude (m)	Rainfall (mm)	Planting date?	Days to maturity	Grain yield q ha ⁻¹	Row spacing cm	Plant spacing Cm
Variety							
76-T1-23	<1600	335-513		90-120	25-45	50-75	15-30
Meko-1	<1600	500-600		90-110	30-50	50-75	15-30
Gobiye	<1600	500-700		90-100	30-50	50-75	15-30

Note: plating date should be adapted to the climatic conditions of Borena area.

Some important characteristics of the improved sorghum varieties

Gambela-1107 (released in 1978): This variety has good emergence capacity, which is important for sorghum production in the dryland areas. It has good seed

quality with white seed very good injera making quality and is preferred by farmers. It fits to well-moist semi-arid areas.

Seredo: It is released specifically for bird resistance (Quqlea qulea) in the rift valley and similar areas. The seed quality is not good for injera making it has sour taste due to high tannin content. However, if composite flour is prepared by mixing 50% tef: 50% seredo flour it can make good injera. It is however, good for making local drink called 'areke'.

76-T1-23: This variety is very early maturing (60-70 days to anthesis) and fits well to the dry semi-arid areas with short growing period. It has good quality seed white in color with high preference of customers. It is widely adapted in many areas which include North Wello in Kobo Alamata area, in south Wello in the Cheffa area, north Shewa and Meiso area.

Meko-1: released in 1998, is early drought resistant, white seed with injera making quality. Relatively tall with higher biomass production. This variety fits well for dry semi-arid areas with short growing season. It is released for north Shewa, Kobo

Gubiye (P-9401): Released and Meiso areas and well adopted by farmers. in 1998, is early drought resistant, white seed with injera making quality, relatively tall with higher biomass production. This variety fits well for dry semi-arid areas with short growing season. It is released for north Shewa, Kobo and Meiso areas and well adopted by farmers.

Abshir: Good potential yield (2.5-4.5) and earliness. It is tall with high grain. It is also drought resistant. It is specifically bred for striga resistance. It fits well areas with short growing period.

7.1.2 Management Practices

In order to devise appropriate crop and soil management practices it is important to identify the major problems limiting the sorghum production in the dryland areas. Therefore, the major production problems and causes are summarized in the following table.

Land preparation

In the dry lands the growing period is very short, therefore farm operations should be performed in time. Land preparation and planting are the two most important activities, which should be performed as early as possible just with the start of rains or before. If one or two effective rains are passed the low yield of crops or even total crop failure could be encountered.

Weeds should also be controlled in the right time, or else they compete with the limited water and nutrients in the soil and could cause substantial losses in crop production. Therefore, timeliness in field in these types operation is critical for successful crop production in the dryland areas. A summary of the recommend cultural practices for the dryland areas of Ethiopia is presented below.

Time of Sowing

In the dryland areas limited soil water is the over all riding factor constraining crop production. As a result, selecting appropriate crop species and cultivars which can fit to the growing period of a given area and adjusting planting dates in such a way that critical growth stages coincide with the optimum environmental conditions generally leads to efficient utilization of the limited resources (Kidane 1988).

Experimental results under dryland farming conditions have clearly revealed that dry planting or early sowing gives substantially higher yield compared to the traditional late planting after two or three effective rainfall. For example, at Kobbo dry sown sorghum (1-15 June) produced $2.3t\ ha^{-1}$, whereas, sowing after one, two and three effective rains gave 1.8, 1.4, $1.1t\ ha^{-1}$ (Table 20). Keating and Cooper (1983) also indicated that early planting of chickpeas resulted increased grain yield ranging from 1.9 to $4.2t\ ha^{-1}$ grain yield in the dryland areas of Syria. In South Australia French and Schultz (1984) studied the effect of sowing time in over 200 trials and found that for each week's delay in sowing after the sowing time, grain yield was reduces by $200-250\ kg\ ha^{-1}$.

Table 20 The effect planting date on sorghum grain yield in Kobbo area

Planting date	Sorghum Yield $q\ ha^{-1}$			
	1983	1984	1985	Mean
Dry planting	34.55	6.11	27.46	22.68
After one effective rainfall	24.66	6.18	25.06	17.71
After two effective rainfall	15.30	4.63	23.83	14.07
After three effective rainfall*	10.41	3.19	18.97	10.86

* Farmers' practice

Source: (Kidane and Rezene 1989)

In dryland crop production, the time of sowing may have a significant effect on the optimization of soil water use by ensuring that the growth of the crop is adjusted to the available soil water. Early-sown crops have the advantage of a longer growing season than later-sown crops, though the latter are sown under more favorable conditions of soil water supply. A longer growing season reduces the risk of water stress during grain filling. Early sowing also takes advantage of the flush of nitrates produced at the onset of the rains. Makatiani (1970b)

showed that delaying sowing for three weeks after the onset of the rains reduced maize yields by 76% during a season in which rainfall was below average and by 21% during a season in which rainfall was above average.

Planting methods:

Row planting and broadcasting are the common traditional planting methods in Ethiopia. But, row planting is the recommended practice. Controlling planting depth at practical level is not easy, especially with local Maresha. But very shallow planting depth ranging from 2 to 4 cm is recommended in both methods. If broadcast method is used seeds should be distributed uniformly.

Plant Density and spacing

Population density should also be adjusted to the available resources particularly soil water and nutrients to improve water use efficiency. The first step is to determine the optimum plant population for a particular locality. Thereafter, maximum exploitation of the available resources (available water, nutrients and radiant energy) could be made by using appropriate special arrangement of plants. Accordingly, research results from the dryland areas of Ethiopia indicate that 88,888, 15 x 75 cm were optimum for sorghum production. The recommended seed rate for sorghum production varies with the method of planting used. High seed rates should be used at the rate of 10-20 kg ha⁻¹ due to uneven seed distribution with broadcasting and also poor seedling emergence inherent problem with most sorghum cultivars. When sowing in rows a seed rate of 5-10 kg ha⁻¹ is recommend.

Weeding

Weed competition affects sorghum production adversely. A yield reduction of up to 60% may be caused if weeds are not controlled at the right time. It is important to destroy weeds at early stage of crop development. Two-hand weeding are necessary, the first 20-25 days after emergence and the second 45-50 days after emergence.

Striga is one of the major weed problems in sorghum production particularly in the semi-arid areas. This parasitic weed can result in substantial crop loss and or total crop failure in heavy infestation situations. Some of the traditional control measures include hand picking after flowering before seed setting, manuring, water retention intercropping and rotation with legumes. For example, intercropping mung bean with sorghum reduces striga infestation substantially (refer to the section on intercropping sorghum with mung bean in the coming section).

Sorghum/legume intercropping

In many parts of Ethiopia sorghum is usually grown mixed with crops, especially legumes. Intercropping is one of the cropping systems covering about 20% of the total sorghum production in the country (Yilma 1977).

Some preliminary sorghum/legume intercropping trials were conducted at Kobbo cropping season to identify the influencing of growing legumes (mung bean, cowpea, pigeon pea, hyacinth bean, and chickpea) in association with sorghum. The results indicated that sorghum yield can be significantly increased by growing mung bean as an intercrop. On the other hand, sorghum yields were significantly reduced when intercropped with hyacinth bean, cowpea, chickpea and pigeon pea (Table 21). Yields of all the intercrops were low. Only mung bean and cowpea gave relatively better yields. The results clearly show that when sorghum is intercropped with mung bean, the practice gave an extra yield of 495kg/ha-1 of sorghum . The association appears to be synergistic. The reputed ability of mung bean to stimulate striga germination reduced the parasitic lead on sorghum plant (Whitman 1977).

Table 21 Sorghum-Pulse Intercropping

Planting Method	B	C	D	Mean	Intercrops
Pure sorghum	18.87	23.96	15.90	19.12	-
Sorghum + Chick pea	13.63	19.02	14.34	15.53	1.18
Sorghum + mung bean	21.25	24.95	20.00	24.07	2.36
Sorghum + Pigeon pea	17.59	14.99	18.44	16.97	0.33
Sorghum + hyacinth bean	8.17	13.31	11.17	10.89	0.12
Sorghum + cow pea	9.00	12.48	10.96	10.73	3.32
Mean	15.57	18.10	15.07	16.25	

Plowing methods:

B = broadcast and buried to leave 45 cm ridge and furrow

C = sorghum in alternate furrows at 90 cm apart

D = sorghum in every third furrow at 135 cm apart

The importance of reduction in weed infestation with mixed or intercropping is also well documented (Reddy and Kidane 1993). For example, in Kobbo area

striga infestation was reduced when mung bean was intercropped with sorghum (Table 22).

Table.22 The effect of intercropping and planting pattern of mung bean with sorghum on striga infestation and grain yield of sorghum at kobbo

Treatment	Grain yield t ha ⁻¹		Stand count/plot
	Sorghum	Mung bean	
Pure sorghum (2-8-76)	1.8	-	29.5
Sorghum (2-8-76) + mug bean (22-7-76)	0.9	0.7	7.0
Sorghum (2-8-76) + mug bean (22-7-76), but remove on (2-8-76)	1.5	-	11.5
Sorghum + mung bean planted at the same time (2-8-76)	1.3	0.4	9.5

Source: Whiteman (1976)

Alley cropping

Alley cropping of woody species with crops of various forms, which is also called agroforestry, is widely practiced by traditional farmers in the tropics. Despite its potentials, this old practice is still a much-neglected area in terms of research and needs a lot of quantification to improve productivity. There is a substantial evidence to show that alley cropping can result in higher productivity, better control of environment, and safeguard against unfavorable conditions.

Experiments were conducted to determine the adaptation of some selected legumes, trees, and shrubs (*S. sesban*, *L. leucocephala* *C. cajan*, etc.). Besides, their suitability in alley cropping with food crops including sorghum, maize under the semiarid conditions, the results indicated that *S. sesban*, *C. cajan*, and *L. leucocephala* were promising and could be adapted to the conditions of the testing sites. The results also indicate that in general there is a possibility of producing two crops without reduction in yield. It can be observed in almost all testing sites that stover and grain yields of food crops from the alley cropping system were more or less equal or better than yields from pure stands (Table 23). In addition, the legume trees, especially *S. Sesban* and *C. cajan*, produced substantial amounts of dry matter about 3 t ha⁻¹ which can be used for animal feed, fuel wood or as a green manure or mulch to improve soil fertility (Table 30).

In the alley cropping experiments conducted at Melkasa, Sirinka, and Kobo, food crops were grown in alley of 4 m wide between rows of densely planted trees (50 cm between plants) which were pruned two-three times during the growing season.

Table 23 The effect of alley cropping *Sesbania sesban* and *Leucaena leucocephala* on grain yield of sorghum, wheat, faba bean, and tef at Sirinka

Treatments	Seed yield (kg/ha)			
	Sorghum	Wheat	Faba bean	Tef
Sole	1993	2324	2165	747
S. sesban	2057	1707	2828	716
L.leucocephala	2075	2809	2158	637

Source: (Kidane et al 1988)

Table 24 Effect of alley cropping *Sesbania sesban* and *Leucaena leucocephala* on stover yield of sorghum, wheat, faba bean, and tef at Sirinka

Treatment	Stover yield (kg/ha)			
	<i>Sorghum</i>	Wheat	Faba bean	Tef
Sole	8215	2918	2710	2300
S. sesban	8025	2166	2076	2399
L. leucocephala	8889	2808	2694	2158

Source: (Kidane ea, al, 1988)

7.2 Haricot bean

Haricot bean (*Phaseolus vulgaris* L.) is one of the most important grain legumes grown in many areas of the lowlands of Ethiopia, particularly in the Rift Valley. In these areas farmers grow white beans mainly for export purposes. Thus beans are important cash crops commodity. Haricot bean is also a principal food crop particularly the brown seeded in southern and eastern part of Ethiopia.

It is a cheapest source of plant protein for farmers in the dry areas. This is particularly important in southern and eastern part of the country. Because there is an export induced demand for white bean types there is a good internal market for growers. Further more the crop plays an important role in various cropping systems. Its nature of crop and tolerance to shading makes it an ideal crop to fit to different crops and double cropping in some production areas.

In Ethiopia bean has wide range of adaptation, it grows well between 1400-2000 m., the optimum temperature ranges from 18-23⁰ C. The rainfall in the bean growing areas range fro 350-700 mm. Common beans can be grown under a wide range of soils, from light to heavy clay soils. However, the soils should be well drained, because beans are very sensitive to waterlogging. The pH should be above 5.

There are a number of constraints, which limit bean production in Ethiopia. Some are specific to some production areas and others have wide range spectrum. In the low rainfall areas the constraints include water stress, use of low yielding varieties, pests and diseases (rust, anthracnose, and common blight) and weeds.

7.2.1 Improved Haricot Bean Varieties

In an attempt to address the production constraints several research activities were conducted. The following varieties are recommended for drylands.

Table 25 Haricot Bean varieties recommended for different agroecological zones

Variety	Suitable areas	Days to maturity	Yield (q/ha)		Seed colour
			Traditional	Potential	
Mexican-142	Nazret, Alemaya, Awassa,	80-100	10-13	16-20	White
Awash-1	Nazret, Alemaya, Awassa,	75-90	12-15	20-24	White
Roba-1	Nazret, Alemaya, Bako, Awasa,	75-95	10-12	20-24	Yellow
Red-welaita	Awasa, Welaita	90-100	7-9	10-14	Red
Atndaba	Nazret, Alemaya, Awassa,	90-95	-	20-25	cream
G2816	Nazret, Alemaya, Awassa,	100-110	15-25	20-35	cream
GLPX92	Nazret, Alemaya, Awassa,	100-110	15-25	20-35	Speckled

The varieties with white seed color are mainly used for export, while the red and yellow varieties are used for local food consumption.

Source: (IAR, Haricot Bean Handbook 1995)

According to experts at Melkassa Agricultural Research Center Mexican-142, Roba 1, Red Wolaita, and Awash1 are suitable for introduction to Borena area. As mentioned earlier, a pilot work has to be made before a large scale introduction.

7.2.2 Agronomic Management Practices

Land preparation and planting time

Haricot bean does not need fine seedbed preparation. However, the land has to be ploughed properly. It should be free of weeds, soil clods and other undesirable materials. Three plowings, first immediately after harvest, second with the onset of the *belg* rains and third one during sowing is recommended for the rift valley areas. Here, the recommended sowing time is from mid June to the first week of July following the onset of the rainfall.

Sowing method: seed rate and plant population

Haricot beans should be sown in rows to facilitate weeding and other cultural practices. The row sowing can be done by a row planter or by hand. It is also possible by local plough *maresha*. The seeds are then sown in furrow and covered with ox plough or by disk harrow. The recommended seeding depth is 4-8 depending on seed size. The seed rate should be chosen to give 400,000 to 500,000 plants ha⁻¹. To achieve this much plant population seed rate of 90-100 kg ha⁻¹ is required for row planting and 120-130 kg ha⁻¹ for broadcasting. The row spacing should be 40 cm and between spacing 5 cm.

Weed Control and Use of Fertilizer

The recommended fertilizer rate is 50 kg ha⁻¹ in low potential areas and 100 kg ha⁻¹ in high potential areas should be used as a basal. The small amount of N fertilizer will help the plant to get a good start.

Beans do not compete well with weeds, especially at early stage. Therefore, early weeding is important. The recommended weeding time is twice 2-3 weeks after emergence before flowering. Hoeing with a light hoe or by using a row weeder can preferably do if beans are planted in rows weeding. In case of chemical weeding the herbicide recommended is alachlor at 2.92 kg a.i. ha⁻¹ after sowing and before emergence of beans is recommended.

Improved Pest Control Measures

Haricot beans suffer from a number of leaf, stem and root diseases, in Ethiopia Common bacterial blight, anthracnose and rust are the most important and widely distributed, while others are much more restricted in their distribution. The available research results on control measures of some of the important pests of beans are indicated below.

Table 26 Recommended disease and pest control measures for haricot bean

Anthracnose	Bean rust	Bacterial blight	Bean fly	African bollworm	Weevils
Use of clean seed	Use of clean field	Use clean seed	Plant early	Use strip cropping	Keep store clean
				10 rows of bean-	
				2 rows of maize	
Use rotation for 2-3 years	Use of resistant varieties such as	Use clean field	Use strip cropping		Harvest when properly mature
	Roba-1 and	Use crop rotation	Use high seed rate		
	Awash		90-100 kg ha ⁻¹		Treat seed with
Use of clean field		Weeding after dew			primiphose-
Use of resistant			Use resistant		methyl (2%)
					dust
varieties such as			varieties such as		at rate 2.5 g/10
					g/10 kg
			Awash-1		of seed
Treat seeds with					
Benomyl					

Source: (IAR, Maize Handbook 1995)

7.3 Cow pea (*Vigna unguiculata*)

This crop is a principal food legume of many African countries where the tender leaves and pods as well as grain are consumed. It is important in the semi-arid areas of Tigray.

Cowpeas can with stand heat better than most grain legumes and is drought resistant. Water deficiency has adverse effect mainly on vegetative growth; seed formation is less affected. It can be grown successfully in great variety of soils, provided they are well drained. Light sandy loam soils are more suitable than heavy soils.

7.3.1 Recommended Varieties of Cowpeas

Some experiments carried out on varietal screening, sowing dates, fertilizer, intercropping with sorghum in the Kobo area indicate that the crop has a great potential for the semi-arid areas. The main findings are summarized as follows:

The potential yield ranges from 3 to 5 t ha⁻¹ under experimental conditions. The crop has good drought resistance and early varieties have good promise. The recommended varieties with length of growth period are given below:

Table 36 Recommended cow pea varieties for the Kobbo-Alamata valley

Varieties	Days to maturity	Characteristics, plant habit
Late varieties		
TVU 1977-OD	90-106	Intermediate, semi-erect
TVU 1502-11-B	65-90	Intermediate, semi-erect
White wonder trailing	67-90	Indeterminate, tailing
Early variety		
Black-eye-beans (DZ)	50-90	Determinate, erect

Source: (IAR 1973-75)

Once again, the introduction of cowpeas should be made first at a pilot scale. At least two seasons must pass before the adoption of the varieties by farmers.

7.3.2 Agronomic practices

Sowing date:

The recommended sowing dates are end of May for the late varieties and end of June for the early June.

Population density:

66,666 plants ha⁻¹ for the spread types
111,111 plants ha⁻¹ for the erect types

Spacing

75 x 20 cm
45 x 20 cm

Depending on size of seed, the average seed rate is 16 Kg ha⁻¹.

7.4 Mung bean (*Vigna radiata*)

Mung bean is very early maturing crop and also drought resistant and has great potential for the semi-arid areas with short growing cycle. Farmers in Shewa Robit area in northern Shewa zone grow mung bean and is believed that it was introduced to Ethiopia during the Italian occupation. Special features are high yield; good nutritive value, the earliness and drought escape features, the reasonable cost of production, and the ability to stimulate striga without being parasitized. The research results are indicated as follows:

The yield of the crop in the Kobbo-Alamata plain ranges from 1.5-4 t ha⁻¹
The best late varieties identified are M1134 and M109.

Table 27 Recommended mung bean varieties and management practices for the Kobbo-Alamata area

Varieties	Sowing	Days to	Population	Spacina	Potential
	Date	Maturity	Density	(cm)	Yield
Early varieties					t ha ⁻¹
M61	End June-mid July	65-70	222,222 (11 kg ha ⁻¹)	45 x 10	1.5-2.0
M76	End June-mid July	65-70	222,222 (11 kg ha ⁻¹)	45 x 10	1.5-2.0
M140	End June Mid July	65-70	222,222 (11 kg ha ⁻¹)	45 x 10	1.5-2.0
Late varieties					
M1134	Mid June	90-105	222,222 (11 kg ha ⁻¹)	45 x 10	3.0-4.0
M-109	Mid June	90-105	222,222 (11 kg ha ⁻¹)	45 x 10	3.0-4.0

Source: (IAR 1973-75)

Intercropping mung bean with sorghum gave very satisfactory results. These associations appear not only non-competitive but also synergistic, specially grown at closer spacing. Sorghum should be planted in alternate rows of 45 cm furrow 90 x 17 cm) and mung bean in the furrows left in between (90 x 5 cm). Simpler and effective way is to broadcast the sorghum (6-8 kg ha⁻¹) and mung bean (10-12 kg ha⁻¹) as a mixture, then cover with the local plough *Merasha* leaving land in 45 cm ridges and furrows. Thin both crops later on sorghum 45 x 35 cm and mung bean 10 cm apart from the sorghum. This association was found to give higher yield for both crops. This inter crop combination has the advantage that both crops can be sown at the same time, preferably mid-June, otherwise in early June.

7.5. Pigeon pea: a potential crop for the dryland areas

The crop is grown extensively throughout most semi-arid areas of Africa as a perennial garden crop and is commonly seen in Konso area of southern Ethiopia as an intercrop with sorghum and cotton. It is mainly consumed locally; the green immature pod's are frequently used as vegetable and dried peas as pulse. The nutritive quality of pigeon pea is excellent. Dried stalks may be used for fuel, even for charcoal production. This can contribute in alleviating the serious problem of lack of energy source for fuel wood in the Semi-arid areas. The leaves are also a good source of fodder.

In addition, because of its drought resistance and its multipurpose use among the grain legumes pigeon pea (*Cajanus cajan*) deserves a special attention. Once established pigeon pea is one of the most drought resistant crops found in Africa. This is because it has very deep root, which can penetrate hard soil layers, which other crops cannot. The plant also has the ability to shade its leaves and greatly reduces growth during prolonged water stress and may yield after several months of dry weather.

Pigeon pea can also thrive on very poor soils. Pigeon pea is very important as intercrop and in rotation with cereal based cropping systems. There is a limited research work on this aspect in the country. Except in the Kobbo-Alamata plain some preliminary research results indicated that intercropping pigeon pea with sorghum has indicated that pigeon pea can be intercropped without material reduction in sorghum yields with an overall of slightly increased gross return. In fact, one of the promising intercrops with cereals particularly sorghum and maize is the late maturing pigeon pea. Even though early growth of the legume is reduced when intercropped with maize or sorghum, pigeon peas compensate by continuing to grow after maize harvest and produce large quantities of biomass about 3 t ha⁻¹ of dry matter from leaf litter and flowers (Sakala 1994). Pigeon peas is easily intercropped with cereals and even the seed is harvested for food, the leaf fall is sufficient to N and organic matter accumulation.

The yield responses of a cereal crop following pigeon peas can also substantial. Research results indicate that grain yield of the first crop of maize following pigeon peas average 2.8 t ha⁻¹ higher than that of continuous maize that received 35 kg ha⁻¹ N each year. In Malawi MacColl (1989) estimated net nitrogen of 23 to 110 kg ha⁻¹ from pigeon peas.

The Ethiopian Agricultural Research Organization, has now introduces several pigeon pea cultivars from the ICRISAT eastern Africa grain legume program to screen the cultivars, which fit the growing conditions of the dryland areas of Ethiopia. They were on quarantine trials for a year and now they are sent to different sites for further screening. Some of the cultivars have been released in more than 5 countries in Kenya and other eastern African countries with similar agroecologies and farming systems as the dryland areas of Ethiopia. Therefore, there is high probability that they will adapt in the dryland of Ethiopia too.

7.6 Ground nut (*Arachis hypogaea* L.)

Groundnut is exotic to Ethiopia; it was introduced first to Haragie area in the 1920 by the Italian explorers (Yebio 1984). Currently the crop is widely grown in the warm lowland areas of the country. It is mainly produced in Haragie area. But, Gamogofa, Ilubabor, Gojam, Shewa, Wello, Sidamo, and Wellega are also identified as potential areas (Adugna 1991).

Similar to sesame groundnut is also very important cash crop for the smallholder dryland farmer in particular and the country in general. The crop provides cash revenue to the small farmer and their family on local market, for instance, a Kilo of ground is sold at 4 Ethiopian birr.

The major constraints to groundnut production in Ethiopia include disease and insect pests, lack of improved varieties, drought, and lack of harvesting technologies. The Lowland Oil Crop Improvement Program have conducted several research activities to improve ground production in the country and released several varieties (Table 28).

Table 28 agronomic characteristics and mean grain yield of the improved groundnut varieties in the semi-arid areas of Ethiopia under irrigated and rainfed conditions.

Variety	Grain Yield t ha ⁻¹		Oil content (%)	Days to Maturity
	Irrigated	Rainfed		
Shulamith	5.0-6.5	2.0-3.5	44-49	130-165
Nc-4X	5.0-7.0	2.0-4.0	42-49	130-160
NC-343	4.0-6.0	2.5-3.0	45-50	140-160
Roba	5.0-7.0	3.0-5.0	44-55	130-160
Sedi	3.2-4.7	1.1-2.5	45-52	100-110
Manipeter	4.5-5.1	1.9-3.5	48-50	120-150

Source: (EARO files)

Candidate varieties for Borena Areas are shaded, based on recommendation by researchers at Werer Agricultural Research Center.

8. Other technologies

Dry planting: Early planting makes the best use of limited rainfall. In some areas it may be best to plant seeds before the rains arrive. This technique is known as "dry planting".

Experimental results under dryland farming conditions have clearly revealed that dry planting or early sowing gives substantially higher yield compared to the traditional late planting after two or three effective rainfall. For example, at Kobbo dry sown sorghum (1-15 June) produced 2.3t ha⁻¹, whereas, sowing after one, two and three effective rains gave 1.8, 1.4, 1.1t ha⁻¹ (Table). Keating and Cooper (1983) also indicated that early planting of chickpeas resulted increased grain yield ranging from 1.9 to 4.2t ha⁻¹ grain yield in the dryland areas of Syria. In South Australia French and Schultz (1984) studied the effect of sowing time in

over 200 trials and found that for each week's delay in sowing after the sowing time, grain yield was reduced by 200-250 kg ha⁻¹.

Table 29 Effect planting date on sorghum grain yield in Kobbo area

Planting date	Sorghum Yield q ha ⁻¹			
	1983	1984	1985	Mean
Dry planting	34.55	6.11	27.46	22.68
After one effective rainfall	24.66	6.18	25.06	17.71
After two effective rainfall	15.30	4.63	23.83	14.07
After three effective rainfall*	10.41	3.19	18.97	10.86

* Farmers' practice

Source: (Kidane and Rezene 1989)

Ato Jateni Wario, a farmer in Bura Derra PA, is now practicing dry planting and follow-up and subsequent extension of the technique could be made if this is found successful.

Transplanting

In semi-arid areas one of the biggest problems facing farmers is the unpredictability of rain. All too frequently rains come late or end early, and with such a short growing season, harvest time never comes; the half-grown crops left to wither in the fields. Irrigation is seldom an option, with scarce water sources under pressure from competing demands of drinking, cooking and washing. But, as recent research has shown, raising crop seedlings in nursery beds could be a way for farmers to both maximise the efficiency of their water use, and tackle the problem of shortened growing seasons. The idea that has been tested by Zimbabwean and Ghanaian farmers and crop researchers, in partnership with the Centre for Arid Zone Studies (CAZS) in the UK, is a simple one. Towards the end of the dry season, farmers sow sorghum in specially prepared nursery beds, located near a reliable water source. Once the seeds have germinated, the seedlings are carefully tended and watered, and when the rains come, are transplanted into the fields. A nursery bed of five by six metres can produce enough seedlings to cover a hectare of land. Naturally the seedlings have a head-start over direct sown plants, greatly increasing the chance of producing a crop should the rains end early.

Trials of the transplanting system have been conducted for three years in Zimbabwe and for two years in Ghana, and so far the results have been very positive. The farmers undertaking the trials were all used to growing sorghum, and had experience in transplanting, since it is a common method for filling gaps and spreading out dense patches of plants that result from uneven germination of broadcast crops. They were asked to grow a transplanted crop next to a direct sown crop, and keep careful records of planting dates, watering regimes and

yields. All reported that they had harvested their transplanted crop two to three weeks before the direct sown crop, and 89 per cent reported higher yields from the transplanted sorghum, sometimes doubling their yield.

Integrating trees on farmlands

Scattered trees: leaving 40-60 trees per hectare as it is practiced in Niger. Trees that do not compete with crops such as *Acacia tortilis* and *Balanites aegyptiaca* should be encouraged when they emerge as natural regeneration on farmlands.

Strip farming: when the land opened for cultivation for the first time it is recommended that leaving strips of land that is equal in size to the cultivated land. In West Africa there is a special adaptation; farmers leave about 10m wide strip for every 90m wide cultivated land. The strips protect crops against wind and improve the fertility of the cultivated land through organic matter supply and erosion control.

Dry Season Garden

This is a technique developed in the Sahel for growing vegetables in farmlands during the dry season. Trees such as *Zizyphus* or *Balanites* species are planted around the garden as live fence. Fruits are also integrated in the system. This is a very effective method for ensuring food security at household level. It, however, requires installation of rain water harvesting structures and local irrigation systems such as low cost drip irrigation techniques (e.g., Chapin drip irrigation of Chapin).

Chapin System: Smallholder drip irrigation system

Efficient use of water is seen as a key to crop production in arid and semi-arid areas. This is increasingly true because of ever increasing population and demand for food production coupled with growing competition and increasing energy costs. For small holder farmers, drip irrigation provides a means of maximizing returns on their croplands by increasing the economic biomass production per unit of water and increasing cropping intensity by also growing a crop during the dry season. The development of low-head emitters and simple filtration has reduced much of the initial capital investment necessary, making small scale drip irrigation systems affordable to smallholder farmers. Research and experience is providing tailor-made drip irrigation systems to suit different field and water conditions.

Drip irrigation systems are normally used for row crops (vegetables, fruits and food crops). Smallholder drip irrigation systems are being used in some parts of Africa, for example Chapin bucket kits are being used in Kenya, Tanzania, Malawi, Zambia, and Uganda. Elsewhere in the world, for example in India, poor farmers have used drip irrigation systems with reported success.

Smallholder drip irrigation systems operate under pressures of 0.5-25m head. The coverage area determines the water pressure required to overcome friction

associated with water delivery and filtration. In low-pressure systems, water containers such as buckets and drums, raised 0.5-1.5m above the ground, are used as header water tanks to enable the filling of the container manually by pails or hand pumps.

Drip irrigation systems consist of water storage, water filtration, water conveyance and distribution, and water application sub-systems. Common preparation requirements and features are as follows:

1. Prepare the area to be irrigated:
 - Lay out the planting bed depending on the length, spacing and number of the drip lines
 - Excavate shallow trenches (15-30cm deep) lengthwise where the row crops will be planted
 - Place plant stover or green material in the trench to a depth of about 15cm
 - Add a 5-10cm layer of fresh manure, on the top of green material
 - Cover the trench and level the ground to form a raised bed 10-20cm above the aisles.
2. For best results, drip systems are used to irrigate level beds. If the drip tubes go uphill, downhill, and around corners, the system will not give equal water flow from each dripping outlet.
3. Construct the water container stand. Ensure that it can support the weight of the container and water when full.
4. Mount the water container on the stand so that the water outlet is at a height necessary to provide the water pressure required to operate the system.
5. Mount the water container outlet, water filtration and flow regulator fittings.
6. Lay the water distribution system components that connect the water container to the individual drip lines. Make sure that open ends are closed to avoid foreign material entering the pipe.
7. Unroll the drip lines and lay them along the full length of each row of plants to be irrigated.
8. Connect the drip lines with water distribution system (header pipes).
9. Flush the system to remove any foreign matter that may have entered the pipeline.
10. Close the end of the drip lines.

It must be emphasized that any training or advice on the use of drip kit systems should not only cover actual kit installation and maintenance, but also all aspects of growing vegetables under drought conditions since the purpose is to increase farmers yields. Thus training and advice should include lessons about bed preparation and composting, transplanting irrigation water management and pest and disease control.

The Chapin System

Description of the system

Chapin bucket kits were developed by Richard Chapin of Chapin Living Water Foundation. The system consists of a 20-liter bucket mounted 1m above the ground and 30m of drip tape. The detailed system components are 20-liter bucket, timber and nail for bucket stand, 2 piecesX15m drip tapes, 2 piecesX1.5m supply tubing, filter screen, washer, 2 barb fittings, male adapter and female adapter.

The assembly instruction is as follows:

- ◆ Prepared the filed to be irrigated as described earlier.
- ◆ Mount a 20- or 30-liter bucket (supplied by the farmer) with a $\frac{3}{4}$ inch hole cut at the bottom 1 meter above the ground.
- ◆ Assemble the outlet from the bottom of the bucket by connecting the male adapter, rubber washer and female adapter.
- ◆ Install the filter screen at the bottom of the bucket.
- ◆ Install the two supply tubes running from the filter to the barb fittings.
- ◆ Connect the 15m drip irrigation tape through the drip lock fittings.

Other forms of drip irrigation systems also exist that differ in size and structure such as Waterboys system, IDE bucket kit, Kari Drum kit (with a 200-liter drum), Wagon wheel system, Family drip system, Plastro system and Microtal system (see Sijali, 2001).

Drip irrigation suppliers could be contacted through the following address:

Amiran Keny Ltd, e-mail: amiran@africaonline.co.ke or

Kenya Agricultural Research Institute, KARI, e-mail: irrigation@iconnect.co.ke; lisquest@kari.org

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