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Zai pit photo by Brandon Lingbeek

*by Tim Motis (PhD), Chris D'Aiuto
and Brandon Lingbeek*

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INTRODUCTION

What is the zai system?

“Zai” is a term that farmers in northern Burkina Faso use to refer to small planting pits that typically measure 20-30 cm in width, are 10-20 cm deep and spaced 60-80 cm apart (Fig 1). In the Tahoua region of Niger, the haussa word “tassa” is used. English terms used to describe zai pits include “planting pockets”, “planting basins”, “micro pits” and “small water harvesting pits.” Seeds are sown into the pits after filling them with one to three handfuls of organic material such as manure, compost, or dry plant biomass. The following quotes provide further detail.

Tony Rinaudo, in Amaranth to Zai Holes (ECHO book), wrote:

Oxfam, working in Burkina Faso, promotes this method of tillage. This is a traditional practice of digging a 20 x 20 cm hole 10 cm deep [dimensions of the pits can vary] during the dry season and filling it with mulch such as crop residue or manures. This leads to increased termite activity which, in turn, increases the rate of water infiltration when the rains come. Millet is planted in the individual holes, which also help protect the seedlings from wind damage (100 km/hr winds at planting time are not uncommon).

Dr. Sawadogo, working in northern Burkina Faso with the National Center of Technology and Scientific Research, spoke on zai at ECHO's 2011 Annual Agriculture Conference. Sawadogo writes:

There is a longstanding and well-documented tradition in the Sahel-zone, specifically in the north of Burkina Faso, of technologies that make farming more productive through improved rainwater management and protection of the soil. Zai is probably the most renowned example of such a technology, which was developed locally based on indigenous knowledge... In Yatenga province, zai are traditionally used to improve poor (bare) soils in drought conditions. Organic matter like composted manure is placed in holes measuring 20 cm across and 15 cm deep, creating a micro-environment that helps increase drought resistance and improve the yields of crops like sorghum and millet.

Where are zai pits likely to be most relevant?

The use of zai pits originates in the western Sahel where infertile, encrusted soils receive low and often highly variable rainfall. On such dry, fragile lands, smallholder farmers face a constant challenge to produce enough food to feed their families and generate much-needed income. Where population growth is high, the challenge is even

more difficult due to increased pressure on the land to produce crops. Consequently, innovation is critical to survival in many parts of Sub-Saharan Africa where traditional methods, such as that of long fallow periods, are no longer adequate or feasible.



Figure 1. Millet growing in zai pits in Burkina Faso. Photo courtesy of Hamado Sawadogo.

Zai pits are an innovation that addresses issues of land degradation, soil fertility, and soil moisture. Through the digging of zai pits, degraded, hard-pan soils impossible to plow can still be productive rather than abandoned. Organic materials such as compost and manure need only be added to the planting holes instead of spreading them over the entire field area. The improved efficiency makes it easier for farmers to obtain and apply the fertility inputs needed to maintain productive soils.

The pits also play an important water harvesting role. Instead of being lost to runoff, rainfall water is trapped in the zai pits close to crop roots. Zai pits are especially relevant to areas receiving 300-800 mm annual rainfall (Roose et al. 1993). Higher rainfall amounts could cause water-logging of the pits. In summary, the zai system

allows farmers to concentrate both fertility and moisture close to crop roots and, in so doing, addresses some of the major challenges to crop production in Sub-Saharan Africa.

Do zai pits work?

Testimonial from Tony Rinaudo in Niger (from ECHO's book, Amaranth to Zai Holes)

Where farmers are using it, the zai method is making a big impact on crop yields. Soils here are infertile and if farmers have manure at all they just broadcast it on top of their fields. Much of this is baked, blown and washed away. If the manure and organic matter is placed in a zai hole, losses are minimized and nutrients are concentrated where the plant can use them. Crop plants have a competitive advantage over weeds that are not in the zai hole.

We convinced one farmer to try zais on a small plot of barren land. He did and harvested 100 kg of corn and 15 kg of sorghum. The next year farmers in 20 villages dug over 50,000 zai holes! We urged farmers to also try zai holes in their sandy soils. The results were so convincing that many are now digging holes on their own initiative. (Tony also wrote of one area in which millet yields were often less than 350 kg/hectare; with zai holes, the yields reached 1,000 to 2,000 kg/ha. Farmers in 87 villages dug almost two million zai holes for their millet.)

For some time we have been trying to re-establish cassava as a major crop in the district. There have been more failures than successes because of the harsh climate and poor soils. ...In 1993 we only received 1/3-1/4 of the average rainfall (130-240 mm). Despite this, because we insisted that farmers dig zai holes, 80% of the 44 ha planted survived. Even in good years we have never had such a high success rate using other planting practices.

Abstract of zai research in Ethiopian highlands (Amede et al., 2011)

Is the zai system relevant in high rainfall areas? Although waterlogging can result from high rainfall, especially on flat ground, Amede et al (2011) showed that zai pits were effective in a highland area of Ethiopia that receives in excess of 1300 mm annual rainfall and where water infiltration into the soil is limited by losses of rainwater to runoff, a lack of organic matter, and hardpans. Recognizing the high potential for soil erosion, the pits were enlarged to withstand the strong downhill flow of rainfall runoff. Potatoes and beans were grown over a 3 year period from 2004-2006. Zai pits, in combination with additions of nitrogen, increased potato yields 500%-2000%; bean yield increased by 250% with zai pits. The pits themselves contributed more to yield increases than the nitrogen inputs, indicating the significant role that water can have on crop growth and use of existing soil nutrients. Importantly, farmers earned 20 times more income than the cost of the labor required to dig the pits.

HISTORICAL BACKGROUND

In a publication entitled "Re-Greening the Sahel," Chris Reij et al. (2009) outlined the background and development of the zai system in Burkina Faso. This account is summarized as follows:

During the 1960s and 1970s, despite major efforts by foreign aid donors to construct earthen bunds, land in the densely populated Central Plateau region degraded to the point that farmers were faced with a decision to either reclaim their land or leave the area. With encrusted soils and a bare, heavily eroded landscape, many families and wage earners did in fact leave the region.

In the early 1980s, several farmers in the Yatenga province began experimenting with traditional planting pits (known as zai) dug into the rock-hard soil. They improved upon them by increasing the depth and width of the pits and adding various organic materials. In fields that had been yielding virtually no grain, farmers began to see yields of 300 kg/ha (in years with low rainfall) to 1200 kg/ha (in years of good rainfall) (Kaboré and C. Reij. 2004).

The use of the improved pit system spread rapidly. Key farmer innovators including Yacouba Sawadogo, Oursseni Zoromé, and Ali Ouedraogo were especially instrumental in promoting the system by organizing special market days and trainings. Progress since the early 1980s has continued. By 2001, Oursseni Zoromé had established a network of over 20 “zai schools” and 1000 members, with each group given the charge of rehabilitating their own piece of land. Through these trainings, and the exchange of knowledge that took place, farmers adapted the system to meet their own cropping needs. For instance, the pits began to be used for cereal/tree combination systems instead of just for cereal staples. To do this, farmers varied the density and size of pits as well as the quantity of organic matter placed in them. Such modifications are a good indicator of overall success of zai.

TECHNICAL ASPECTS OF ZAI PITS

Microcatchments in general

What types of plants grow best in microcatchments?

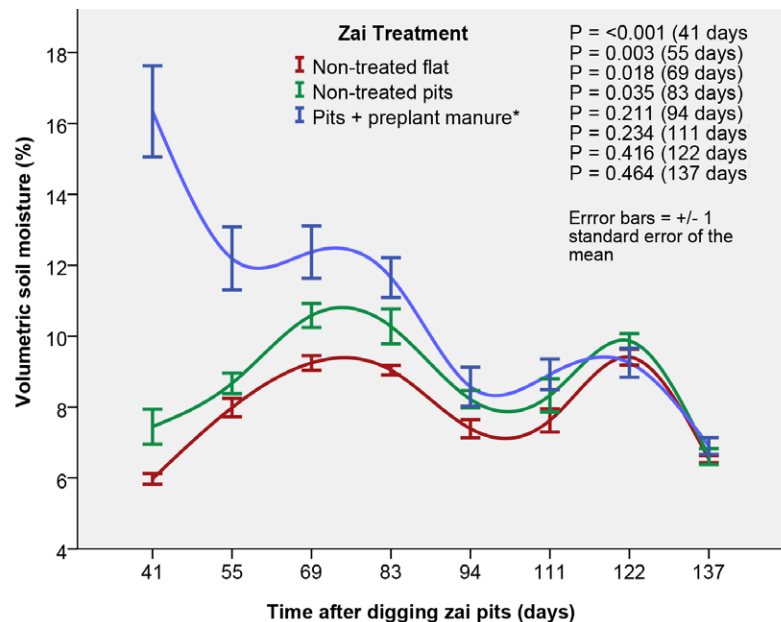
Microcatchments are most likely to be used in drought-prone areas. Soils in these areas will likely be very dry during parts of the growing season. During times of rainfall, however, the water collected in the microcatchments can significantly increase soil moisture. Plants that are best suited to these systems, therefore, are those that grow well with alternating dry and wet soil conditions.

Renner and Frasier (1995) mention that sorghum and pearl millet are excellent choices; sorghum can tolerate both drought and water-logging while millet is tolerant of drought but not water-logging.

Do microcatchment systems work best on certain soils?

Both soil depth and texture need to be considered (Renner and Frasier, 1995). Soil texture affects water runoff, infiltration and water holding capacity. In deep sand, for instance, infiltration can be so high that little water runs into the catchment basins and the water that does filter into the microcatchments quickly drains past the root zone. By contrast, high-clay soils may allow so little infiltration that water is easily lost to evaporation. The best soils allow for adequate water infiltration with good water-holding capacity. Note, however, that organic amendments play a significant role. Even with a soil that is nearly 90% sand, the addition of cattle manure significantly improved soil moisture within zai pits (Fig. 2).

Figure 2. Soil moisture on flat ground versus zai pits, from 41 to 137 days after the pits were dug during mid September of 2012. Data are the average of four replications and collected by ECHO staff in South Africa.



*Each manured zai pit received 400 grams of cattle manure applied at the time the pits were dug, 1 month before sorghum seeds were planted on 15 October 2012.

Is there an ideal slope for microcatchment systems?

Renner and Frasier (1995) suggest an ideal slope of 3% to 5%. Steep land results in swift-moving water runoff that may cause soil erosion. On very flat land, however, runoff is so low that much of the water infiltrates without running into the microcatchments. Even if soil conditions and slope preclude optimal water harvesting, microcatchments are still an effective means of concentrating fertilizer/organic-matter inputs around crop plants.

Zai pits: steps and function

Steps in establishing zai pits

The zai pits are dug during the dry season when labor constraints are minimal (Fig. 3). Each pit is 20-30 cm wide, 10-20 cm deep, with the soil from the pit thrown downhill to form a crescent-shaped dam. The spacing of pits within a row, as well as the space between rows of pits, varies between 60 and 100 cm. At the beginning of the rains, 200-600 g of dung or compost (two handfuls of organic matter are approximately 300 g) are added to the pits (Roose et al. 1993). Cow dung is collected from areas where cattle graze or gather (e.g., around water holes). Other organic materials added to the pits include straw residues of crops such as millet, sorghum or maize. The organic matter is mixed, in the bottom of the hole, with approximately 5 cm soil (Sawadogo, personal communication). Each pit is then sown with 8-12 millet or sorghum seeds.



Figure 3. Photos showing the marking of lines on the ground to indicate rows of zai pits (left), pits being dug (middle), and manure being placed into the pits (right). Photos courtesy of Hamado Sawadogo.

Kaboré and Reij (2004) shed light on the use of existing vs. new pits in subsequent years. They state that farmers dig pits in year one. Two to five years later, many farmers dig new pits in between existing pits. The new pits increase the amount of land that can be managed with a hoe or plough. On shallow or sandy soil that is not heavily encrusted, the pits are often maintained on a more or less permanent basis. When using the same pits year after year, the soil/debris that fills up the pits over time is cleared to prepare for planting each growing season.

Functions of the pits

Harvest rainwater

The small pits act as microcatchments that collect water and sediment. The soil placed downhill from each pit enhances their water-harvesting function. The added organic material improves the infiltration and retention of water in the soil. The water-harvesting function of microcatchments helps to mitigate against periods of drought that occur frequently in semi-arid regions (Zougmore et al. 2004; Fatondji et al. 2006).

Zai pits in ECHO research plots in South Africa increased soil moisture above that with flat ground (Fig 2). This was especially true early in the season and in zai pits amended with cattle manure. With 87% of the soil being sand, the pits filled in over time. The decline in soil moisture over time during the growing season could have been caused by sand filling in over time, as well as less rainfall at the end than the beginning of the season. See EDN 121 for more detail.

Concentrate fertility

In addition to water-harvesting, the pits also concentrate fertility near the crop root zone. Wind- or runoff-driven debris, including leaf litter from nearby vegetation, is “caught” in the holes. Fertility gained from these sediments is

augmented by organic and/or mineral fertilizer added to the pits. Soil fertility and soil biology improve. Sawadogo et al. (2008) also found increases of carbon, nitrogen, phosphorus and pH in the composted zai pits in comparison to non-treated controls. Zombre (2006) noted increased biological activity with zai compared to bare soil.

Similarly, in ECHO research plots in South Africa, levels of nearly every nutrient were markedly higher in manured than non-treated zai pits (Table 1). At 9 weeks after planting sorghum in season two, as an indication microbial activity in cycling nitrogen, potential mineralized N increased from 0.8 µg N/g dry soil/week with no manure to 3.9 µg N/g dry soil/week with cattle manure added to the pits prior to planting. Increased turnover of nitrogen by soil microbes helps to reduce the time it takes for nitrogen in organic matter to become available for plant use.

Table 1. Effect of cattle manure application timing on soil pH and nutrients in zai pits. Soil was sampled at 0 and 9 weeks after planting sorghum on 15 October 2012. Data were taken by ECHO staff in South Africa.

Manure*	Soil nutrient levels (mg/kg)									
	pH	NO ₃ ⁻	P	K	Ca	Mg	S	Fe	Mn	Zn
0 weeks after planting										
None	5.83 c	5 b	32 c	63 c	230 c	42 c	3 c	4 c	3 c	4 c
Preplant	7.17 a	21 a	181 a	423 a	549 a	205 a	25 a	29 a	15 a	17 a
Split	6.85 b	14 ab	103 b	235 b	337 b	112 b	10 b	17 b	10 b	10 b
P value**	<0.001	0.017	<0.001	<0.001	<0.001	<0.001	0.001	0.001	<0.001	0.001
9 weeks after planting										
None	5.86 c	7	24 c	29 c	221 b	41 c	2	5 c	3 c	4 c
Preplant	7.07 a	11	167 a	131 b	591 a	199 a	10	36 a	17 a	21 a
Split	6.93 b	12	130 b	257 a	486 a	139 b	17	31 b	14 b	15 b
P value**	<0.001	0.086	<0.001	<0.001	0.001	<0.001	0.079	<0.001	<0.001	<0.001

*Except for the non-treated controls, each zai pit (30 cm wide X 15 cm deep) received 400 g of cattle manure. Manure was applied preplant (400 g applied 1 month before planting) or split (200 g 1 month before and 2 months after planting).

**Data were averaged over four replicates. Within each column of means, at least two are statistically different from each other if the corresponding P value is ≤ 0.05. Within each column, means were separated via Duncan's multiple range test if P ≤ 0.05; any two values are statistically different if none of the letters following them are the same.

Role of termites

In the semi-arid tropics, termites are abundant. Their activity contributes significantly to the decomposition of organic amendments and the cycling of nutrients in the soil (Bachelier, 1978; ; Lobry De Bruyn and Conacher, 1990; Mando and Brussaard, 1999). It should be noted that not all termite species behave the same. It is the composting species of termites that are of benefit in zai holes. These termites are able to convert and enrich organic matter into good soil for the seedlings. However, the water harvesting and other benefits of this idea could be helpful even where there are no such termites.

Effect on crop yields

Substantial grain yield increases have been reported. As mentioned earlier, yield increases of 300–400 kg/ha in a year of low rainfall and as much as 1500 kg/ha in a year with good rainfall were observed by Kaboré and Reij, 2004. With rainfall amounts ranging from 359–449 mm, over three rainy seasons, sorghum yields in farmer's fields increased from 319–642 kg/ha without zai to 975–1600 kg/ha with zai (Sawadogo 2011).

Issues to be aware of:

Establishing the 20,000-25,000 holes/ha (depending on size and spacing of holes) requires significant labor. One source stated it takes about 300 hours/ha to dig the zai pits (Barro et al. 2005). Others have said it takes 450 hours/ha to dig the holes, plus another 250 hours/ha to fertilize them (Kaboré et al., 1994; Maatman et al. 1997). For this reason, the zai system is more realistic when undertaken by groups of farmers instead of individuals. Such physically demanding work is typically done by adult men working a few hours each day.

Weeds can be an issue if the organic inputs contain weed seeds. The area requiring weeding is lessened, somewhat, by the fact that water and nutrients are more concentrated in the pits than in the space between the pits, giving a competitive advantage to the crop plants as long as early weeding is done. When weeding, take care not to destroy the mound of soil on the downhill side of each pit (this would reduce the water-catchment function of the pit). Encourage composting of manure, as this can generate enough heat to kill many weed seeds.

Organic inputs must be gathered. It takes at least 4 tonnes (and up to 18 tonnes/ha depending on factors such as spacing and size of the holes) of manure to amend 1 ha of zai (INADES, 1993; Kaboré et al., 1994; Sawadogo, 1996). If composting (Fig 4) is done, the gathering of this material needs to be done several months before field preparation.



Figure 4. Compost pile for use in zai pits. Photo courtesy of Hamado Sawadogo.

HOW CAN THE ZAI SYSTEM BE OPTIMIZED?

Optimize the density and dimensions of the pits to suit specific crops.

As mentioned previously, traditional planting pits existed before zai. The principle innovation of zai, the result of experimentation in 1980, was to deepen the pits and add organic material to the bottoms (Reij et al., 2009). Farmers have continued to adapt pit dimensions to suit various crops and growing conditions. The zai system is now used to grow, not only cereal grains, but also tree and vegetable crops. Pit dimensions can be adjusted to accommodate the crop grown, as well as prevailing conditions. For example, pits can be enlarged to grow trees, to resist water erosion on steeply-sloped land, or to increase water-harvesting capacity. Observe what farmers are doing, try to understand underlying reasons for adaptations, and think creatively in terms of ways to further improve the system or modify it for specific cropping needs.

Optimize the nutrient content of fertility inputs placed in planting pits.

Adding small doses of mineral fertilizer is one way to do this. Scientists at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), since the early 1990's, have promoted the concept of microdosing by applying a bottle capful (6 grams) of ammonium nitrate fertilizer in each planting hole at the time seeds are sown (ICRISAT 2009). The approach uses only a fifth of recommended fertilizer rates (ICRISAT 2013). Smallholder farmers--about 25,000 of them--in west Africa have seen 44% to 120% increases in sorghum yields and 50% to 130% increases in family incomes (ICRISAT 2009). Microdoses of mineral fertilizer can be mixed with organic inputs in the planting holes, thus supplying plant-essential nutrients from the fertilizer while also building soil organic matter.

Not all farmers can afford mineral fertilizers. Another approach, is to enhance the fertility of applied manures. This can be done by gathering manure from areas where cattle have been confined (e.g., in corralled fields overnight), or at gathering points such as water holes (Tarawali, 1998). In these areas, manure and urine are more likely to be mixed, resulting in more nitrogen in the manure.

Also, ECHO research has shown that various, commonly found weeds are high in certain elements. For example, khaki bush (*Tagetes minuta*) biomass contained 2% potassium, which was nearly double the 1.2% potassium found in above-ground biomass of several legumes (jackbean, lablab, and pigeon pea). Adding fresh, green matter not only increased plant-essential nutrients in manure-based compost but also compost temperature. The amount of phosphorus in composted cow manure (collected from pasture land), for example, increased from 0.15% dry weight with no greens to 0.20% with dayflower (*Commelina benghalensis*) and 0.26% with khaki bush. Compost temperature increased from 36 °C with no greens added to as high as 49-50 °C with khaki bush and Terminalia

(*Terminalia sericea*) tree leaves, enough to kill most weed seeds that could be present in manure (Wiese et al., 1998). Be mindful that beneficial microbes are killed at temperatures over 70 °C; turn the pile as it reaches this threshold, and perhaps reduce the percentage of fresh, green plant matter in future compost piles.

Do not discount the value of cow dung collected from open pastures. A preliminary ECHO study has shown that composted pasture manure contained at least double the amount of bacteria and fungi as feedlot manure. In this study, the cow patties were crushed, moistened, and placed into piles that were then turned as needed (to avoid temperatures higher than 70 °C). Even if a farmer can only obtain 1 t/ha of manure or less, that material concentrated in planting basins can become an important means of inoculating the field with soil microorganisms that play a valuable role in maintaining the availability of soil nutrients for crop uptake. For more information on composting, and the value of compost as an inoculant, see EDN 96.

Combine use of the pits with other practices.

Stone bunds (Fig. 5) are used on 60% to 80% of cultivated land in Burkina Faso (Sawadogo 2011), often in combination with zai. Established along the contours of the land, the stone barriers slow water runoff to improve the water-catchment capacity of the zai pits. Rock bunds can be implemented with materials that are obtainable for most smallholder farmers. These include water levels [A-frames would also work] for marking contours and wheelbarrows or carts for moving rock.

Split applications of amendments can extend the time over which nutrients are made available to the crop. Split applications of fertility inputs involve the initial fertilizer application, prior to planting, followed by one or more applications later in the season. Fatondji et al. (2006) reported that the zai technique did not always improve millet yields beyond those obtained with surface-applied organic inputs. This was attributed, at least in part, to the loss of nutrients due to leaching, as influenced by the timing of organic amendment application. They observed that nutrient release to crop plants, for the most part, followed the rate of decomposition of the organic materials. With enhanced water-retention in the zai pits, much of the organic matter decomposition—and subsequent nutrient release—occurred while the crop plants were still quite young and, therefore, unable to completely utilize the added nutrients before some of them (e.g., nitrogen) were leached below the root zone. In one location, manure decomposed twice as quickly as millet stalks. Based on their findings, they suggested that farmers consider split applications of organic amendments.



Figure 5. Zai pits in combination with stone bunds. Photo by Chris Reij.

Research can play an important role in determining the best timing and placement of split applications of various organic amendments. In a zai study conducted by ECHO in South Africa, splitting the manure into two applications (1 month before and 2 months after planting) had the effect of extending the availability of some nutrients, most notably potassium (see 9 week after planting data in Table 1).

Intercropping of a legume with a cereal crop may be advantageous, provided there is adequate soil moisture for both crops, and the legume does not shade the cereal crop. In an ECHO zai trial in South Africa, combined grain yield of cowpea + sorghum was as much as three-fold higher than sorghum alone. In this trial, legume and sorghum plants were established in alternating rows of zai pits (Fig 6). This resulted in a row-rotation system in which, for instance, the rows of zai pits planted to sorghum in season 1 are planted to legumes in season 2. Thus, the principle of crop rotation is incorporated into the zai system while being able to grow a cereal grain every year; this is an important consideration in areas where traditional fallow periods are no longer an option due to the food requirements of an ever-increasing human population. A row-rotation system also increases the space between legume and cereal crop plants, decreasing the likelihood of competition for plant resources (e.g., light and soil moisture) in comparison to that which could occur with both the legume and the cereal crop sown in the same zai pit.

Edible legumes such as lablab and cowpea, when intercropped with a cereal grain, present farmers with more harvest options. Cowpea can provide a source of food, in many cases, before a sorghum crop is ready to harvest. Legume vine and root biomass can also augment animal manure as a means to build soil organic matter. In the study shown in Fig 6, just the above-ground portion of legumes added 3 t/ha of residue with cowpea and as much as 10 t/ha with lablab; lablab continued to grow well after both cowpea and sorghum were harvested, developing a

dense canopy by the onset of the dry season and producing a late-season bean harvest. Legume vines can also be a source of animal fodder, although their complete removal from the field reduces their soil improvement potential.



Figure 6. An ECHO zai experiment in South Africa with sorghum and legume plants grown in alternating rows of zai pits. Photo by Brandon Lingbeek

Look for ways to minimize labor

On hard, encrusted soils, digging zai pits may be easier than tilling an entire field. Nevertheless, considering the labor-intensive task of digging the pits, smallholder farmers could benefit significantly from any practice or technique that makes it easier and faster to dig the pits. Dr. Sawadogo, at ECHO's 2011 Annual Agriculture Conference, presented a novel approach of using animal draft power to dig perpendicular plow lines in the field (Fig 7). We at ECHO would welcome any other suggestions on how to minimize the labor requirement of the zai system.



Figure 7. Donkeys used as draft power to mechanize the digging of zai pits. Intersecting plow lines mark and form planting pits. Photo courtesy of Hamado Sawadogo.

OTHER SYSTEMS UTILIZING PLANTING BASINS

Negarim microcatchments are much larger than zai pits. They were developed for growing trees in dry areas receiving as little as 150 mm annual rainfall. This type of microcatchment is a diamond-shaped basin surrounded by earthen walls (bunds). A water infiltration pit is dug in the lowest corner of each basin (from www.fao.org/docrep/u3160e/u3160e07.htm).

Half-moon and V-shape microcatchments are similar but with differing shapes. They are used mostly in West Africa. As with the Nagarim system, they are often used for growing trees (or a combination of trees with crops). They can also be used for growing cereal crops (Fig 8). Half-moon basins are dug to form a half-circle that is about 4 m wide with 6.3 m² of cultivated area (Zougmore et al., 2003). The distance between each half-moon basin, within a row of basins (following the contour), is 2 m. Half-moons are used on up to 30,000 ha of land in northwestern Burkina Faso (Sawadogo 2011).



Figure 8. Millet growing in half-moon basins. Photo by Chris Reij.

Another conservation agriculture system utilizing the idea of planting micropits is called Foundations for Farming (FFF). Dug 15 cm (long) X 5-6 cm (deep), FFF-style planting stations are smaller than zai pits. As with the zai system, fertility inputs and seeds are placed into planting stations. Information sources on water harvesting and basin-based cropping systems are listed below:

- Soil Ecology and Restoration Group: www.sci.sdsu.edu/SERG/techniques/microcatch.pdf This link contains information and photos on several types of water catchment systems.
- Water Harvesting: A Manual for the Design and Construction of Water Harvesting Schemes for Plant Production by W. Critchley and K Siegert: www.samsamwater.com/library/Water_harvesting_-_Critchley.pdf This publication gives extensive background and information on water harvesting.
- Runoff Farming by D. Prinz and A. Malik: www.plantstress.com/Articles/drought_m/runoff_farming.pdf This pdf contains a wealth of information and diagrams illustrating both macro- and micro water harvesting techniques.
- Water Harvesting: www.fao.org/docrep/u3160e/u3160e03.htm#TopOfPage This FAO publication presents design and layout information for a number of water catchment techniques.
- Foundations for Farming: <http://wwwFOUNDATIONSforfarming.org/> and <http://www.farming-gods-way.org/>

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