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Low Input Agricultural Systems Based on Cactus Pear for Subtropical Semiarid Environments

Candelario Mondragon Jacobo

The biological productivity of semiarid lands is typically restricted by the amount of rain. Agricultural systems relying in C4 and C3 plants are present throughout the world. In Central Mexico maize and dry beans have been the cornerstones for centuries. Some CAM plants can provide an opportunity to improve the productivity in these regions, due to their higher water use efficiency. According to Nobel (1988), the water use efficiency, averaged over a season, in mmol CO_2 per mol H_2O typically is 1.0 to 1.5 for C3 plants, 2 to 3 for C4 plants, and 4 to 10 for CAM plants. Moreover, certain irrigated CAM plants can have an annual productivity that exceeds that of nearly all cultivated C3 and C4 species. In particular, *Opuntia amychlaea* Tenore and *O. ficus-indica* Mill. can produce annual aboveground yields of at least 45 t/ha. The inclusion of cactus pear (*Opuntia* spp. Cactaceae), a perennial crop plant for fruit, vegetable and/or forage production can enhance sustainability in the long term, however its inception as a sole crop represents an important financial drain to the typical farmer of this regions.

With the idea of improving overall productivity several combinations of cactus pear and annual crops have been attempted. Annual crops represent competition for the cactus pear both below and aboveground. Crops which have a low canopy planted in rows and are short lived could provide less competition for the perennial cactus pear. On the contrary dense tall crops can cripple cactus pear growth and yield, because it is very sensitive to shading in the first two years. However growing cactus pear alone produces no income before the first commercial harvest is obtained.

Mixed cropping has been reported as an efficient practice to improve overall yield and reduce risk. The combination of plants which have different morphology, depending on different soil depths and exploiting several aboveground strata allow for a more effective tapping of the resources (Cannell et al. 1996).

Cactus pear can be grown in dense planting layouts of up to 66,000 plants/ha under rainfed conditions. It also tolerates heavy and repeated pruning when managed as a perennial shrub, producing tender pads which can be consumed as a vegetable. Under restrictive moisture environments the last flush of cladodes can be allowed to mature, collected, and used as a survival forage for livestock during the dry winter season.

THE REGION

The North of Guanajuato Research Station (Instituto Nacional de Investigaciones Forestales y Agropecuarias, Mexico) is located in Central Mexico at the Southern tip of the Chihuahua–Sonoran desert 21°N, characterized for its limitative rainfall pattern, an average of 548±112 mm a year, shallow sandy-clay soils (less than 40 cm), the traditional cultivation of corn and beans, and the intensive use of overgrazed natural pastureland.

The presence of a few heavy rains followed by numerous events of short duration and low intensity is typical of the Northern semiarid areas of the Mexico. Fig. 1 presents the rainfall recorded during 1990 and 1991 years in which we conducted the experiments on multiple cropping.

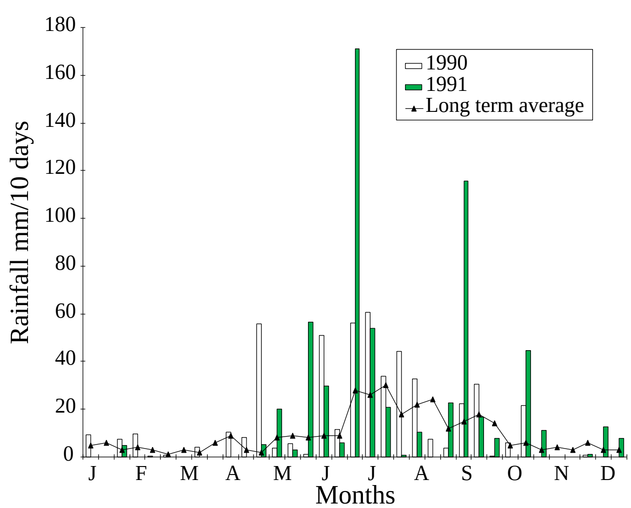

Fig. 1. Precipitation pattern on the experimental site.

Water Harvesting

Intelligent use of rainfall is a prerequisite for successful farming in semiarid areas. Rainwater should be handled in such a way that at least the water that falls upon the plot of interest is fully kept in the soil profile.

More sophisticated systems, but also more expensive, can be designed preparing runoff collection and storage areas. Fig. 2 shows a water harvesting system chosen for its simplicity for our experiments and suitable for farmers with limited financial resources. The land is plowed at the end of winter and "microcatchments" are constructed by means of a simple mechanical device attached to the small tractor (60–80 HP) common in the area. Water is impounded allowing its penetration into the soil in order to be later used by the annual crop. The actual cost of this practice is about $30/ha, it ensures an effective intercrop germination, a better control of weeds and higher response to fertilizer, therefore higher yields of both the perennial and the annual crop.

Multiple Cropping of Annuals and Cactus Pear

The water needs for cactus pear cultivation are satisfied by 500–600 mm of annual rainfall (Pimienta 1990). The distribution of the rainfall will determine the possibility of mixed cropping.

A fully mature cactus pear plant is expected to take up a circular area measuring anywhere from 2 to 4 m in diameter depending upon the cultivar and crop management. A typical planting layout will have rows 4 to 7 m apart and 2 to 4 m in between plants. Plants will need from 5 to 6 years to reach full size and yield. In the first year the cactus plant will produce a single set of pads (in wet years it can produce up to two) which does not interfere with the growth or the operations associated with the field crops. Beyond the second year the plant will cover a larger area, reducing the number of rows that can be interplanted and interfering with operations, spiny cultivars such as 'Cristalina' which was used in the experiment pose special difficulties. As all orchards are started from small vegetative pieces (either single or double pads) there will be some temporary empty space in between rows. In mechanized orchards pruning is considered a regular practice to get a clear space in which machinery can transit. A secondary advantage of the mixed crop systems is that better weed control is accomplished. Controlling weeds on the annual crop, either mechanically or with herbicides, automatically reduces competition for the cactus pear, as well. This is important considering that in practice the commercial orchards in Mexico are left almost abandoned during the juvenile stage of the crop.

In 1990 a new cactus pear orchard was planted in a 4 × 3 m layout using the native greenish pulp cultivar 'Cristalina' (Mondragon and Perez 1996). Maize, dry beans, and forage sorghum were planted in between rows on top of the furrows in late May. Planting densities were 40,000, 100,000 and 60,000 plants/ha for these row crops. Four rows 85 cm apart were placed in between the cactus plants. Small cereals and canola (Fig. 3) were broadcasted on 3.5 m of the empty space using early cultivars of all the crops (100–120 days): 'Cerro Prieto' barley, 'BN-00' canola (*Brassica napus*), 'VS-201' maize, and 'FMBajio' and 'Canario' dry beans. For cereals and canola 120 and 6 kg of seed/ha respectively, were planted and 25N–20P–0K fertilizer was applied simultaneously, with an additional 25 units of N fertilizer applied 45 days later. Weeds were controlled either mechanically for row crops or by herbicides in cereals. The additional cost for having an intercrop varied according to the crop. Small cereals represented an investment of US $185/ha whereas for row crops $207/ha were needed.

Agronomic Performance of Annual Crops

In 1990 the site received 497 mm of total rain, slightly below the long term average. In 1991 there was 625 mm, 14% above average. Both years were characterized by the presence of a single heavy rainfall (55 and 56 mm in less than an hour) early in the season which allowed the collection and storage of water in the soil profile used for germination by the annual crops.

Yields (Table 1) were comparable to those observed in the region for these crops after adjusting for the area taken up by the cactus pear. In the second year all the crops had reduced yields which ranged from 30% for wheat to 43% for dry beans,

Fig. 2. Water harvesting system. Two months old cactus pear orchard with "microcatchments" after a heavy rain (45 mm) early in the rainy season in Northern Guanajuato, Mexico.

Fig. 3. Canola and rye intercropped in a two year old cactus pear orchard under rainfed conditions.

Table 1. Performance of annual crops planted in between rows of a cactus pear orchard.

Annual crop	1990 yield (kg/ha)	1991 yield (kg/ha)	1st year net income (US$/ha)
Wheat	1354	947	-50
Canola (BN-00)	480	392	-147
Barley (Cerro Prieto)	872	--	-115
Barley + canola	564 + 294	376 +110	-99
Foxtail millet	12364	--	-2
Maize (VS-201)	936	--	-136
Dry beans (Canario)[z]	439	250	+10
Dry beans (FMBajio)[y]	1337	426	+99
Sorghum (forage)	17,608	--	+54

[z]110–130 days to maturity.
[y]90–110 days to maturity.

presumably attributed to the competition effects of the cactus pear. Foxtail millet and forage sorghum are unknown in the area but the yields observed were encouraging considering the climatic limitations, additional difficulties for these potential crops are their acceptability by ranchers which in turn will define their adoption in the market. The dry bean 'FMBajio' performed better than 'Canario' due to its longer flowering season with more than one flush of flowers.

An economic analysis indicated that none of the cereals produced enough to cover expenses, a fairly common situation in the area for all the traditional rainfed crops, due to the low prices usually obtained from these grains in a government controlled market. The best option is dry beans which have a steady market as a result of their status of staple grain for the Mexican population. Both cultivars were associated with positive net profits, but 'FMBajio' is a favorite and commands a higher price than 'Canario', US $0.90/kg vs $0.60/kg.

Growth of the cactus pear plant reduced the plowable area about 30% in the second year and planted only two rows of dry beans and half of the original area with some cereals. The cost of cultivation and yields were also diminished by approximately 60%. According to our data, only high value crops such as dry beans are a sound alternative for two consecutive years. Overall they represented less competition for the perennial crop which is associated with nonsignificant effects on fruit yield.

Effects of Intercropping on Yield of the First Commercial Harvest of Cactus Pear

Intercropping in general reduced the yield of cactus pear from 19% to 176% (Table 2). The effect can be attributed to competition for light. Shaded plants tend to grow slower and had a lower number of new buds. Small cereals which are planted in dense stands, grow faster and closer to the cactus pads, had the most significant effect. The lowest loss, 19.1% was observed in dry beans probably due to its small size and short growing period.

Intensive Production of Mature Cactus Pear Pads for Forage

Spineless cactus pear were planted on raised broadbeds 150 cm wide (Fig. 4). Year old cuttings were obtained from mature plants. Before planting they are placed in a shady and dry spot for 2–4 weeks to pro-

Table 2. Effect of intercropping on first commercial harvest (1995) of cactus pear.

Intercrop	Fruit yield (kg/ha)	Gross income ($/ha)	Income difference[z] (%)
Barley	1684	69	-177
Canola	2000	82	-149
Barley + canola	2438	122	-0.6
Foxtail hay	2221	91	-34
Dry beans (FMBajio)	2517	102	-19
Maize	1771	68	-80
Cactus pear (microcatchments, no irrigation)	3503	175	+44
Cactus pear (limited irrigation, no microcatchments)	5835	285	+233
Cactus pear (no microcatchments, no irrigation)	2982	122	--

[z]Compared to rainfed cactus pear as a sole crop.

Fig. 4. Intensive production of cactus pear pads (cv. Seleccion Pabellon) for vegetable or forage on raised broadbeds.

mote wound suberization and partial dehydration. Cladodes are planted on a 40 × 30 cm layout (up to 66,000 pads/ha can be used depending upon the space between broadbeds), burying the cladode halfway into the ground. On low sloped land microcatchments can be created in the ditches between beds at regular distances to promote even distribution of rain. Response to manure and fertilizers have been reported, for our location a maximum 6 tonnes of manure and 60 kg/ha N and 16 kg/ha P (on annual basis) can be used for rainfed conditions. A residual effect of manure, up to three years has also been observed.

Supplementary irrigation greatly increase yields, and therefore higher dosages of manure and fertilizers can be used. Up to 90 kg N and 16 kg P/ha fertilizer plus 9 t/ha of dry manure, assuming that additional 30 cm of water are applied throughout the year, as needed, can be applied. The plants are maintained as bushy perennials, keeping only two to three pads per plant in the second story. The plant responds to pruning during the wet season, quickly producing new shoots. Depending on the length of the rainy season up to two harvests of tender pads suitable for human consumption as a vegetable are possible, leaving the third flush to ripen for forage. Mature pads can be harvested at the end of the season (October through December), and stored in a dry and shady location for later use. The pads can be stacked on piles 30–40 cm high, or placed in rows, they can keep their appearance and palatability for up to six months, provided that they are flipped over one or two times to avoid rooting. The best results are obtained by selecting a spot near to the farm household, which reduces the damage by wild rodents. In our trials yields of fresh pads ranged from 43 t/ha obtained with the control to 53 t/ha associated to the fertilized treatment.

This planting layout has been adopted in Central Mexico to produce vegetable cactus pear. It is labor intensive because the tender shoots are collected at least once a week. It is practiced in small plots (0.5 ha). However, if adapted for forage production the need for labor is greatly reduced because the mature pads are to be collected in a single harvest. It has been estimated that 1 ha of this system could cost up to $4600, 95% attributed to the cost of the planting stock.

The initial cost of planting can be greatly reduced if the planting stock is produced on site. This requires the acquisition of a fraction of the total needed to establish a nursery which in turn will provide for the needs of the commercial plantation. The size of the nursery will depend on the area and the timeframe of the operation for forage. Calculation is done considering that each plant will produce at least 3 pads per season, or more if it is irrigated and fertilized.

In the second year of the commercial planting the costs are minimal, fertilization and labor for harvest. The perennial nature of the plant and their tolerance for continuous pruning allows the system to be considered a long term investment. There are commercial as well as experimental plots in Mexico which have been under continuous cultivation for more than ten years. Considering a minimum price of US $30/t of fresh pads, up to 28% of the cost of planting can be recovered in the first year for the cheapest option, that is using no fertilizer. Some of advantages of the system include low maintenance, continuous supply of fresh animal forage during the dry season, and easy storage.

Grassland and Cactus Pear Association

Combining two perennials in semiarid conditions in the same piece of land does not seem to be a sound alternative. However, under natural conditions the association of xerophyte shrub vegetation, grasses, and cacti form successful communities. Both are perennial plants which are unaffected by long dry spells and can grow quickly after a heavy rain, which make them a good alternative for areas of scant rainfall pattern.

We designed a system in which the empty space among cactus pear rows was occupied by buffel grass (*Cenchrus ciliaris*), a native perennial grass (Fig. 5). In the first three years the grass was planted from seed and allowed to grow without any disturbance. After the prairie was fully established the orchard was laid out. Minimal perturbation of the grass canopy was accomplished by a subsoiler which opened a ditch just wide enough to place the cactus pear pads. Loosening the soil with this tool also allowed better establishment of the cactus pear crop. The pastureland has been managed according to the following criteria: in "good" years (with rains early in the season) the grass cover can be expected to produce a single harvest of fresh grass. The grass is clipped as soon as it reaches 10–20% of flowering and hay bales can be prepared to be used at will.

Fig. 5. One year old cactus pear orchard on a induced pastureland. The empty space among cactus pear rows is occupied by buffel grass (*Cenchrus ciliaris*) a perennial grass.

The time left at the end of the season allows the plant to recover and accumulate reserves for the next dry season. In "bad" years no harvest of the grass is obtained. The pastureland is left undisturbed, the grass flowers and produces seed. Natural dehiscence of the grass spikes insures reseeding of the pastureland maintaining the vegetative cover.

Additional advantages of this system are that dicot weeds are reduced due to the cyclic clipping which normally is done before they reach maturity, thus preventing seed formation. If machinery to harvest and preserve grass as a hay is not available direct rotational grazing can be an alternative. The yield of grass does not have economic value, due to the availability of other feedstuff but it has possibilities for a complex system with limited sheep grazing. Additionally, its ecological value is high because the area has been subjected to overgrazing and is prone to eolic erosion.

CONCLUSIONS

Intercropping decisions are dependent on factors such as economic value and potential on-farm utilization of crop intercrop. Small cereals are not favored because of low prices, but maize and dry beans can be readily utilized and marketed because they are the staple food of the Mexican population. Dry beans can be also considered a cash crop due to the demand and steady high price (up to $1/kg depending on the cultivar). They represent the top choice to include in this system. Cultivars with short plant type and extended flowering such as 'FMBajio' produced better results on these regions with scant rainfall.

The production of mature cactus pear pads for forage is best suited for an integrated system in which the forage will be utilized in a dairy or beef production operation in those locations in which traditional forages are not readily available. Intensive utilization of wild populations of cactus pear is routine in Northern Mexico (Dela Cruz 1994); they are over exploited and left to recover without human intervention leading to ecological devastation. The total cost of the cactus pear crop can be reduced if a small nursery is prepared in advance. The inception of on farm production systems of cactus pear could alleviate the pressure on natural populations. The combination of pasture and fruit production system is an example of complementation of two perennial plants exploiting different strata. Both species endure drought and are flexible in their water needs. Integrating small ruminants to use the grass on site may improve the benefits.

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