Field Evaluations of Agave in Arizona

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Abstract

Four agave species (*Agave americana* L., *A. murpheyi* F. Gibson, *A. palmeri* Engelm., and A. *parryi Engelm.)* have been evaluated in a four-year study conducted at four Arizona field locations. Survival data, growth rates, approximate water requirements, and insect predation have been analyzed under Arizona field conditions. All species showed good survival at the Marana location, with *Agave americana* exhibiting the most rapid growth increment, averaging fresh weight gains of 70 to 110 kg per plant in the four-year period, with minimal supplemental irrigation. Analysis of carbohydrates in these plants showed an average 50% sugars on a dry weight basis. Projected growth parameters and biomass accumulation data are presented.

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Introduction

Increasing economic pressures on the irrigated agriculture of the Southwest necessitate the evaluation of alternative agricultural technologies. One approach to dealing with the increasing cost of water, reduced availability of prime farm land, and depressed crop prices is to explore the usage of existing arid land crops which require minimum agriculture inputs, but which nevertheless produce an acceptable return to the farmer, and which keep agricultural land in production. One such potential crop is agave. Cultivated by man for many centuries, agave has proven to be an extremely adaptable crop plant, one which is presently grown in nearly every agricultural area of the world where climatic extremes are not limiting. A rather large compendium of information on the culture of agave for food, fiber, and pharmaceuticals now exists. Although Arizona has the largest number of native agave species of any state, with a single exception, this author can find no record of current agave cultivation in the state. In neighboring Sonora, Mexico, native stands of agave have been exploited for the production of alcoholic beverages for many years. Given the widespread occurrence of native populations of agave in Arizona, and their role as an economic crop in the adjacent northern states of Mexico, it seemed reasonable to investigate the potential of agave in Arizona agriculture.

Experimental Approach and Design

Four agave species were selected for the initial phases of this study, based upon three criteria: 1) the ready availability of planting stock; 2) the anticipated adaptation of the species to the climate of the farm sites available; and 3) a history of use of the species for alcohol production. Four locations were chosen based upon proximity to existing agricultural areas in the southern part of Arizona or to approximate rangeland conditions. Two sites were situated on University farms, where supplemental irrigation was available; two were dryland, desert locations. *Agave americana* was evaluated in a fifth location, at the Campus Agricultural Center in Tucson. Table 1 presents a summary of the locations, their elevation and the size of the present agave fields. These locations are fairly representative of the mid to high elevation agricultural areas in the southeastern Arizona counties.

An evaluation of the agave species grown at each location in the course of these studies and an overall assessment of their crop potential are given in Table 2. Six agave species, as well as the closely related *Dasylirion wheeleri* S. Wats. (Desert Spoon) have been evaluated as row crops. General evaluations to date rate *Agave americana* and its variants as the best adapted species, judged by survival and growth data. *Agave murpheyi* also looks extremely promising at some locales.

Table 3 illustrates the observed increase in fresh weights of *Agave americana* at three field locations. In a second planting at Tucson, *A. americana* plants averaging 20 kg or more each were lost when a section of the campus farm adjacent to the river was washed away. The effect of favorable climatic conditions as well as supplemental irrigation is clearly evident in the growth increments observed by comparing the Marana location to the Page Ranch environment. Both plots were established without irrigation, and

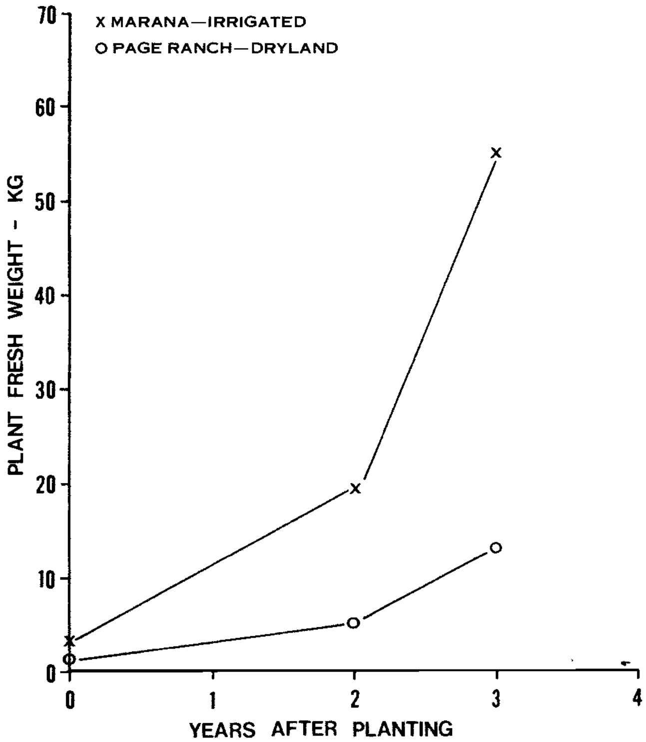

Figure 1. *Relative biomass accumulation of* Agave americana *cultivated at two Arizona locations, Marana and Page Ranch.*

the Marana plot received only infrequent unscheduled irrigation due to accidental overflow from adjacent borders. Figure 1 points out the rapid increase in agave biomass accumulation by the third year following transplanting at Marana. Nondestructive growth measurements made at the end of the fourth year of growth (November, 1984) indicate that many of these plants exceeded 90 kg. Figure 2 shows the recent appearance of a portion of this field.

Agaves were established by transplanting at the Page Ranch Agricultural Center in a grid pattern 4.3 meters apart with minimum disturbance to the desert surroundings. The purpose of this strategy was two-fold. First, it was important to evaluate the performance of these plants in a high elevation rangeland environment protected from grazing. Second, such a planting would allow testing the theory that the agave would offer a protected site for germination and establishment of native range grasses and other species. This premise was based upon observations by the author that the protected area around the base of the agaves encouraged the establishment of grasses in an otherwise unsuitable environment. Continued observations at Page Ranch following the introduction of cattle onto the ranch supported these observations, although no definitive data by a range specialist have been gathered yet. Clearly, the several agave species tested show promise as adaptable crop plants for several agricultural areas in southern Arizona. Figure 3 shows the recent appearance of part of this field.

Another principal agave test was initiated at the Safford Agricultural Center, with the plants established in three adjacent plots, each irrigated infrequently with water at three distinct salinity levels. Mortality data and growth data will be collected in November, 1985, but it is clear from viewing the fields that small (0.5 kg) transplants are markedly stunted by high salinity levels (approx. -18 bars).

Table 1. *Agave americana* L. evaluated under cultivation in Arizona.

Field Location	Elevation	Hectares Presently Cultivated	Original Planting Established
Marana Agricultural Center (I)	1900 Ft (580m)	0.9	1980
Avra Valley (D)	2000 Ft (610m)	0.7	1980
Tucson (2) (I)	2500 Ft (760m)	0.1	1979, 1983
Page Ranch Agricultural Center (D)	3800 Ft (1160 m)	0.8	1981
Safford Agricultural Center (I)	2900 Ft (885m)	0.2	1980

I = irrigated farmland; D = desert, abandoned farmland or pasture.

Table 2. *Agave* species evaluated under cultivation in Arizona.

Field Location	Species	Evaluation
Marana (with supplemental irrigation)	*Agave palmeri*	Slow growth
	*Agave murpheyi**	Rapid growth, prone to waterlogging
	Agave parryi	Extremely slow growth
	Agave weberi	Rapid growth, well adapted
	Agave fourcroydes	Failed to survive winter
	Agave americana	Rapid growth, well adapted, many off-shoots
Safford (two irrigations at each of three salinity levels	*Agave americana*	Rapid growth, some off-shoots
	Agave palmeri	Slow growth, high mortality at high salinity level
	Agave murpheyi	Slow growth and high mortality at high salinity level
	Dasylirion wheeleri	Very rapid growth, relatively little effect of high salinity
Page Ranch	*Agave americana*	Rapid growth, few off-shoots
	Agave palmeri	Slow growth, some mortality
	Agave murpheyi	Slow growth, high mortality

*Several plants already blooming at this location.

Table 3. Relative growth rate of *Agave americana* at three field locations.[1]

Location	Fresh Weight in Kilograms At Planting	Year 1	Year 2	Year 3
Marana	1.2-5	——	16-23	31-80[2]
Page Ranch	0.2-1.2	——	4-5	11-14
Tucson	0.1	——	1.2	3.7

[1]Final data are on a fresh weight basis, and include the majority of the root mass.
[2]These plants produced several dozen offshoots averaging over a kilogram each during the three-year period. Biomass of these offshoots was excluded from the calculated weights of these plants.

Table 4. Soluble solids in leaf homogenates of agave.

Species	Soluble Solids
Agave americana	7-9%
Agave palmeri	8-12%
Agave parryi	12-18%
Agave schottii	18-22%
Agave murpheyi	14-16%

Sections were cut from mature leaves of nonflowering specimens approximately 15 cm from the leaf base. Sap was expressed by crushing the leaf with a mallet. A series of sap samples were collected dropwise in micropipettes, and soluble solids (sugars, glycosides, amino acids, organic acids) were determined by refractometry. Specimens were collected in early March.

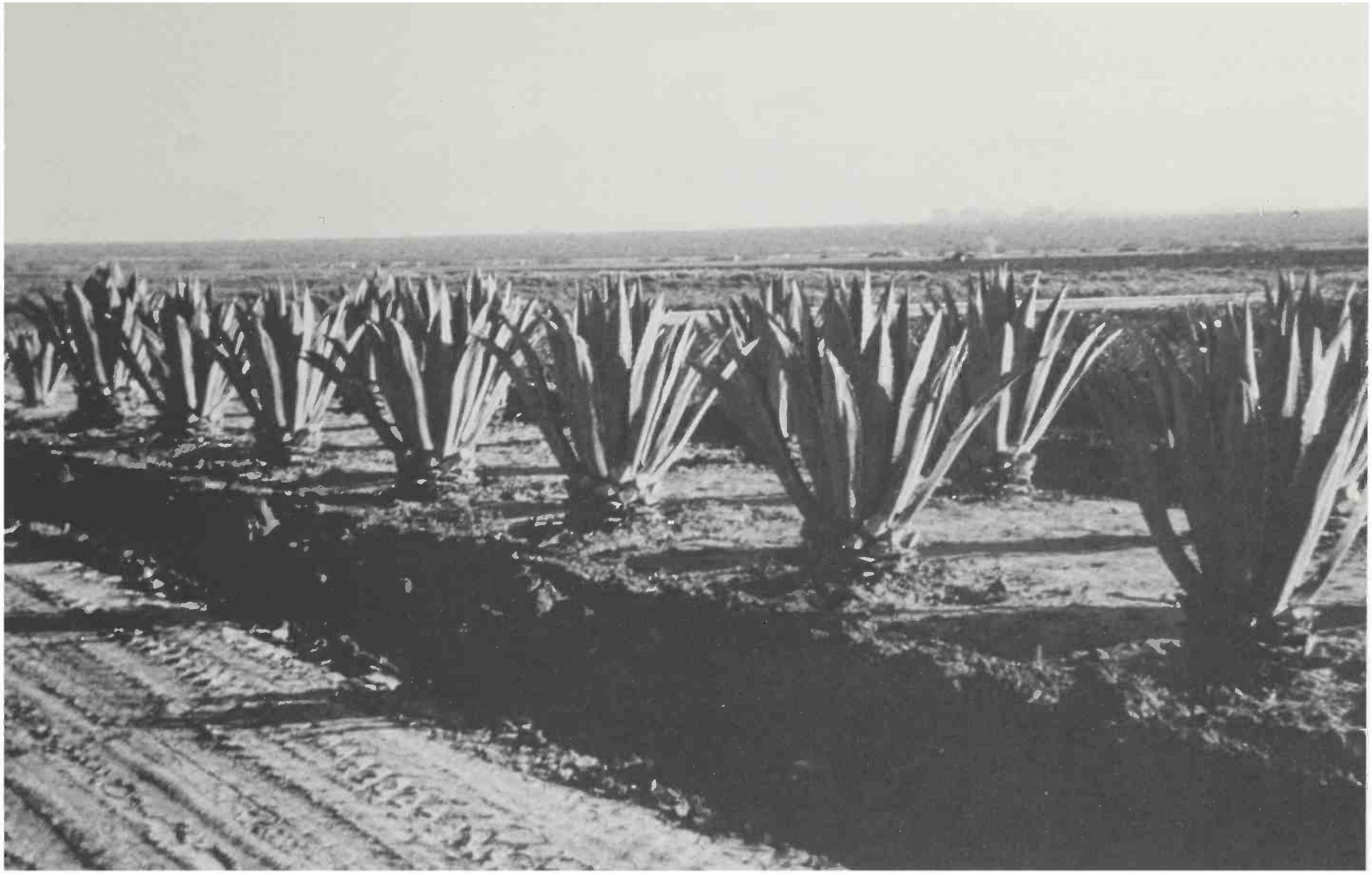

Figure 2. *A view of* Agave americana *four-year-old transplants at Marana, Arizona.*

Physiological Aspects of Field-grown Agave

Agaves occupy a rather unique ecological niche in that they are semi-succulents whose prime drought-avoidance strategy is Crassulacean acid metabolism (CAM). CAM plants avoid excessive transpirational water loss at high temperatures by stomatal closure. Additionally, they possess an extremely thick waxy cuticle (plants may average 0.2% wax on a dry weight basis). Winter (1974), Nobel and Hartsock (1979), and Ehrler (1982) have discussed these survival strategies of agave from the standpoint of water relations. The evident proliferation of agave species in the Arizona desert environment attests to the effective adaptation of agave (Gentry, 1982).

At the initiation of this study, emphasis was placed on the potential of agave for the production of ethanol for gasohol (Meckhof *et al.*, 1980). Ethanol production is a well-documented attribute of many agave species, and the literature of agave abounds with descriptions of the fermentative products of this plant (Gentry, 1972, 1982; De Barrios, 1971). Consequently one of the physiological traits of interest was the production of sugars by agaves under cultivation. Table 4 presents data illustrating the soluble solids in the leaves of several agave species. Refractometry provides a rapid, accurate, in the field analysis of agave sugar content, even though steroidal glycosides make a contribution to the reading. When compared to actual sugar percentages determined colorimetrically, shown in Table 5, the refractometer readings for *Agave americana* specimens fall within about 2 to 3% of actual sugar content. A sugar content of 50% on a dry weight basis is extremely high, and commends agave as an alternative source of ethanol in a suitable economic situation.

Agaves represent a world-wide source of steroids which find a market in the pharmaceutical industry. As byproducts of sisal fiber production, agave steroidal sapogenins account for about 6% of the world supply of precursors for corticosteroid synthesis (Blunden *et al.*, 1975; Bokirko and Kintya, 1975). These chemicals also find use as animal feed supplements (Jones and Conner, 1918; McKeen and Haas, 1964); and even show promise as anti-cancer agents (Bianchi and Cole, 1969). A domestic industry presently exists whereby steroids extracted from native yucca stands in the Mohave desert supply a commercial steroidal sapogenin extract. Industrial tests of agave steroids indicate that they have considerable promise as a substitute for yucca harvested from the wild. Table 6 gives a projection of the economic potential of agaves cultivated in Arizona judged by their steroid content. As a minimal input crop on marginal farmland in the mid-elevation areas, with limited or poor quality water, agave looks opportune. Johnson (1977) has briefly discussed some of the potential uses of agave in arid land agriculture.

Pests and Predators

Although the prospects for a place for agave in Arizona agriculture seem favorable, especially if breeders can profit from incorporation of hybrid materials produced locally or obtained from breeding programs worldwide (Wienk and van S'chendellaan, 1976); and if mechanization can be adapted to agave culture and harvesting, several problems do exist. First among these is the predation by agave weevils (Vauri,

Figure 3. *A view of* Agave americana *three-year-old transplants at Page Ranch, Arizona.*

Table 5. Sugar content of leaves and underground stems of *Agave americana*.

	Moisture Content (%)	Sugar Content (%)	
		(dry weight basis)	(fresh weight basis)
Leaves	89.5	50.7	5.35
Stems	85.5	48.7	7.05

Data are means of duplicate determinations on each sample. Percent sugar analyzed by the anthrone test with glucose as standard and expressed on a plant weight basis. Analysis courtesy of Dr. Joseph Scheerens, Department of Plant Sciences.

Table 6. Projected biomass accumulation of *Agave americana* under supplemental irrigation at Marana, Arizona.

Average estimated biomass per plant in kg[1] (Four-year production cycle)	95
Plants per hectare (Plants spaced 2.2 meters apart on 3-meter-wide beds)	1,650
Total biomass accumulated per hectare in kg	156,750
Water use: Rainfall plus some supplemental irrigation[2] (in mm)	250
Value of crop (for steroidal sapogenins at $50/ton[3]	$3,500

[1]Assumes initial offshoot transplants averaged 5 kg or greater weight.

[2]In October, 1983, the Santa Cruz river flooded the Marana Agricultural Center, leaving standing water in the field for several days. The actual water "applied" was impossible to calculate, but undoubtedly contributed to the growth of plants before representative plants were harvested in November, 1983.

[3]Price at farm, calculated on the basis of 10% soluble solids. (Personal communication, R. C. Fudge and D. T. Williams, 1984.)

Table 7. Projected probable uses of agave cropped in Arizona.

1. Production of steroidal sapogenins (for corticosteroid synthesis and odor control)
2. Production of ethanol (following conversion and fermentation of sugars)
3. Fiber production
4. Animal ration supplements
5. Erosion control and soil stabilization
6. Plant micro-climate for range grass reestablishment under grazing pressure
7. Ornamental for landscape use (application of biotechnology via tissue culture to create favorable variants)

1971) which are endemic to the Tucson basin (Waring, 1981). These insects can rapidly destroy mature agaves; but can be readily controlled by systemic insecticides. Although the Avra Valley planting was infested by agave weevils introduced from a transplant with unnoticed grubs, complete biological control of the weevil was achieved by black widow spiders, which evidently moved to the spiral-leaved habitat of the agave field from an adjacent cotton gin. Gophers have also been found to kill agaves of high sugar content by burrowing from beneath the plant and chewing out the "heart" of the plant.

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Conclusions

Probably the greatest advantage of agave as a potential agricultural crop in Arizona is the multiplicity of uses for which it might be cultivated. A number of products from agave are illustrated in Table 7. At present the economic return from sale of steroidal sapogenins is sufficient to encourage establishment of plantations and the possibility of additional income from the remainder of the plant following extraction exists. Likewise, the climate in some agricultural areas of southern Arizona appears ideal for the cultivation of the Tequila Agave (*Agave tequilana* Weber) which would support the establishment of an industry for the distillation and sale of spirits derived from agave fermentation. The increasing sales of tequila worldwide suggest the success of such an enterprise.

With millions of acres in the Southwest suitable for agave plantations an enormous potential production is possible. Agave, by reason of its shallow root system and perennial growth habit, should act to stabilize desert soils and control erosion during the several years of growth before harvest. The agronomic attributes of agave make it a plant of choice for effective biological energy conversion in the arid Southwest.

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A Demographic Study of Maguey

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half the offsets showed at least one type of damage. But only 12% of the within-clump protected offsets were damaged, compared with over 80% for clump-edge exposed offsets. Damages due to trampling, predation, and stress/pathogens/insects were all significantly lower for protected offsets. Offsets in within-clump exposed positions generally suffered damage similar to that suffered in clump-edge semi-protected positions.

Data on soil compaction (Table 1) show clearly that a major soil difference between protected positions in agave clumps and open degraded grassland is at least a fourfold increase in resistance to penetration in the open grassland soil. Resistance to penetration decreased progressively in the following order: open grassland, exposed edges, semi-protected edges, exposed within-clump positions, protected within-clump positions. This pattern helps to explain the increase in stress-related damage to offsets outside the immediate protection of other agaves. There was also a mean 10% decrease in soil depth in open grassland when compared to adjacent agave clumps, irrespective of absolute depth. These differences in soil depth and degree of compaction appear to be due to the differential effects of overgrazing on open grassland versus agave-protected soil. Clump area may be restricted both by direct biotic interactions (trampling and predation) at edges and by soil heterogeneity that itself seems to have been induced by overgrazing.

In order to evaluate plant size at flowering as an index of site deterioration, we examined three size class distributions. Figure 5a shows the distribution for plants in the nondestructively sampled clumps which reached sexual maturity during the study, while Figure 5b is based on the dead plants in the same clumps. Both show a preponderance of the largest size classes, and the two are statistically not distinguishable. This suggests that, at least in the relatively favorable environment of the nondestructively sampled area, there has been no major change in plant size at flowering within the last ten years (the estimated persistence period for dead plant remains). In contrast, Figure 5c shows the distribution for the more extensive sample of living plants, which included more obviously degraded areas with hardpan showing at the surface. Modal plant size in this sample was Size Class 10, while modal size in samples from the less-degraded area was Size Class 13. Plant size at flowering is clearly plastic and appears to