reports by other researchers (Hall et al., 1971, Jackson et al., 1972; Olson and Eaton, 2001). Similarly, flowers of the saskatoon berry (Amelanchier alnifolnia) are rendered sterile by night time temperatures of –3 °C (Olson and Steeves, 1983), whereas highbush blueberry (*Vaccinium corymbosum*) flowers are killed by temperatures as high as 0 °C (Gough, 1994).

The study of the effects of frost events on plants in the field pose special problems for researchers. Frosts, while predictable by short term weather forecasts, occur too rarely to allow the planned conduct of replicated experiments at particular phenological stages. The portability, precision and flexibility of the system we have described makes it a valuable tool in investigations into frost effects at bloom or any number of other developmental stages. The limitations of the system relate primarily to the type of frost conditions that can be simulated. The chambers reproduce the mass movement of cold air that creates conditions of advective frost in the field. They do not control air moisture content, though, and so chamber frosts may be either white in saturated air, or black in air of lower moisture content. Neither are they capable of reproducing the relatively common radiation frost that occurs on clear nights as plant tissues lose heat to the sky. The bulk cooling of the air inside the chamber means that all parts of the covered plants experience similar temperature conditions so vertical temperature gradients that develop in the canopy under radiation frost conditions are not simulated. Still, these limitations are not serious when effects of low temperatures on individual organs are the focus of the experiment. Overall the system is efficient and relatively inexpensive to construct, especially using preowned refrigeration units. The computer program provides nearly unlimited flexibility to design temperature regimes that simulate various frost events, including the sometimes precipitous decline in temperature that occurs frequently in the Canadian maritime climate. Extended periods at low temperature are also possible. With relatively minor modifications this system could be used to control on the basis of tissue temperature. Copies of the software and additional programming and engineering details are available from the senior author on request.

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Yield Potential of Selected Medicinal Herbs Grown at Three Plant Spacings in New Mexico

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Summary. Field studies were conducted to determine the production potential of echinacea (*Echinacea purpurea*), valerian (*Valeriana officinalis*), mullein (*Verbascum thapsus*) and yerba mansa (*Anemopsis californica*) medicinal herbs at two sites in New Mexico. Las Cruces, N.M., is at an elevation of 3,891 ft (1,186 m) and has an average of 220 frost free days per year, whereas Alcalde, N.M., is at an elevation of 5,719 ft (1,743 m) and averages 152 frost-free days per year. In-row plant spacings of 12, 18 and 24 inches (30.5, 45.7, and 61.0 cm) were compared at both locations. The corresponding plant densities for the 12, 18 and 24 inch spacings were 14,520 plants/acre (35,878 plants/

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ha), 9,680 plants/acre (23,919 plants/ha), and 7,260 plants/acre (17,939 plants/ha), respectively. Data were collected on growth rates, fresh yield, and dry yield for the herbs grown at each site. All crops at both sites had highest plot yields at the 12-inch spacing, suggesting that optimum in-row plant spacings are at or below the 12-inch spacing. Yields of 1.94 ton/acre (4.349 $t \cdot ha^{-1}$) of dried yerba mansa root, 0.99 ton/acre (2.219 $t \cdot ha^{-1}$) of dried echinacea root, and 2.30 ton/acre (5.156 $t \cdot ha^{-1}$) of dried mullein leaves were realized at the 12-inch spacing at Las Cruces in southern New Mexico. Yields of 1.16 ton/acre (2.600 $t \cdot ha^{-1}$) of dried valerian root, 0.93 ton/acre (2.085 $t \cdot ha^{-1}$) of dried echinacea root, and 0.51 ton/acre (1.143 $t \cdot ha^{-1}$) of dried mullein leaves were harvested at the 12-inch spacing at Alcalde in northern New Mexico. Yields of fresh echinacea flowers were 1.56 ton/acre (3.497 $t \cdot ha^{-1}$) in Las Cruces. Yields of dried mullein flowers were 0.68 ton/acre (1.524 $t \cdot ha^{-1}$) in Las Cruces and 0.66 ton/acre (1.479 $t \cdot ha^{-1}$) in Alcalde.

Herbs have been used by virtually every culture since history has been recorded. While the use of medicinal herbs has fluctuated throughout modern times, herb use is currently increasing. Retail sales of herb-related products in the United States were estimated at close to $4 billion annually (Brevoort, 1998). Initially these plants were gathered from the wild, however increased demand has put pressure on native stands, creating the need for commercial cultivation.

Medicinal herbs are being tested on small farms in other areas of the southern U.S. as high value crop alternatives, but limited production information is available to growers. The purpose of this study was to determine the production potential of selected medicinal herbs grown at three in-row plant spacings in southern and northern New Mexico. The herbs in the study were echinacea, mullein, valerian and yerba mansa. All of these plants are perennials, except mullein which is a biennial. These crops were chosen based on a national market survey of 98 herb buyers (Falk et al., 1996). The survey showed which herbs were in highest demand and the herbs for which buyers were looking for additional sources of.

Echinacea is valued as an immune stimulant and is commonly used to treat skin inflammations, colds, and flu-like symptoms (Foster, 1993). The root was traditionally used , but some companies are now harvesting both portions of the plant. Echinacea ranks at the top of the medicinal herb market (Brevoort, 1998). Mullein leaf has been used to treat respiratory conditions, throat irritations and coughs, and the flowers are used to treat earaches (Moore, 1979). Valerian root is an effective herbal sedative used to treat anxiety and insomnia (Tyler, 1994). Clinical studies have shown that valerian causes patients to fall asleep faster and improves sleep quality (Leathwood et al., 1982). Yerba mansa is a plant native to the southwestern U.S., and has antibacterial, antifungal, and anti-inflammatory properties (Moore, 1989). The root is sold commercially, but traditional Hispanic cultures have also used the leaves (Davidow, 1999). Yerba mansa has been suggested as an alternative to goldenseal (*Hydrastis canadensis*) for healing infections and sore throats (Moore, 1989). Yerba mansa has been recommended for increased commercial production because its native range is limited (Knight, 1999)

Much of the horticultural research on echinacea has focused on germination techniques (Baskin et al., 1992; Feghahati and Reese, 1994; Smith-Jochum and Albrecht, 1987; Wartidiningsih and Geneve, 1994; Wartidiningsih et al., 1994). Some field studies have been conducted in New Zealand and Europe to evaluate optimum plant densities and fertilization parameters in these environments (Galambosi, 1993; Parmenter et al., 1992; Parmenter and Littlejohn, 1997; Shalaby et al., 1997). Mullein is a common roadside plant that grows naturally throughout many regions of the United States. Literature on this plant is mainly found in rangeland journals associated with ecological distribution studies. Likewise, yerba mansa has been evaluated for it's chemical constituents, but production studies are scarce. Research is needed to evaluate specific production criteria in various geographical areas, because these crops are relatively new to growers and the commercial market.

Materials and methods

Field studies were conducted in 1995 and 1996 in Las Cruces and Alcalde, N.M. Las Cruces and Alcalde were chosen for this study to evaluate growing conditions in the southern and northern parts of the state, respectively. The Fabian Garcia Science Center in Las Cruces is at an elevation of 3,891 ft has an average of 220 frost-free days per year (Herrera, 1989), and is in climate zone 7. The crops were grown on soil that is a Glendale loam [fine-silty, mixed (calcareous), thermic Typic Torrifluvent] with a pH of 7.82. The Alcalde Sustainable Agriculture Science Center is at an elevation of 5,719 ft, averages 152 frost-free days per year (New Mexico State University, 1998), and is in climate zone 5. Crops were grown on a soil that is classified as a Fruitland sandy loam, [course-loam, mixed (calcareous), mesic Typic Torriorthent] with a pH of 7.48. Fresh cow manure was incorporated into the soil at a rate of 3.57 ton/acre (8.003 $t \cdot ha^{-1}$) in the fall of 1994 at the Las Cruces site, and the Alcalde site was planted in an area that was previously in alfalfa.

Yerba mansa was established using crowns harvested in the fall of the same year, prior to a frost in Las Cruces. Mature plants were left intact, but the stolons from these plants were collected and separated in between each node. Every young plant contained leaves and roots and was planted bare root. The plants had approximately three weeks in the field to establish before a frost came and they went dormant. Reemergence in Spring 1996 was very successful using this technique. Transplants of echinacea, mullein and valerian were started in a greenhouse in the early Spring 1995. Seeds were sown in germination trays using Premier Pro-Mix PGX medium (Premier Horticulture Ltd.,Steinbach, Canada). Echinacea seeds were placed on top of the growing medium and not covered by soil, because germination is greatly enhanced by light (Emal and Conrad, 1973; Foster, 1991). Seedlings were watered twice daily and fertilized once a week with Alaska brand fish fertilizer (Alaska Fish Fertilizer Co. Renton, Wash.) starting when the plants were about 3 weeks old. Plants were grown for about 8 weeks before they were hardened off and transplanted into the field.

In-row plant spacings of 12, 18, and 24 inches were compared at both locations. The corresponding plant densities for the 12, 18, and 24 inch spacings were 14,520 plants/acre, 9,680 plants/acre, and 7,260 plants/acre, respectively.

At both locations, the experiment was arranged in a randomized complete block design with four blocks. In Las Cruces, the beds were 30 ft (9.1 m) long and 4 ft (1.2 m) wide on 6-ft (1.8-m) centers. Each bed contained two rows of plants with border plants at the end of each row. An area of 77.5 ft^2 (7.20 m^2) was harvested from each plot. All weeding was done by hand in Las Cruces, and the herbs were watered by drip irrigation as needed.

In Alcalde furrow irrigation was used, and beds each with a single row of plants were created on 3 ft (0.9 m) between centers. Each plot contained two beds that measured a total of 30 x 6 ft. Border plants were at the end of each bed. The harvested area for each plot was 116 ft^2 (10.8 m^2). Weeding was accomplished by hoeing between the plants and by using a tractor-drawn rolling-tine cultivator in the furrows. Irrigation was done weekly during establishment and then every 2 to 3 weeks throughout the growing season, depending on precipitation. At both stations, all cultural growing practices were consistent with the guidelines for organic farming, as outlined by the New Mexico Organic Commodity Commission.

Data was collected on growth rates, and fresh and dry weight yields for the two sites in New Mexico. In the first year (1995), growth rates were measured every 2 weeks, using height and width measurements, and harvests were made based on the species and market requirements.

Valerian grew poorly in Las Cruces, therefore in the fall of 1995, these plots were replaced with yerba mansa rhizomes.

In Las Cruces, leaves were harvested from mullein in 1995, and flower stalks were collected in 1996. Echinacea flowers were harvested both years, and the roots of echinacea and yerba mansa were harvested in 1996. Roots were dug with a shovel and cleaned with a high pressure washer. The roots were dried on wooden drying racks under ambient temperature in a shed. Fresh and dry weights were recorded for all harvests. Echinacea flowers were dried in an oven at 100.4 °F (38 °C). Mullein flowers and leaves were dried at ambient temperatures.

Harvests were made in Alcalde using the same methods as described for the Las Cruces site. Plant material was placed on racks and allowed to air dry. However, total dry weights were determined from subsamples of the fresh harvest due to inadequate space to dry all the plant material.

The data were analyzed using the general linear model procedure of SAS version 6.11 (SAS Institute, Cary, N.C.) for a randomized complete block design. Data from each location were analyzed separately. Yield data were analyzed using an analysis of variance for each species followed by orthogonal polynomials to detect trend differences across plant spacings.

Results and discussion

Las Cruces. Growth rates (determined by height and width measurements), for plants at the three densities did not differ for echinacea, mullein or yerba mansa (data not shown). Valerian growth was not measured after 100 d due to the deteriorating condition of the plants. The climate of Las Cruces was not suitable for valerian production. When the air temperature reached about 95.0 °F (35 °C), the plants exhibited leaf scorch and most died. Consequently, there was no harvest of valerian in Las Cruces. These plots were replanted with yerba mansa rhizomes.

Dry weight yields of echinacea roots grown after 2 years, showed a strong linear trend ($P \leq 0.001$) to plant density (Table 1) and were 0.99, 0.78, and 0.46 ton/acre (2.219, 1.748, and 1.031 $t \cdot ha^{-1}$) at the 12, 18 and 24-inch spacings, or 0.33, 0.22, and 0.17 plants/ft^2 (0.031, 0.020, and 0.016 plants/m^2) respectively. This trend is consistent with the yields reported in one New Zealand study, (Parmenter et al., 1992) where dried root weight was 1.7 ton/acre (3.811 $t \cdot ha^{-1}$) at a plant density [0.56 plants/ft^2 (0.052 plants/m^2)] that was 1.7 times greater than the highest density (0.33 plants/

Table 1. Yield of yerba mansa (*Anemopsis californica*), echinacea (*Echinacea purpurea*), and mullein (*Verbascum thapsus*) in a plant-spacing experiment in Las Cruces, N.M.

Crop	Part harvested	Harvest year	Plant spacing[z] (inches)	Mean yield[y] fresh wt (ton/acre)	SE	Linear effect	Mean yield[y] dry wt (ton/acre)	SE	Linear effect
Yerba mansa	Root	1996	12	4.96	0.42	*	1.94	0.07	***
			18	3.19			1.27		
			24	3.20			1.06		
Echinacea	Root	1996	12	2.34	0.17	***	0.99	0.07	***
			18	1.78			0.78		
			24	0.99			0.46		
Echinacea	Flowers	1995	12	1.56	0.15	**	0.34	0.15	**[x]
			18	1.55			0.31		
			24	0.70			0.17		
Mullein	Leaves	1995	12	8.12	0.95	*	2.30	0.25	*
			18	5.85			1.48		
			24	4.26			1.40		
Mullein	Flowers	1996	12	1.89	0.34	NS	0.68	0.15	NS
			18	1.46			0.44		
			24	1.14			0.34		

[z]12-inch (30.5-cm) spacing = 14,520 plants/acre (35,879 plants/ha), 18-inch (45.7-cm) spacing = 9,680 plants/acre (23,919 plants/ha), 24-inch (61.0-cm) spacing = 7,260 plants/acre (17,940 plants/ha).
[y]Harvested area per plot was 77.5 ft^2 (7.20 m^2). Each plot had one bed with two rows per bed. Means are averages of four blocks. 1.00 ton/acre = 2.242 $t \cdot ha^{-1}$.
[x]Quadratic effect was also significant at $P \leq 0.03$.
*,**,***Linear effect significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

ft²) used in this study. In comparison, echinacea root yields in another New Zealand study, averaged 0.85 ton/acre (1.9 t·ha⁻¹) after 2 years growth, and increasing plant population from 1 to 2 plants/ft² (10.8 to 21.5 plants/m²) increased yields by 40% (Martin and Deo, 1997). Li (1998) recommended a maximum plant density of 30,500 plants/acre (12,343 plants/ha) [0.7 plants/ft² (0.065 plants/m²)] for echinacea, but did not report yield results.

Echinacea flowers were harvested to estimate production for the cut flower market. Previous studies have examined echinacea as a potential cut flower (Starman et al., 1995). Fresh weight yields of echinacea flowers at the 12, 18 and 24-inch spacings were 1.56 ton/acre (3.497 t·ha⁻¹), 1.55 ton/acre (3.475 t·ha⁻¹), and 0.70 ton/acre (1.569 t·ha⁻¹). However, most of these flowers had stem lengths less than 16 inches (40.6 cm), the minimum acceptable for marketing as a cut flower (Barr, 1992). Flowers may also be included in tinctures along with fresh leaves and stems, although, echinacea roots are in highest demand.

Some pests and pathogens were observed on the echinacea grown in Las Cruces. A few echinacea plants were infected with aster yellows in the summer of 1995. These plants were stunted and had flower phyllody symptoms characteristic of infection by the mycoplasm-like organism that causes aster yellows (Muller et al., 1973). The purple pigment on the ray petals was diminished, and the achenes had a green hue instead of the usual orange-yellow tones. Viral testing also confirmed the presence of tobacco etch virus on several of the echinacea plants.

Echinaeca flowers were infested in both years by the sunflower moth (*Homoeosoma electellum*). This insect has never been documented on echinacea before. Small, tan larvae, approximately 0.8 inch (20 mm) long, with dark longitudinal stripes, were observed in the achenes. Large amounts of frass were seen on affected florets, along with a fine webbing of silk. The adult moth was never observed in the field; however, it is a small, grey moth with an approximate wing span of 0.8 inch (20 mm) and a body length of about 0.44 inch (11 mm) (Carter, 1978). The growth habit of these plants was unaffected by the sunflower moth, and the plants developed normally. *Bacillus thuringiensis* var. *kurstaki* was effective in controlling the sunflower moth larvae in echinacea. Foliar applications [0.5 fl oz/gal (11.72 mL·L⁻¹)] were applied on all flower heads and emerging buds at 5-d intervals.

In Northern climates, echinacea roots may require 3 to 4 years of growth to reach significant biomass for profitability (Foster,1993) . However in southern U.S. climates which reach day and night time temperature differences (DIF) of 30 °F (16.7 °C) or more, growth rates are accelerated and plants harvested after 2 years of growth exceed yields reported by Trout Lake Farm, Wash. (Foster, 1991). High pressure liquid chromatography (HPLC) analysis of roots grown in Las Cruces after 2 years, report higher levels of phenols than plants grown in the Pacific northwestern U.S. after 3 years (T. Johnson, personal conversation).

Root crops are known to be more challenging to harvest and clean since they grow underground. Smaller roots may break off and remain in the soil, decreasing biomass. The crown and upper portions of echincacea tend to hold soil, which creates a greater labor strain on the cleaning of the roots. Recently farmers have begun to harvest the aerial portions of the plant to sell, while waiting for the roots to reach sizeable mass for harvesting. Research conducted in Kentucky indicated that the harvest of shoots and flowering tops can be a viable way to increase biomass and offset the higher labor cost of cleaning the roots (Vires, 2001). However, HPLC analysis of the flowers varied between two years, and did not meet the 4% phenol content that is the established criteria for echinacea on a whole plant basis during the second year (Vires, 2001).

Dry weight yields for mullein leaves harvested in 1995 from the 12, 18, and 24-inch spacing were 2.30, 1.48, and 1.40 ton/acre (5.156,

Table 2. Yield of echinacea (*Echinacea purpurea*), mullein (*Verbascaum thapsus*), and valerian (*Valeriana officinalis*) in a plant-spacing experiment in Alcalde, N.M.

Crop	Part harvested	Harvest year	Plant spacing[z] (inches)	Mean yield[y] fresh wt (ton/acre)	SE	Linear effect	Mean yield[y] dry wt (ton/acre)	SE	Linear effect
Echinacea	Root	1996	12	2.78	0.23	*	0.93	0.07	*
			18	2.12			0.72		
			24	1.94			0.65		
Mullein	Leaves	1995	12	2.90	0.22	*	0.73	0.09	*
			18	1.74			0.39		
			24	1.76			0.42		
Mullein	Leaves	1996	12	2.26	0.28	NS	0.51	0.05	NS
			18	1.83			0.42		
			24	2.27			0.54		
Mullein	Flowers	1996	12	2.03	0.21	NS	0.66	0.08	NS
			18	2.00			0.63		
			24	1.91			0.53		
Valerian	Root	1996	12	4.17	0.63	NS	1.16	0.17	NS
			18	3.37			0.93		
			24	3.23			0.94		

[z]12-inch (30.5-cm) spacing = 13,067 plants/acre (32,289 plants/ha), 18-inch (45.7-cm) spacing = 9,966 plants/acre (24,626 plants/ha), 24-inch (61.0-cm) spacing = 6,540 plants/acre (16,160 plants/ha).
[y]Harvested area per plot was 116 ft² (10.8 m²). Each plot had two beds with one row per bed. Means are averages of four blocks; 1.00 ton/acre = 2.242 t·ha⁻¹.
*Linear effect significant at $P \leq 0.05$.

3.318, and 3.138 t·ha^{-1}), respectively (Table 1). Mullein yields were high despite infection of mullein plots by *Fusarium oxysporum* in both years. Symptoms included wilting, followed by yellowing, and eventual necrosis. Some plants died after rapid collapse. Vascular discoloration of the stems was observed and *F. oxysporum* was isolated from this tissue.

Mullein flowers were harvested throughout the growing season in 1996 and dry weight yields were 0.68 ton/acre (1.524 t·ha^{-1}) at the 12-inch spacing, 0.44 ton/acre (0.986 t·ha^{-1}) at 18 inches, and 0.34 ton/acre (0.762 t·ha^{-1}) at 24 inches. After the initial flower stalks were harvested, multiple stalks began growing from the cut area, as well as from various points along the plant stem. These flower stalks were smaller in length and diameter than the central stalk, but the number of lateral stalks increased yield. One herbalist recommended cutting the primary flower stalks early to obtain secondary stalks that have a greater flower to stalk ratio (G. Asher, personal communication).

Dry weight yields for yerba mansa roots were higher than those for echinacea roots, and there was a significant linear relationship between yield and plant density ($P \leq 0.001$). Yerba mansa produced 1.94 ton/acre (4.349 t·ha^{-1}), 1.27 ton/acre (2.847 t·ha^{-1}), and 1.06 ton/acre (2.376 t·ha^{-1}) at the 12, 18, and 24-inch plant spacings, respectively (Table 1). Yerba mansa reproduced asexually from stolons and produced a large number of daughter plants. After one season of growth the plots were full of daughter plants, the initial crown had increased many times over, and root yields were high. The soil and climate conditions of southern New Mexico seemed ideal for yerba mansa production. Economic analyses estimated a positive 1-year return to land and risk of $4,896/acre ($12,098/ha) for yerba mansa if yields were 1.4 ton/acre (3.138 t·ha^{-1}) and the crop sold for $4/lb ($8.82/kg) (Falk et al., 1999). Returns to land and risk is defined as the amount of money that is remaining after all relevant expenses, except land and risk were covered. Yerba mansa sold for $4 to $10/lb ($22.05/kg) in 1996 (Falk et al., 1999). Current prices for yerba mansa remain stable at $8.00/lb ($17.64/kg) for root.

Alcalde. In northern New Mexico, echinacea plants at the 24-inch spacing grew tallest, reaching over 1.4 ft (0.43 m) during the first year of growth (data not shown). At the end of the season these plants were almost four inches taller than the plants grown at the 12 and 18-inch plant spacings. Mullein plants grew to a height of 9.6 inches (24.38 cm) at the 12-inch spacing 100 d from planting, whereas plants grown at the 18 and 24-inch spacings were significantly shorter, 8.6 and 8.2 inches (21.844, 20.828 cm), respectively. There was no difference in plant height among valerian plants grown at the three spacings (data not shown). At 120 d from transplanting, valerian plant height averaged 9 inches (22.9 cm) at Alcalde.

Dry weight yields of echinacea roots increased linearly ($P \leq 0.05$) with increasing plant density, and were 0.93, 0.72, and 0.65 ton/acre (2.085, 1.614, and 1.457 t·ha^{-1}) at the 12, 18, and 24-inch spacings, respectively (Table 2). Economic analyses showed a positive return to land and risk for the echinacea crops at both locations (Falk et al., 1999). After two growing seasons, using the 12-inch plant spacing, and assuming a $12.00/lb ($26.46/kg) selling price, returns were estimated for a 10-acre (4.0 ha) farm to be $16,093/acre ($39,750/ha) in Las Cruces and $14,612/acre ($36,092/ha) in Alcalde (Falk et al., 1999). At the time of this study, $12.00/lb was the market price, but recently echinacea root prices have plummeted to $4.00/lb for dried root and $0.75/lb ($1.65/kg) for tops (T. Johnson, personal communication).

Mullein leaves were harvested in both years at Alcalde. In 1995, dry weight yields were 0.73, 0.39, and 0.42 ton/acre (1.636, 0.874, and 0.941 t·ha^{-1}), and in 1996, harvests were 0.51, 0.42, and 0.54 ton/acre (1.143, 0.941, and 1.210 t·ha^{-1}) at the 12-, 18-, and 24-inch spacings, respectively (Table 2). In 1995, the yield response to density was linear ($P \leq 0.05$), but in 1996 that trend was no longer evident. Harvests of dried mullein flower stalks at the 12, 18 and 24-inch spacings in 1996 were 0.66, 0.63, and 0.53 ton/acre (1.479, 1.412, and 1.188 t·ha^{-1}), respectively. Results on the in-row plant spacings of mullein differed between the two sites. In Las Cruces, yields were higher than in Alcalde and they followed a linear trend of increased yields with greater plant populations. Alcalde showed nearly identical yields at the 12-inch and 24-inch plant spacings. This may be attributed to differences in harvesting techniques. Cultivation of mullein is not recommended, because the commercial market is small (Falk et al., 1999).

Valerian had the highest yields of all the herbs grown in Alcalde. Dry root yields were 1.16, 0.93, and 0.94 ton/acre (2.600, 2.085, and 2.107 t·ha^{-1}) at the 12-inch, 18-inch, and 24-inch spacings, respectively. These yields are slightly lower than production rates in New Zealand, where valerian root yields averaged 1.3 ton/acre (2.914 t·ha^{-1}) after 2 years growth in one study (Martin and Deo, 1997), and 1.78 ton/acre (3.990 t·ha^{-1}) at a plant density of 0.4 plants/ft^2 (4.306 plants/m^2) in another study (Parmenter et al., 1992). Cultivation of valerian in northern New Mexico was shown to have profit potential (Falk et al., 1999). In Alcalde, a valerian yield of 1 ton/acre (2.2 kg·ha^{-1}) would return $1,748/acre ($707.39/ha) to the grower if sold for $4/lb (Falk et al., 1999). Prices for valerian today hover at $4.00/lb for the American market. However, overseas prices for valerian from Poland range from $2.45 to $2.75/lb ($5.40/kg to $6.06 kg), (S. Foster, personal communication).

Conclusions

Medicinal herbs grown at both locations generally produced the highest yields at the 12-inch plant spacing, with corresponding densities of 14,520 plants/acre. Echinacea root and yerba mansa root yields in 1996, and echinacea flower and mullein leaf yields in 1995, showed significant linear increases with increasing plant density. However, mullein leaf and flower yields, and valerian root yields did not differ among plant spacing treatments in 1996.

Based on these results, a grower could use a minimum in-row plant spacing of 12 inches for production of echinacea and yerba mansa roots. Higher plant densities may increase yields further, and should be evaluated in association with organic fertility, weed control practices, disease incidence and irrigation management. A premium price is received by the grower for organically-grown medicinal herbs. Studies conducted in New Zealand produced higher yields at greater plant densities for echinacea and valerian (Martin and Deo, 1997;

Parmenter et al., 1992). In some cases, plant densities were double those used in this research.

Economic analyses conducted on these herbs indicate that New Mexico farmers could grow echinacea profitably in a significant portion of the state (Falk et al., 1999). Northern New Mexico farmers could grow valerian profitably, while southern New Mexico farmers could grow yerba mansa (Falk et al., 1999). Trials were not conducted for yerba mansa in Alcalde, therefore no recommendations can be offered for yerba mansa production in northern New Mexico. Cultivation of mullein for leaves and flowers is not recommended, because of poor market demand and abundant natural stands.

Small niche markets may be the only possibility for farmers in New Mexico. There are few large herb buyers in America and much of the large scale production has moved overseas where labor costs are lower.

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