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MAGUEY BAGASSE WASTE AS SUSTAINABLE SUBSTRATE IN SOILLESS CULTURE BY MELON AND TOMATO CROP

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□ *The soilless culture of vegetables in protected environments has increased in southern Mexico. However, the use of materials such as mineral wool or perlite as substrates is expensive and unsustainable. Therefore, the use of alternative, local materials such as the waste from mescal and coconut industries, including maguey (*Agave *spp.) bagasse, coconut fruit fiber and dust, as well as non-metallic mining products, such as vermiculite, is desirable. In this study, the physical, chemical and biological properties of vermiculite, coconut fiber, and maguey bagasse were determined, and their potential for cultivating melons (c.v. 'Magno F1') and tomatoes (Mill. c.v. 'Don Raúl') was evaluated. Moreover, 13 different substrates, based on combinations of the aforementioned materials, were analyzed. Materials were characterized at the Oaxaca Unit of the National Polytechnic Institute, and experiments were conducted in a multi-tunnel greenhouse in a randomized block design. Results indicated that materials possessed a narrow particle size distribution, where the lowest percent weight was observed for coarse particles (> 2 mm), resulting in a low coarseness index. Alternatively, the highest percent weight was observed in medium particles (0.25 mm). Values of apparent density, total porosity, electrical conductivity, and germination rate of lettuce seeds were acceptable for soilless substrates. The highest yield of tomatoes (12.4 kg m^{-2}) was observed on a substrate composed of 25% coconut dust and 75% vermiculite. In contrast, a mixture of 25% maguey bagasse and 75% vermiculite produced the highest yield of melons (3.1 kg m^{-2}). Moreover, the concentration of total soluble solids was not affected by the substrates. In conclusion, mixtures of maguey bagasse and/or coconut dust with vermiculite are superior to pure materials and can be used for the soilless cultivation of melons and tomatoes.*

Keywords: mescal, coconut dust, vermiculite, soilless culture, *Cucumis melo*, *Lycopersicon esculentum*, waste reclamation, sustainable agriculture, growing media, particle size

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INTRODUCTION

In Oaxaca, the cultivation of tomatoes and other vegetables in greenhouses has increased dramatically over the last ten years (OEIDRUS, 2008), and this trend will likely continue. In greenhouses, cultivation is conducted on soil or organic and inorganic substrates. As long as soil is not infested with disease, displays a high degree of fertility, and possesses a satisfactory texture, crop cultivation in soil is 50 and 70% more efficient with respect to nutrient and water usage, respectively, than substrate-based crops (OjodeAgua et al., 2008; García et al., 2001; Castellanos, 2004). However, desertification in some regions of Oaxacan Mixteca and the proliferation of soil pests such as nematodes of the genus *Meloydogine* in the Central Valley region have forced producers to discontinue soil-based crop production. Inorganic substrates such as mineral wool or perlite are used all over the world; however, in Mexico, these materials are expensive and have detrimental effects on the environment. Therefore, producers must search for alternative, local materials to compliment or substitute inorganic substrates. One option is the use of local agricultural byproducts such as maguey bagasse, coconut fiber and coconut dust. Alternatively, inorganic materials such as vermiculite, which is a residue of non-metallic mining, can be used as a substrate. Maguey bagasse, coconut residue and vermiculite are abundant in southeastern and southern Mexico.

The Mescal Region of Oaxaca is an area known for the cultivation of maguey mescalero (*Agave* spp), where approximately 11,756 hectares are grown. This region is located in the Oaxacan central valley and south sierra and encompasses 59 municipalities and 152 communities (Arredondo et al., 2003). In 1999, there were approximately 11,329,553 agave plants, which were used as a raw material for the production of 3,433,768 liters of mescal. Over time, the production and consumption of mescal has increased. During mescal extraction, a byproduct known as maguey bagasse is eliminated after fermentation and distillation. Depending on the grinding process, maguey bagasse represents approximately 14 to 20% of the plant weight (Silva et al., 2003). The mescal industry of Oaxaca produces approximately 4,807,275 tons of bagasse annually, most of which is dumped into rivers and creeks, creating a serious environmental hazard, or is used as fuel in brick kilns. However, in the mescal region of northern and central Mexico, the successful use of maguey bagasse for paper production has been reported (Idarraga et al., 1999), and the results are comparable to those of eucalyptus and pine fiber. In Mexico, maguey bagasse is often combined with grains and cereal and used as animal feed (Iñiguez, 2001a, 2001b). Currently, studies on the use of maguey bagasse as a substrate in soilless crops have not been conducted. Nevertheless, due to its morphological characteristics (hard fibers, low density) and annual availability, maguey bagasse has a high potential for use as an organic substrate alternative or as a supplement to materials currently in use for plant propagation and crop production. Thus, the goal of this research was to study the use of residual bagasse from the mescal industry for the cultivation of vegetables. This study analyzed the use of pure bagasse and bagasse-based mixtures of coconut dust and vermiculite. Specifically, the physical, biological and chemical properties of bagasse-based substrates were assessed. Furthermore, an agronomic evaluation of the experimental substrates was conducted in melon and tomato crops.

MATERIALS AND METHODS

This research was conducted at the Oaxaca Unit of the Interdisciplinary Research Center for Regional Integral Development (CIIDIR-IPN in Spanish). In this study, residual bagasse from the mescal industry was used a substrate for the cultivation of vegetables. Bagasse was obtained from Antequera Siglo XXI, a distiller located in the central valley of Oaxaca, and composted naturally for approximately six months. Coconut dust and fiber were obtained from the mechanical separation of the mesocarp of coconut palm (*Cocus nuccifera* L.) fruit, which was produced in the Oaxacan coastal region and processed in CIIDIR's workshop. Vermiculite was obtained from Materiales de Antequera S.A. de C.V®. With these materials, 13 mixtures were prepared in different volumetric proportions (v/v), yielding a total of 15 treatments (Table 1).

Physical properties, including coarseness (expressed as the percent weight of particles with Ø > 1 mm) (Richards et al., 1986) and particle distribution (expressed as the percent weight), were determined (Martinez, 1992). Furthermore, the actual and apparent density, total porosity, water retention capacity, and humidity were evaluated according to the methods proposed by Martínez (1992), and De Boodt and Verdonck (1972). Physical-chemical properties, including pH and electrical conductivity, were analyzed with the saturation method described by Warncke (1986). The organic matter content was analyzed according to the method proposed by Martínez (1992). All physical, chemical and biological determinations were conducted in triplicate.

Germination bioassays were conducted with lettuce seeds (*Lactuca sativa* L.) according to a method proposed by Urrestarazu et al. (2008a) and Zucconi and de Bertoldi (1991). All samples were analyzed in triplicate.

Experiments were conducted in a multi-tunnel greenhouse. To cultivate melons (*Cucumis melo* c.v. 'Magno F1') and tomatoes (*Lycopersicon esculentum* Mill. c.v. 'Don Raúl'), plants were grown on experimental substrates in 18 L black polyethylene bags. Crops were sequentially established under a randomized block design with four repetitions, where experimental units included one melon and two tomato plants. Fruit yield (kg m^{-2}) and quality, expressed as the total soluble sugar (°Brix), were used as variables.

TABLE 1 Texture and particle size distribution (% weight) and coarseness index (CI) of maguey bagasse from mescal (A), coconut fiber (B), vermiculite (C), and their mixtures in vol/vol

Substrate mixture			Particle size (mm)						
			Fine or small		Medium or intermediate		Coarse or large		
A	B	C	< 0.125	0.125–0.25	0.25–0.5	1–2	2–4	4–8	CI
0	0	100	0.4f[1]	15.2d	78.7a	2.9a	—	—	2.0c
0	25	75	1.5g	17.7d	78.2a	0.2d	1.4c	0.5c	2.0d
0	50	50	3.1g	19.7d	71.8a	0.9d	2.5b	1.5b	4.9c
0	75	25	2.8g	26.8d	66.4b	0.5d	0.1c	—	1.4d
0	100	0	5.0d	30.0a	53.6d	2.7a	2.7b	—	5.5c
25	0	75	3.9e	20.0c	74.5b	0.5d	0.6d	—	1.1d
25	25	50	4.2e	20.7c	70.8b	0.8d	1.1c	0.8c	3.6c
25	50	25	6.5d	28.0a	61.7b	1.2c	2.6b	0.4c	4.2c
25	75	0	9.6c	24.8b	47.7c	2.6a	6.4a	6.3a	15.3a
50	0	50	6.9d	20.8b	69.3c	1.0c	1.2c	—	2.2d
50	25	25	5.5d	24.4b	62.9d	1.9b	3.1b	1.3b	6.4c
50	50	0	13.3b	25.4a	50.8d	2.7a	4.7a	1.2b	8.7b
75	0	25	7.3d	23.5a	63.2d	1.8b	2.8b	—	4.6c
75	25	0	11.6b	28.5a	48.4c	2.9a	6.1a	1.1b	10.1b
100	0	0	16.4a	25.1a	51.6c	2.1b	2.6b		4.7c

(1) Letters mean significant difference at $P > 0.05$ based on Tukey's test.
The results are the average of three replications.

An analysis of variance (ANOVA) was performed, and significant results were subjected to the Tukey's test ($P \leq 0.05$). Statistical analyses were conducted with Statgraphics Plus 4 software (Statistical Graphics Corporation, Rockville, MD, USA).

RESULTS AND DISCUSSION

Table 1 shows the particle size distribution and thickness index of maguey bagasse, coconut dust, vermiculite, and other materials resulting from different combinations (v/v) of the aforementioned substances. Mixtures and pure materials showed significantly different ($P \leq 0.01$) particle sizes. The highest percent weight was concentrated in medium particles (0.25–2 mm), while the lowest percent weight was observed for coarse particles, resulting in a low coarseness index. Alternatively, the combination of 25% maguey bagasse and 75% coconut dust displayed a coarseness index of 15.3, which is similar to the values obtained by Noguera et al. (2000) for various types of coconut dust. On the other hand, these values were lower than those observed in fine grain almond shells (Urrestarazu et al., 2008a). The lack of coarse particles (>2.0 mm) can affect the physical properties of substrates, including the total porosity, water retention capacity, and water-air ratio, which were significantly higher in vermiculite-based mixtures. Ansorena (1999) suggested that particles less than 1 mm in diameter have a significant effect on water retention and speculated that larger particles were of little importance.

As shown in Table 2, the physical properties of pure materials and mixtures were significantly different ($P \leq 0.01$). The apparent density of pure maguey bagasse was 0.41 g cm^{-3}, which was the highest density observed in this study. Moreover, the density of maguey bagasse was slightly higher than optimal and was similar to the density of almond shells (0.40 g cm^{-3}) in a study conducted by Urrestarazu et al. (2005). Mixtures based on coconut dust and vermiculite possessed a lower than optimal apparent density. Specifically, a mixture composed of 25% maguey bagasse and 75% coconut dust presented the lowest density (0.11 g cm^{-3}). Moreover, the density of this mixture was lower than the values reported by Konduru et al. (1999) for coconut dust with a particle diameter of 6 mm. However, a low apparent density is favorable for the transfer and distribution of crops inside a greenhouse. Other parameters such as total porosity showed trends that were similar to the apparent density. The lowest total porosity (76.51%) was observed in maguey bagasse, where the observed porosity was less than optimal. The total porosity of this mixture is similar to the porosity of mineral wool.

The water retention capacity of all materials was less than optimal (Abad et al., 2004). The lowest values were observed in pure maguey bagasse and

TABLE 2 Selected physical and chemical properties from mezcal maguey bagasse (A), coconut fiber (B), vermiculite (C), and their mixtures in vol/vol

Substrate mixture			Bulk density	Total pore space	Total water-holding capacity	Humidity
A	B	C	(g cm^{-3})	(% vol)	(mL L^{-1})	(%)
0	0	100	0.25b[1]	89.90a	482.9b	65.59c
0	25	75	0.37b	84.90b	334.2d	46.35d
0	50	50	0.22d	90.54a	380.6c	62.56c
0	75	25	0.21d	89.13a	578.9a	72.92b
0	100	0	0.13c	91.48a	565.1a	81.13a
25	0	75	0.35b	84.80b	564.6a	61.20c
25	25	50	0.29b	86.12b	544.5a	65.10c
25	50	25	0.22d	88.38b	540.5a	70.83b
25	75	0	0.11c	92.53a	526.5a	81.65a
50	0	50	0.36b	81.86d	585.1a	61.33d
50	25	25	0.24d	87.23c	636.8a	72.09b
50	50	0	0.15c	84.80c	605.6a	79.29b
75	0	25	0.28b	90.08a	553.8a	66.10d
75	25	0	0.25d	84.60c	607.1a	70.98b
100	0	0	0.41a	76.51d	410.4c	46.55d
Optimum value[2]			< 0.40	> 85	600–1000	85.9–87.92

[1] Letters mean significant difference at $P > 0.05$ based on Tukey's test.
[2] Abad et al. (2004).
The results are the average of three replications.

mixtures containing vermiculite, whereas the highest water retention capacities were observed in mixtures of coconut dust and maguey bagasse. To produce a cultivation medium, all the necessary physical properties must be present in one material; however, it can be incredibly challenging to find one substrate that possesses all the desired characteristics (Abad et al., 2004; Gruda et al., 2001; Islam et al., 2002). Thus, to achieve the desired properties, materials are often combined, which raises the cost of the final product. Except for pure coconut dust and a mixture containing 25% maguey bagasse and 75% coconut dust, the humidity of evaluated materials was lower than optimal.

All physical-chemical properties of pure and mixed materials (Table 3) were significantly different ($P \leq 0.01$). In most materials, the pH was slightly higher than optimal, and only materials based on vermiculite displayed an optimal pH. A high pH is characteristic of organic materials; for instance, Abad et al. (2002) and Urrestarazu et al. (2008b) found that coconut dust and compost based on vegetable residuals possessed a high pH. In this study, the electrical conductivity (EC) of all materials was optimal, and the highest value observed was 3.59 dS m^{-1}. A high electrical conductivity can hinder plant growth, particularly in plants that are sensitive to salinity. However, in

TABLE 3 Selected physico-chemical and chemical properties from mescal maguey bagasse (A), coconut fiber (B), vermiculite (C), and their mixtures in vol/vol. Germination percentage (G), stem length and the radicle under bioassay using saturated extract and lettuce seeds

Substrate mixture							Length (cm)	
A	B	C	pH	EC (dS m^{-1})	O.M. (%)	G (%)	Stem	Radicle
0	0	100	7.99a[1]	1.02f	—	85.00c	3.82g	1.42e
0	25	75	6.87d	1.65e	9.24*j*	87.00b	5.19d	1.66d
0	50	50	6.48d	2.39c	16.03*j*	86.33b	6.29a	2.23c
0	75	25	6.62d	2.30d	37.93g	86.67b	7.53a	3.22a
0	100	0	6.54d	2.34c	74.15b	86.00b	6.72a	2.26c
25	0	75	7.73b	1.04f	15.21i	85.67b	4.69e	2.64b
25	25	50	6.93c	1.79e	31.06h	85.33b	3.48g	3.69a
25	50	25	7.14c	2.77b	46.10f	82.33c	7.28a	3.48a
25	75	0	7.87b	3.59a	81.85a	90.00a	6.51a	2.51c
50	0	50	7.09b	2.31d	36.34g	84.33b	5.58c	3.57a
50	25	25	7.91a	0.94f	44.91f	86.00b	7.01a	3.77a
50	50	0	7.48b	2.56b	79.29a	86.33b	5.82b	3.31a
75	0	25	8.19a	0.92f	52.26e	86.33b	7.10a	3.51a
75	25	0	7.86b	2.89b	71.05c	87.67b	4.38f	2.13c
100	0	0	8.05a	1.50e	61.72d	85.33b	7.38a	3.41a
Optimum value			5.20–6.80[2]	1.0–5.0[2]	>90[2]	>50%[3]		

O.M.: Organic matter

[1] Letters mean significant difference at $P > 0.05$ based on Tukey's test.

[2] Abad et al. (2004).

[3] Zucconi and Bertoldi (1991).

The results are the average of three replications.

most cases, a substrate with a high pH and EC does not negatively affect plants because the irrigation program used during cultivation causes an effective lixiviation of soluble salts (Noguera et al., 1997; Abad et al., 2002; Martínez et al., 2009). The concentration of organic matter was lowest in substrates based on vermiculite. As reported by Iñiguez et al. (2006), these results are similar to those obtained for bio-solid compost and maguey bagasse from the tequila industry.

As shown in Table 3, the biological properties of pure and mixed materials were significantly different ($P \leq 0.01$). In all materials, the germination rate of lettuce seeds (*Lactuca sativa* L.) was greater than the recommended minimum (Abad et al., 2004). Consequently, all stem and root lengths were also acceptable. These results are similar to those obtained by Ortega et al. (1996) for eight different species of vegetables cultivated on shell extracts of *Quercus suber* L, obtained from different extraction methods involving hot and cold water.

The yield of pear-type tomatoes and melons cultivated on pure and mixed substrates were significantly different (Table 4). Plants cultivated on 25% coconut dust and 75% vermiculite produced the highest tomato yield (12.4 kg m^{-2}), which was greater than the yield (9.98 kg m^{-2}) obtained from cultivation on almond shells in 25 L bags (Urrestarazu et al., 2005). However, tomato yields in this study were considerably lower than the yields (30.4 kg m^{-2}) obtained by OjodeAgua et al. (2008) on conventional soil

TABLE 4 Yield and total soluble solids (TSS) of tomato (*Lycopersicon esculentum* Mill. c.v. 'Don Raúl') and melon (*Cucumis melo* L. c.v. 'Magno F1') grown under soilless culture in mescal maguey bagasse (A), coconut fiber (B), vermiculite (C), and their mixtures in vol/vol

Substrate mixture			Tomato	Fruit number		TSS	Melon	TSS
A	B	C	(kg m^{-2})	Marketable	Non-marketable	(Brix)	(kg m^{-2})	(°Brix)
0	0	100	9.8b[(1)]	25c	38b	3.6b	1.9c	6.12c
0	25	75	12.4a	50a	36b	3.6b	2.0b	8.00a
0	50	50	11.7b	38b	39b	4.0a	2.4b	8.80a
0	75	25	10.8b	32b	34b	3.8b	2.5b	7.60b
0	100	0	7.0b	20c	26c	4.0a	2.2b	7.00c
25	0	75	10.4b	18c	45a	3.8b	3.1a	8.33a
25	25	50	10.0b	28b	42a	3.5b	2.6b	9.41a
25	50	25	10.0b	22c	44a	3.4b	2.4b	8.00a
25	75	0	6.3c	21c	27c	3.0c	2.4b	8.20a
50	0	50	8.9b	10d	45a	3.4c	2.4b	8.70a
50	25	25	9.9b	33b	37b	3.0c	2.5b	7.50b
50	50	0	7.0b	33b	44a	2.8c	2.2b	8.10a
75	0	25	8.8b	40b	45a	3.2c	2.2b	8.00a
75	25	0	6.4c	32b	37b	4.0a	2.5b	8.90a
100	0	0	6.6c	38b	42a	3.0d	2.5b	6.90c

[(1)] Letters mean significant difference at $P > 0.05$ based on Tukey's test.
The results are the average of three replications.

and black and red tezontle. This disparity could be caused by differences in production time and vegetable varieties.

The highest melon yield was 3.1 kg m^{-2}, and was obtained from cultivation on a mixture of 25% maguey bagasse and 75% vermiculite. This result is similar to the yield obtained by Urrestarazu et al. (2005) from cultivation on almond shell and mineral wool substrates, where yields of 3.13 kg m^{-2} and 3.86 kg m^{-2} were observed, respectively. Physical properties were enhanced by combining organic (maguey bagasse and coconut dust) and inorganic substrates (vermiculite), resulting in improved granulometric distribution and higher yields of tomato and melon. Similarly, Abad et al. (2004) suggested that combinations of diverse materials can be successfully used for vegetable production, as long as cultivation and management (fertilization, irrigation, and container) are properly balanced with medium and plant requirements. The highest production of non-commercial tomatoes was obtained using pure maguey bagasse, coconut dust and vermiculite. Moreover, the sugar content of vegetables was not altered by the use of these materials as substrates.

CONCLUSIONS

Maguey bagasse and coconut dust displayed a wider particle size distribution than vermiculite. Moreover, materials based on the combination of these two materials showed an improved particle size distribution compared to pure substrates.

Except for the pH, all physical, biological and chemical properties of residual bagasse were considered acceptable for soilless substrates. Thus, to achieve optimal results, the pH of experimental substrates should be decreased.

A substrate composed of 25% coconut dust and 75% vermiculite can be used for tomato cultivation, while a substrate containing 25% maguey bagasse and 75% vermiculite is better suited for melon production.

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