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Opuntia ficus-indica (L.) Mill. growing in soil and containers for urban agriculture in developing areas

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Abstract: Urbanization and poverty have brought to worse life conditions in towns of many developing Countries, including difficult availability of food, especially fresh. Urban agriculture and horticulture can contribute to the availability of fresh foods, officinal and medicinal plants, but the little availability of irrigation and surface to destine for cropping suggest the convenience of little water consuming species, with little needs of soil fertility and that can be eaten entirely. *Opuntia fiscus-indica* (L.) Mill. corresponds at all these requirements, and it is a very promising strategic species that can be eaten completely (green parts, fruits and even flowers), it has good nutritional values and also interesting medical properties. A trial has been done to compare the initial productivity of cladodes multiplied in pots, car tires and open field. Our results suggest that the prickly pear can be cropped better in large exhausted tires than in small plots also saving money for the materials.

1. Introduction

Urbanization and poverty cause food insufficiency in many tropical and subtropical Countries and this problem is enhanced in towns and urban peripheries where land plots to crop are few and small and there is irregular availability of foods in local markets. A few examples: Accra (Ghana) is a growing town that loses about 2.600 hectares of farm land every year to buildings and consequently reduces agricultural land availability nearby and into the town. The peripheral agriculture in Hanoi (Vietnam) produces at least 150.000 tons of fruit and vegetables per year. In Cuba urban and peripheral agriculture gives around 60 percent of horticultural produce consumption in large towns. Still in Cuba due to the constraints caused by trade embargo, a growing percentage of the agricultural production is provided by urban agriculture: in 2002 more than 14.000 ha of urban yards produced 3.100.000 tons of food, and 90% of the Habana fresh produce comes from local urban farms. In 2003 more than 200.000 Cubans worked in the expanding urban agriculture sector (Cuban Ministry of Agriculture, 2013). In Kinshasa (Democratic Republic of the Congo), urban agriculture is producing an estimated 75.000 to 85.000 tons of vegetables per year that is 65% of the town supply.

Agriculture is being pushed far from many towns, with increasing costs of food transport, packing and conservation enhanced by the bad conditions of rural roads, and heavy losses in transit.

In these areas, growing fruit and vegetables in and around cities increases the supply of fresh produce and improves the economic access to food for poor people (FAO 2015) that spend 60-80% of their income on food. Urban families may actually grow crops or raise small animals, and so produce some of their own food (Cohen and Garret, 2009). Moreover many foods available in towns and peripheries of developing Countries are introduced with international aid and consequently they are a constraint to food sovereignty.

Opuntia ficus-indica is a wild plant and a cultivated crop, whose value is largely underestimated. Its green parts are commonly used in environmental protection against soil erosion and as forage (Mulas and Mulas, 2004), the biomass is used for biogas (Rosato, 2014), industrial sectors use prickly pear fruits and leaves as raw materials for cosmetics, drinks and food additives (Saenz *et al*., 2013). Its flowers are useful to honey bees, but all its above ground parts are also good meals in form of fruits, fresh and cooked salads, soups, refreshing beverages, flour for breads and pastas. Fruits and cladodes are very nutritional (Saenz *et al*., 2013; Rodriguez *et al*., 1996), and their use a human functional food dates back to pre-columbian times (Ramirez *et al*., 2010). Especially young cladodes (*nopalitos* in Latin America) conserve water that is very useful in hot dry areas for both humans and livestock, around 9% crude protein, low fats (just around 1%), several minerals especially potassium (220 mg per 100 grams), calcium (16-33 mg), phosphorus (13-28 mg), and vitamins especially C vitamin (ascorbic acid 40 mg per 100 grams), with the best nutritive values being in the young cladodes (Retamal *et al*., 1987). The seeds are commonly considered a waste of the food industry however the extraction of oil is under study for applications in food, pharmaceutical and cosmetic industries (De Wit *et al*., 2017). Calories content vary within 25 and 50 kcal per 100 grams dry which is comparable to the most common fruits, moreover it has important pharmaceutical effects including antioxidants and also anti-cancerogenic effects (Livrea and Tesoriere, 2006). For all this uses the prickly pear has to be considered a multipurpose species quite useful also in many agroforestry systems.

Opuntia ficus-indica is a species of the *Cactaceae* with CAM metabolism that favors water conservation, even if young cladodes have a C_3 metabolic pathway (Mulas and Mulas, 2004) that causes water recall from lower-older cladodes during the day reducing water availability for the whole plant on benefit of the growth of younger parts (Wang *et al*., 1997).

Opuntia ficus-indica is a wild plant native of Mexican deserts, with very little needs of soil fertility and capable of growth even without any management. Few parasites treat this plant. All this makes this crop possible in most tropical-subtropical areas with enhanced hot and dry season, with poor soils and little management. It can be cropped also in permaculture and with this techniques it becomes an additional strategic plant useful as disasters relief crop beside short cycle cereals, beans and vegetables, after people displacement due to earthquakes (see in Haiti capital town), hurricanes (as common in Caribbean islands like Cuba), or after war situations (like recently happened in Somaliland, Iraq, Libya) when the whole national or regional agro-food system has to be restarted.

One of the problems related to prickly pear food harvesting and processing is related to the spines or glochids (hichy hair) that can be removed by immersion in water and mechanical treatment or fire burning. However there are spineless varieties (var. *inermis*) commonly used for forage, and also varieties almost without glochids that can be handled safely and make easy harvesting and processing, even if the absence of defensive parts make the plants more sensible to animal predation.

Due to the good nutritional values, the little water and soil needs and the easy management, prickly pears can be advised as a strategic crop for urban and peripheral areas with difficult climate or poor soil, as a green fence and also cropped in pots and exhausted tires as common in many towns of tropical developing Countries.

The productivity of prickly pear has been studied for field production or in greenhouse but still oriented to later in field transplanting. Researches have been done about how cladode size, their position at planting can influence initial growth and production (Bakali *et al*., 2016) and has been suggested that horizontal planting is the best technique in arid regions, and that cladode size influence early dry matter production. The same authors proved that cladode orientation to the sun, and the planting depth had not significant effects on early production. However Singh and Vijai Singh (2003) suggest that planting vertical is generally the best technique together with using cladodes 12 months old, and planting in spring. The effects of planting cladode parts instead of whole has been studied by Stambouli-Essasi *et al*. (2015), that suggest the possibility to use just parts in order to save planting material. Concerning plant densities in open field, Ruiz-Espinosa *et al*. (2008), suggest plantations of 60.000 plants per hectare. Concerning different clones, several authors have got diversified results in different environments, thus suggesting a relationship clone-environment (Flores, 1992; Flores-Hernandez *et al*., 2004; Ruiz-Espinosa *et al*., 2008).

Although there are few data available on *Opuntia* cultivation in containers, these are not intended for food production. Our research is oriented to the production of a strategic food plant and has compared the productivity of prickly pear cladodes grown in soil (as the case of green fencing) or in pots (the case of urban agriculture in balconies) and in exhausted tires (as common in backyards, small plots or balconies of urban peripheries of many developing Countries).

2. Materials and methods

The trial was done on a spineless cultivar of *Opuntia ficus-indica* (L.) Mill. without glochids imported from Cuba in the winter 2011, "*Milpa Alta*" that is the most cultivated in Mexico (Gallegos-Vasquez and Mondragon-Jacobo, 2011), it is an erected cultivar with elliptic cladodes, spineless and practically without glochids, with yellow fruits. The introduced parts have been multiplied for four years in order to have the necessary number of green parts, and then planted for the trial in Central Italy (Florence hills, 250 m asl, exposed to south) on the first of May 2015 and then again on May 2016. The location has 750 mm average annual rainfall with 159 during the 90 summer days, 14.5C° average annual temperature, in the period 1971-2000 there was an average of 62 days with maximum temperatures above 30C°. The soils of the trial location are mainly clayey (45% clay).

The initial plantation has been done using only young cladodes produced by mother plants the summer before (August 2014), planted after winter on 1st May 2015, thus 8 months old. A second plantation was done in 2016 after winter on 1st May, starting from cladodes produced by mother plants in the summer before (August 2015), thus also these 8 months old.

All the cladodes used for first and second planting had similar size, 5-7 cm width and 20-25 cm length in order to have very similar conditions of all plants at the beginning.

Each cladode was planted in a pot or in a tire or straight in the soil. In extensive soil they were planted in three single lines at distances of 50 cm on the line, simulating a soil area available similar to what they have in plots or tires.

Pots were 20 cm large x 30 cm deep that is a size quite common in local canned food tins that are used as flower pots, exhausted tires were borrowed all the same size 70 cm diameter (45 inner) x 23 cm width that is a 4WD type very common in developing Countries. One pot has been got from each tire. Tires were put on cemented area to avoid rooting in external soil. The tires were brought back to the giver after the end of the trial for ecological elimination by existing regulations. Pots and tires were filled with the same soil were cladodes were also planted straight.

Pots and tires were disposed in three lines alternated with the three lines of plants planted in the soil, and mixed in a randomized block design.

Treatments were not irrigated, in the attempt to reproduce conditions of absence or minimal management, common in strategic crops in harsh areas including home yards, balconies and peripheral areas where the water available serves mainly for human needs. Thus we got three treatments: 1) extensive soil, 2) pots, 3) tires. Each treatment was implemented with 8 initial cladodes (8 repetitions), for a total of 24 plants per year.

Measurements were done at the end of the growing season (30 September 2015 and 30 September 2016 for all treatments) on:

total number of new cladodes originated from each planted (counting);

fresh weight of new cladodes (harvesting all new cladodes and weighing fresh with scale), the fresh weight has been considered because this food is eaten fresh (like pineapple or papaya, as examples);

dry weight (after fresh weighting, all new cladodes were split in two halves to favor dehydration and oven dried for 5 days at 80°C, then weighted again to calculate the percentage of dry matter).

Fruits cannot be produced in the trial location during one growth season because it is too short.

Statistical analysis was done with LSD at P= 0.05.

3. Results and discussion

Number of new cladodes

The number of new cladodes (Table 1) was the highest in extensive soil (6 in the average of the two years) and the least in pots (2.5 in the average). Obviously roots explore a larger area of extensive soil than in pots or tires and consequently have higher water and nutrients availability, moreover soil temperature in pots and tires (that are black) rises more than in the soil and this in turn causes higher evaporation and reduces water availability. This somehow contrasts with the ability of a container to conserve water better than extensive soil, but this doesn't happen in full summer when high temperatures cause strong evaporation.

Table 1 - Number of new cladodes in the three treatments in the two years of trial and average

Treatment	Number of new cladodes		
	2015	2016	*Average*
Extensive soil	5 a	7 a	*6.0*
Pot	2 c	3 c	*2.5*
Tire	4 b	5 b	*4.5*
Average	*3.7*	*5.0*	*4.3*

Tires are larger than pots and probably have given intermediate yields because there is more soil than in pots, small plots have brought the plants to stressed conditions very rapidly whilst tires have provided better conditions for some longer time.

The higher number of cladodes in the second year (5.0 in the average of treatments, in comparison to 3.7 of the first year) can be due to warmer temperatures that persisted up to the end of the summer 2016 whilst several cool and some rainy days happened in the year before.

Fresh weight of new cladodes

The fresh weight (Table 2) was higher in the extensive soil (778 grams in the average of two years) than in tires (508.5 grams) and in pots (only 172 grams). The higher yield in 2016 (554.7 grams in the average of all treatments) than in 2015 (417.7) is probably due to warmer summer temperatures of 2016 in comparison to 2015.

Table 2 - Fresh weight (grams) of new cladodes in the three treatments in the two years of trial and average

Treatment	Fresh weight of new cladodes (grams)		
	2015	2016	*Average*
Extensive soil	679 a	877 a	*778.0*
Pot	150 c	194 c	*172.0*
Tire	424 b	593 b	*508.5*
Average not irrigated	*417.7*	*554.7*	*482.2*

Different letters show significantly different values at P=0.05.

Dry weight of new cladodes and percentage of dry matter

The percentage of dry matter (Table 3) was higher in 2016 (14% in the average of all treatments) than in 2015 (12%) probably because the warmer temperatures of 2016 favored evaporation whilst the cooler days and some rains increased water content in 2015.

The total dry matter yield was similarly higher in 2016 (75.4 grams in the average of all treatments) than in the year before (50.9 grams).

The highest yield was got in 2016 in extensive soil (94.4 grams in the average of the two years, with a maximum of 114 grams in 2016) and the lowest was got in pots (24,3 grams in the average of the two years, with a minimum of 19.5 grams in 2015).

Table 3 - Dry weight (DW, grams) and dry matter percentage (DM, %) in new cladodes in the three trial treatments in the two years of trial and average

Treatment	Dry weight of new cladodes					
	2015		2016		*Average*	
	DW(g)	DM(%)	DW(g)	DM(%)	DW(g)	DM(%)
Extensive soil	74.7 a	11 b	114.0 a	13 b	94.4	12.0
Pot	19.5 c	13 a	29.1 c	15 a	24.3	14.0
Tire	50.9 b	12 ab	83.0 b	14 ab	67.0	13.0
Average not irrigated	*48.4*	*12.0*	*75.4*	*14.0*	*61.9*	*13.0*

Different letters show significantly different values at P=0.05.

4. Conclusions

Most households in towns, especially in developing Countries, have not soil available and must rely on small and cheap containers for gardening, under this point of view, tires not only are cheaper then pots and they are easily available in many tropical towns, but they also provide better growing conditions for *Opuntia ficus-indica* than commercial pots. Of course extensive soil is a better condition for growing prickly pears than into containers, at least referring to water needs and taking into account that in extensive soil problems can rise from weeds competition more than in pots or tires.

The production in our trial in Italy has not been much because of the short warm season (4 months, with only three having summer temperatures) and because we planted cladodes not yet rooted. We can reasonably consider that production would be much higher in the tropics and subtropics where temperatures are good all the year through, using, already rooted plants. The production could be increased much if some waste water can be used in the household for irrigation.

The yield of new cladodes can integrate the diet and be a useful supply for a small family during the worst part of a dry season of 3-4 months, can be also a source of herbal medicine extremely useful to families.

Although the limiting climatic conditions of our trial, the results maintains their value of comparison within treatments also for tropical Countries.

A couple of issues to be investigated are whether food production in tires is economically more convenient than transforming them into handmade items such as sandals (it is a common practice), and check food quality for eventual absorption of toxic contaminants from exhausted tires into edible plants.

Finally, a next trial on the use of prickly pear as a strategic plant, could be to start growing cladodes in tires or pots and when grown use some of these to plant green fences. The use of prickly pear for green fences can also be advised in order to shift the common use of planting the poisonous *Euphorbia* spp. (usually *Euphorbia trigona*) that has been much diffused in many and large areas because its spines makes a barrier to uncontrolled livestock. Clearly the use of *Opuntia* as a green fence should be preceded by start of some livestock control, but will also provide food instead of an invasive, useless and poisonous weed.

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