Cladode planting methods improves the initial growth and production of cactus pear (*Opuntia ficus-indica* (L.) Mill.)

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Abstract. The aim of this work was to study how the planting system can affect the initial growth and production for *Opuntia ficus-indica*. For this purpose, we conducted an experiment testing the factors of: I. Cladode size (S5: double cladode – S4: single cladode (control) – S3 two-thirds cladode – S2: half cladode – S1: third cladode). II- Cladode position at planting (S4: cladode upright planted – S6: cladode horizontally side planted – S7: cladode upside down-planted). III- Cladode exposition to the sun (S4: North/South - S8: East/West – S9: North West/South East - S10: North East/South West). IV- Planting depth (S11: third cladode buried down in ground - S4: half cladode buried - S12: two-thirds cladode buried). This study demonstrated that S6, is the best treatment with significant ($p<0.05$) high productivity, high photosynthetic area and better rooting emergence compared to the S4. The results were equivalent to planting double cladode. Regarding the standard upright planting method of cladode, we found that the increase of cladode size was significantly correlated with the dry matter accumulation. In addition, exposition to the sun at planting had almost no significant differences on the growth rate. Finally, for the planting depth, no big differences were registered. However, S12 had the best absolute growth rate (height) and absolute dry matter production thanks to its significant ($p<0.05$) best side rooting development. On the other hand, S11 depth was better than the other depths in term of fruit production.
Key Words: planting system, cladode plantation technique, growth rate, biomass.

Résumé. Le but de ce travail était d'étudier comment le système de plantation peuvent affecter la croissance initiale et la production d'*Opuntia ficus-indica*. A cet effet, nous avons mené une expérience testant les facteurs suivants: I. taille de la raquette (S5: deux raquettes - S4: raquette unique (contrôle) - S3 deux tiers de la raquette - S2: demi-raquette - S1: un tier de la rquette). II- orientaion de la raquette au moment de la plantation (S4: raquette verticalement plantée- S6: raquette horizontalement plantée - S7: raquette plantée à l'envers de la position vertcale). III- exposition de la raquette au soleil (S4: Nord/Sud - S8: Est/Ouest - S9: Nord-Ouest/Sud-Est - S10: Nord-Est/Sud-Ouest). IV- Profondeur de plantation de la raquette (S11: un tier de la raquette enterré dans sol - S4: la moitié de la raquette enterrée - S12: Les deux tiers de la raquette enterré). Cette étude a démontré que S6, en couple de façon significative ($p<0,05$) une productivité élevée, une surface photosynthétique élevée et le meilleur enracinement par rapport à la S4. Les résultats étaient équivalents à la plantation de deux raquettes. En ce qui concerne la méthode classique de plantation verticale de la raquette, nous avons constaté que l'augmentation de la taille de cladode était significativement corrélée avec l'accumulation de matière sèche. En outre, l'exposition au soleil lors de la plantation n'a pas enregistré de différences significatives sur le taux de croissance. Enfin, pour la profondeur de plantation, pas de grandes différences ont été enregistrées. Cependant S12 avait le meilleur taux de croissance absolu (hauteur) et de production de matière sèche absolue, grâce à son développement racinaire importante ($p<0,05$). D'autre part, la profondeur S11 était mieux que les autres profondeurs en termes de production de fruits.
Mots Clés: figuier de Barbarie, plantation de la raquette, taux de croissance, production.

Abbreviations used: OFI (*Opuntia ficus indica*), CAM (rassulacean Acid Metabolism), AGR (Absolute Growth Rate), RGR (Relative Growth Rate), CCGR (cumulative crop growth rate), DM (Dry Matter), HP (Height of the Plant), HR (Root lengh), DPG (Big Diameter of the Plant), DRG (big side root), NR (number of pads) PDAS (Aboveground Dry Matter Accumulation), PDRS (root mass), PA (Photosynthetic Area).

Introduction. Drought and aridity are normal phonema limiting the efforts of rangeland rehabilitation and agricultural potential in arid environments. In recent years, interest has been growing in prickly pear (*Opuntia ficus-indica*) as promising drought resistant fodder shrub and a mean of combating desertification in rangelands and diversifying rain-fed farming production in marginal arid and semi-arid lands of North Africa (Le Houérou 1996; Nefzaoui & Ben Salem 2002; Mulas et al 2006; Guevara et al 2009; Neffar et al 2013). *O. ficus-indica* L. Mill one of several long-domesticated cactus species, is widely represented in the Moroccan rural landscape, his area has doubled to more than 120.000 ha over the last twenty years (Arba 2009; Bouzoubaâ et al 2014).

O. ficus-indica, known as prickly pear, is a succulent, xerophytic, spiny or spineless plant of multiple uses (Felker et al 1997; Nefzaoui & Ben Salem 2002). It is a highly drought-tolerant plant, exhibits crassulacean acid metabolism (CAM) that endures drought by maintaining night-time CO_2 uptake, together with morphological succulence and anatomical modifications such as thick cuticles and low stomatal frequency (Nobel 1985). These features permit a very high efficiency in converting water to biomass even in area receiving 150 mm (ie :south of Morocco along the Atlantic Ocean shore) (Nobel 1995; Le Houérou 1994; Felker et al 1997; De Kock 2001; Snyman 2004, 2006). It is propagated by cladodes/stems (pads), or even by their pieces. It has low ecological requirements (Snyman 2006) and requires low inputs to provide fresh fruit and fodder for sustainable development in arid and semiarid regions. The fruit of this species has many uses (Barbera et al 1991; Felker & Inglese 2003; Felker et al 2005), young cladodes are consumed as vegetables (Florez-Valdez 1995, 2001) and mature stems or cladodes can be used for feeding ruminants (De Waal et al 2006).

From country to another different method of planting cactus pear are applied according to the production object (fruit or forage), the aridity, wind direction, slope, soil type, availability of machinery etc. The size of cladode is very important to rapid growth and earlier fruit production. The more areoles we have in the aboveground and in the ground according to the size the more branches, flowers or roots are developed (Gibson & Nobel 1986). Size and age of cladodes influence growth and development of *O. ficus-indica*. When starting an *O. ficus-indica* plantation, Sudzuki et al (1993) & Franck (2000) recommend the use of double or triple cladodes since this leads to rapid growth and earlier fruit production than when single cladodes are used. Inglese et al (1995) reported that higher levels of production could be achieved by increasing the number of one year-old fruiting cladodes per plant.

The direction of cladode planting is also important, the upright side direction of full cladode size was always recommended as a standard planting method. Most platyopuntias species exhibit a vertical cladode position and nonrandom orientation. Terminal cladodes adopt a smart strategy by reorienting their-self for maximum light interception and, consequently, high yield production and growth during the growing season (Nobel 1988). Further, the vertical configuration has been interpreted as an architectural design that avoids high tissue temperature at midday, when ambient temperature and light interception would be maximized for a flat horizontal surface (Geller & Nobel 1987; Sortibran et al 2005).

Regarding the orientation, Nobel (1995) cited four main environmental factors that determine net CO_2 uptake and biomass accumulation in *O. ficus-indica* are soil-water content, air temperature, solar radiation and soil nutritional elements, while other environmental factors may play minor roles. For that reason, the experimented exposed area and orientation of photosynthetic surface method could affect especially the light interception and carbon gain. The trend is therefore towards the use of planting exposition that reduce the number of years required to achieve maximum light interception and full production. In some case the East/West direction was recommended while in other North/South direction (Pareek et al 2003; Becerra-Rodriguez et al 1976).

Furthermore, planting 1/3 of the complete pad under the ground in East-West direction, aged at least 12 months gives the best results at start (Singh & Singh 2003; Pareek et al 2003; Caloggero & Parera 2004). In Morocco, it was recommended the orientation north-south to get better sunshine for the plants (Arba et al 2000).

For many Opuntia species, the trend is therefore towards the use of adapted planting systems that accelerate crop growth rate through a greater early radiation interception, this leads to a reduction of the number of years required to achieve maximum light interception and full production. The way we are exposing and orienting cladode surface determine light interception and biomass accumulation.

The search for appropriate method for arid environment in Morocco, permitting a good establishment, rapid growth rate and important production are scant. These elements are of a big concern for farmers and managers dealing with this plant. So in our research, it was hypothesized that Opuntia establishment and growth in the first years in arid environment could be enhanced by the planting method and cladode size.

Therefore, this study contributes to the understanding and quantification of growth and production of OFI in relation to the some classical and new planting systems. As the information on *O. ficus-indica* growth and production behavior according to different planting methods is very limited, this paper aims to ascertain the effect of cladode size, position, exposition and depth plantation on growth and production.

Material and Method

Study area. The study was conducted from 2012-2015 (from mars 2012) in the Experimental Station of Errachidia (ESE) located in southeast of Morocco at 1,060 m above sea level (34°51'08.4"N and 08°15'05.3"E). Soils are skeletal and of sandy-loam texture, poor in organic matter. Long-term climatic data (1989–2014) revealed that the Mediterranean climate of this region is arid-type with cold dry winters and severe hot dry summers. The region receives an average of 141 mm of rain per year (SD = 64.9 mm; n = 31). Average annual temperature is about 19°C with a minimum of 8.3°C in January and a maximum of 30.9 °C in July. According the diagram of Gaussen & Bagnouls, the drought period extends over the entire year. In addition, the index of De Martonne (1926) applied for the region revealed an arid climate (De Martonne index value = 5.3).

Plant material and sampling design. At least one-year-old fruiting cladodes of OFI (cultivar Méknès)—(green cladode) were obtained from 7-years old plants in the station (ESE). The origin of the plant is the region Mèknès in center Morocco and 350 km far from the station.

Only healthy cladodes or phylloclades of *O. ficus-indica* were selected. The average size of cladodes were 35.7±3.5 cm long, 20.7±1.3 cm wide, 18.1±1.9 cm thick and 921.7±175.9 g fresh mass (means±SE, n =20). Plants were spaced 2 m apart, rows 2 m apart (density: 2500 plants/ha). Twelve planting systems were tested according to size, orientation, exposition and depth of planting (Table 1).

Table 1

Planting systems studied

Cladode size	*Cladode planting position*	*Cladode face exposition to sun*	*Cladode planting depth*
S4: single cladode (SC)	S4: full cladode upright planted (Normal vertical position)	S4: north/south	S4: The cladode was buried into ground down to half of its volume
S1: One third single cladode upright planted	S6: full cladode horizontally side planted (not a flat position)	S8: east/west	S11: the lower third of cladode total length was buried into the ground
S2: Half single cladode upright planted	S7: full cladode upside down-planted (reversed)	S9: north-east/south-east	S12: Two-thirds of cladode volume buried into the soil
S3: Two-thirds single cladode upright planted		S10: north east/south-west	
S5: double cladode (two cladodes joined together)			

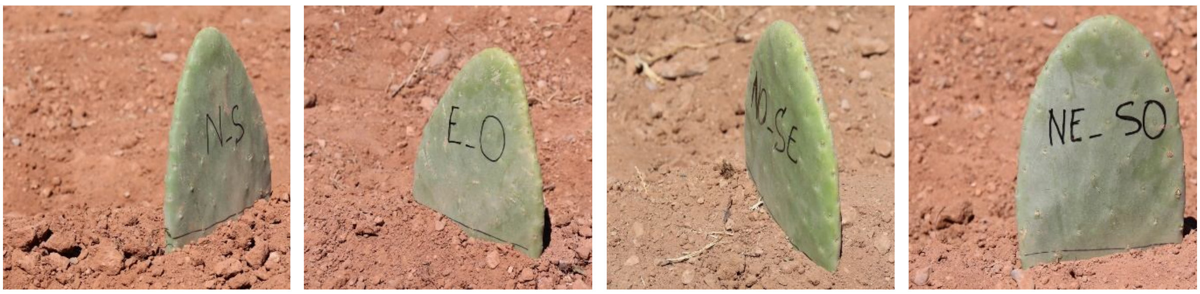
S4 - Control for all categories.

Irrigation was provided from mid-April until the end of September (6 irrigations/year) for about 3-4 h (3 h in spring and 4 h in summer) with 2.8 L/h to ensure adequate growth. Weeds in the planted rows were periodically and manually controlled. All flower buds were removed during the first and the second flowering to promote vegetative growth. The cladodes were planted in March 2012 according randomized complete block design with four replications. The experimental period lasted from July of 2012 to June of 2015. The planting systems are categorized in four groups, the control S4 is the same for all categories. They are described and illustrated in Table 1 and Figure 1.

S4 (Control) S6 S7
Cladode planting position

S5-S4-S3-S2-S1
Cladode size

S12-S4-S11
Cladode planting depth



S4 S8 S9 S10
Cladode face exposition to sun

Figure 1. Cladodes planting position, size, planting depth, and exposition to sun.

Data collection. Cladode growth rate was determined manually, using a measuring tape to measure height, big diameter. Number of cladodes was counted manually and the dry matter accumulation was estimated using a nondestructive method: cladode reference units. It consists in counting the number the cladodes units (U) for each plant then we sum all units (5U1 + 9U2 +…). Afterward, parameters like absolute growth rate (AGR), relative growth rate (RGR) and cumulative crop growth rate (CCGR) were calculated (Scalisi et al 2016; Noggle & Fritz 1983). Moreover, these calculated data are particularly viewed as useful when comparing plants that differ in initial size (Kozlowski et al 1991).

Thereby, the main reason for examining relative growth rates is to eliminate growth differences that arise from initial size differences.

The rate of increase in the growth variable at time 't' is called as absolute growth rate. It was measured by differential coefficient of 'w' with respect of time 't'. The AGR was calculated for variables by using following formula, expressed in cm per day and in g per day for production.

$$\mathbf{AGR} = \frac{W2 - W1}{t2 - t1} g \text{ or } cm/day$$

Where: w1, w2 refer to the plant height or with (cm), number of cladodes or dry matter weight (g) at time t1 and t2, respectively.

RGR is an important parameter, which indicates the rate of growth per unit dry matter. It is similar to compound interest wherein the increment in any interval adds to the capital for subsequent growth. This rate of increment is known as relative growth rate. Relative growth rate at various stages was calculated as suggested by Radford (1967) and Noggle & Fritz (1983): expressed in g per g dry weight per day for phytomasse and cm per cm height or width per day.

$$\mathbf{RGR} = \frac{LogW2 - LogW1}{t2 - t1}$$

Where: Log = Natural logarithms (logarithms to the base of 2.3026); height, width, number of cladodes and weight were measured at the times t1, t2 etc.

For roots observation, three shrub plants from each replication per treatment at the end of the month 2 were selected (having relatively the same height). These shrubs were uprooted carefully to record observations (Figure 2). Before performing root measurement, we have taken data from the above-ground growth plant such as: the height (HP), the big diameter (DPG), number of pads (NR) and the aboveground dry matter accumulation (PDAS).

Figure 2. Carefully uprooting *Opuntia ficus-indica* plants.

Root distribution of *O. ficus-indica* with distance from the first cladode mother plant and depth was determined in the field. The roots were expressed in terms of root mass (PDRS), root length or tape root (HR) and the big side root (DRG). Roots after being removed from the cladodes were cut and sieved in 2 mm mesh before taking the weight.

The roots and the cladodes were dried at 65°C for 48 and 168 hours, respectively, till reaching a constant dry weight.

The photosynthetic area (PA) of each cladode (both faces) was estimated using the following equation:

$$\mathbf{PA1 = 6.31 + 0.8 * (L * W)} \ (r^2 = 0.93)$$ (Caloggero 1995)

$$\mathbf{PA2 = 0.8571 * (L * W) + 0.3652} \ (r^2 = 0.962)$$ (Liguori et al 2014)

Where: L= length of the cladode (cm), and W = maximum width of the cladode (cm).

The measurement of fruit production started three after plantation. So, fruit weight and number were registered during 2014 and 2015 (during the first (2012) and the second year (2013) flowers have been removed).

Statistical analysis. The experimental layout consisted in 12 replications for each planting method. The parameters (RGR, AGR, CCGR) of plants were measured at intervals of 7, 12, 14, 18, 26, 31 and 40 months (timepoints) after planting. Only the Cumulated AGR, RGR are presented to facilitate the lecture, these two parameters include the dynamic of growth during different intervals. Fruit weight was mea determined during the third and the fourth year. Roots were measured at the end of the trial. Photosynthetic area was measured at the last timepoint.

Data were examined by analysis of variance (ANOVA). The adopted model was a randomized complete block design at a significance level of 5%. The effect of each factor (growth rate and number of cladodes, dry matter accumulation, fruit production and photosynthetic area) on the studied parameters, as well as the interactions among the factors, were analyzed. Means were compared using the Student Newmane Keuls (SNK) test and differences were considered significant (*), highly significant (**) or very highly significant (***) for probability-value $P<0.05$, $P<0.01$ and $P<0.001$, respectively (Mendenhall & Sincich 1996). Only for fruit, mean of production and number were separated using Duncan's Multiple Range test at the 5% level (a<0.05). The structure of variability among all planting systems and based on all studied traits was analysis using a Principal Component Analysis (PCA) with the mean population. The data collected were analyzed by SPSS version 18.0 (SPSS Inc., 2009).

Results

Cumulative production and growth rate. Results of cumulative growth and production for the last timepoint were reported in Table 2.

Table 2

Growth and production parameters during the last timepoint

Treatment	*Height (cm) (***)*		*Diameter (cm) (***)*		*Number of cladodes (***)*		*Phytomasse (g DM) (***)*	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
S1	*52.8^{c}*	±13.7	81.6^{b}	±50.3	13.6^{bc}	±12.6	675.8^{cd}	±677,9
S2	62.8^{b}	±12.1	105.7^{a}	±35.8	14.3^{bc}	±6.0	759.5^{bcd}	±342,6
S3	72.5^{ab}	±10.8	122.3^{a}	±34.9	22.1^{ab}	±8.4	1,141.5^{abc}	±455.5
S4	71.3^{ab}	±11.2	129.9^{a}	±30.1	25.1^{ab}	±13.2	1,302.6^{ab}	±643.0
S5	77.8^{a}	±8.0	129.2^{a}	±20.9	29.9^{a}	±12.7	1,504.2^{a}	±618.5
S6	77.6^{a}	±12.8	124.9^{a}	±29.8	29.2^{a}	±10.4	1,457.5^{a}	±516.5
S7	*48.7^{c}*	±11.6	57.7^{c}	±29.2	7.2^{c}	±3.6	328.5^{d}	±215.5
S8	66.1^{ab}	±10.3	126.1^{a}	±24.1	28.5^{a}	±9.8	1,451.2^{a}	±489.7
S9	73.1^{ab}	±11.2	128.1^{a}	±24.0	27.3^{a}	±10.3	1,392.3^{ab}	±509.6
S10	71.6^{ab}	±11.6	128.4^{a}	±21.1	25.7^{ab}	±11.8	1,323.4^{ab}	±565.2
S11	68.6^{ab}	±12.7	120.3^{a}	±31.4	22.5^{ab}	±9.9	1,164.6^{abc}	±508.8
S12	68.6^{ab}	±8.0	118.0^{a}	±27.3	23.6^{ab}	±11.3	1,205.2^{abc}	±567.2

Note. - (Mean ± Standard Deviation (SD), df=16 except for S1 df=13 (three plant died)); The values in the same column followed by the same letter are not significantly different according to SNK test (*** $p<0.001$); S1 to S12 (cf. Table 1).

According to these results, planting system was very highly significant (p<0.001) influencing growth parameters (height and diameter) and dry matter production (number of cladodes and phytomass). The best methods are S5 and S6 that gave high performances for all the parameters. The increase of the cladode size result in better growth, maximum cladode number produced and greater dry matter production (very highly significant [p<0.001]). Indeed, double cladodes gave significant (p<0.05) better production compared to the control (S4); whiles pieces of cladodes gave the lower production compared to the S4. Regarding the planting orientation, there were no differences registered between the different exposition for growth rate, while S8 and S9 methods registered significant better cladode yield and dry matter accumulation (for S9 only number of cladodes). For cladode planting depth, the differences were not statistically significant except for phytomass production that was better for the control (S4). Finally, the position of planting the cladode is very significant, In fact, the upside-down cladode position (S7) was the worst planting method for all the treatments, while the horizontal side position resulted not only better than control (upright position) but reached the same results as planting double cladodes. However, since treatment started with different sizes, we tried to analyze the absolute and relative growth rate.

Cumulated absolute production and growth rate. The cumulative AGR analysis registered very highly significant (p<0.001) differences for all growth and production parameters (Table 3).

Table 3

AGR cumulated during the whole trial

Treatment	*Height (cm/day)* ***		*Diameter (cm/day)* ***		*Number of cladodes* ***		*Phytomasse (g DM/day)* ***
	Mean	*SD*	*Mean*	*SD*	*SD*	*Mean*	*SD*
S1	334.0^{abc}	±120.8	431.4^{bc}	±333.7	±57.9	2,442.5^{bc}	±2,149.7
S2	347.3^{abc}	±144.1	491.7^{ab}	±212.2	±35.8	2,570.2^{bc}	±1,253.8
S3	408.1^{ab}	±110.5	629.2^{ab}	±218.2	±38.8	3,785.8^{ab}	±1,661.5
S4	394.3^{ab}	±130.3	683.0^{a}	±237.3	±82.8	4,431.5^{a}	±2,000.6
S5	280.2^{bc}	±100.5	721.3^{a}	±233.4	±77.4	4,786.8^{a}	±2,085.0
S6	458.9^{a}	±101.6	489.9^{ab}	±194.0	±60.5	4,880.7^{a}	±1,671.3
S7	241.0^{c}	±127.1	282.9^{c}	±222.5	±43.5	1,119.3^{c}	±827.88
S8	362.1^{ab}	±105.1	663.9^{ab}	±159.7	±51.0	4,919.8^{a}	±1,677.6
S9	404.9^{ab}	±111.6	732.6^{a}	±257.9	±67.4	4,625.7^{a}	±1,858.4
S10	370.1^{ab}	±95.0	634.8^{ab}	±187.8	±61.1	4,412.0^{a}	±2,056.8
S11	359.5^{ab}	±111.7	720.7^{a}	±251.1	±53.9	3,691.5^{ab}	±1,803.3
S12	416.7^{a}	±136.3	644.8^{ab}	±252.7	±74.0	4,483.0^{a}	±3,988.7

Note. - (Mean ± Standard deviation (SD), df=16 except for S1 df=13 (tree plant died));
The values in the same column followed by the same letter are statistically not significantly different according to SNK test (*** p<0.001);
S1 to S12 (cf. Table 1).

Differences were registered according to different planting methods. Therefore, S6 and S12 methods were the best in term of growth height (0.4 cm/day). The S1 and S7 methods were the great ones for lateral AGR with very high significant differences (p<0.001) compared to other methods. The S5, S6 and S8 systems produced the top absolute count of cladodes (0.15 cladode/day). The S5, S6, S8, S9, S10 and S12 methods produced the highest absolute dry matter (4-4.5 g DM/day). The S7 was by far the worst method for all parameters. In terms of growth, we can say many treatments like S4, S6, S9, S11 and S12 were superior to the other treatments, but in term of production the S5, S6 and S8 were the most distinguished. Regarding the cladode orientation to the sun, we differentiate S8 as the most productive cladode method. Then, for the cladode depth, S12 was notable essentially as a method that permitted good growth height. Finally, the position of cladode played an important role for growth and production. In fact, S6 was by far the greatest method and in the opposite S7 was by far the wickedest method.

Cumulated relative production and growth rate. The analysis of the cumulated RGR was also very highly significant ($p<0.001$) different for growth and production parameters (Table 4). Differences in parameters were registered according to different planting method. Therefore, S1 compared to its size was the best method in terms of relative growth height and relative phytomass production per unit of the plant followed by S6. For lateral growth, S6 was not among the best treatments because of its initial diameter compared to others. Starting with two cladodes (S5) in plantation does not imply a good relative production and growth except for the width. Whereas there were not big differences between methods in term of relative cladodes production per unit plant, except for S7 method which influence negatively and very significantly the cladodes yield. In fact, S7 was by far the last method in terms of relative growth diameter, number of cladodes and dry matter production. In terms of planting depth, burying a two-thirds cladode (S12) registered significant differences in relative growth production compared to the control and S11 depth. This last registered lowest significant relative production compared to control. The exposition has almost no significant differences in the relative growth rate and dry matter production parameters except for S10 exposition, which affected negatively and significantly the relative growth production parameters.

Table 4

RGR cumulated during the whole trial

Treatment	*Height (cm/cm.day) (***)*		*Diameter (cm/cm.day) (***)*		*Number of cladodes (***)*		*Phytomass (g DM/d.day) (***)*	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
S1	17.3^{a}	±3.3	11.1^{ab}	±6.4	18.7^{a}	±6.4	12.3^{a}	±2.5
S2	12.3^{bc}	±3.4	10.5^{ab}	±4.5	18.5^{a}	±4.1	9.5^{cde}	±2.7
S3	12.1^{bc}	±2.4	12.5^{a}	±3.7	19.2^{a}	±2.6	9.9^{bcd}	±1.6
S4	10.5^{c}	±2.6	13.0^{a}	±3.6	19.3^{a}	±5.6	10.3^{bc}	±1.4
S5	5.5^{e}	±1.8	13.5^{a}	±3.3	17.8^{a}	±5.0	8.2^{e}	±0.9
S6	13.6^{b}	±2.8	8.3^{cb}	±2.5	20.3^{a}	±4.5	10.5^{bc}	±1.4
S7	8.0^{d}	±2.7	6.9^{c}	±3.6	10.2^{b}	±4.4	6.2^{f}	±2.4
S8	10.2^{cd}	±2.3	14.4^{a}	±2.4	20.9^{a}	±3.7	10.7^{bc}	±1.0
S9	10.9^{c}	±2.6	14.1^{a}	±4.0	19.4^{a}	±5.2	10.5^{bc}	±1.4
S10	10.3^{cd}	±2.4	14.1^{a}	±3.9	18.5^{a}	±4.9	9.5^{cde}	±1.5
S11	9.5^{cd}	±2.5	14.1^{a}	±3.9	18.3^{a}	±4.7	8.6^{de}	±1.4
S12	12.3^{bc}	±2.6	13.0^{a}	±3.6	18.9^{a}	±4.6	11.5^{ab}	±1.7

Note: - (Mean ± Standard deviation (SD), df=16 except for S1 df=13 (tree plant died));
The values in the same column followed by the same letter are statistically not significantly different according to SNK test (*** $p<0.001$);
S1 to S12 (cf. table 1).

Photosynthetic area. Regardless the estimating method (they were almost the same), photosynthetic area was significantly ($p<0.05$) favorable for S5, S6 and S9 methods (Figure 3) compared to S4. The treatments they started with fragment of cladodes (except S3) and inverted cladodes plantation (S7) were very significantly ($p<0.01$) affected at the end of trial. The other treatments were not significant. After all, size, position and orientation of the cladode affect the cumulated photosynthetic area.

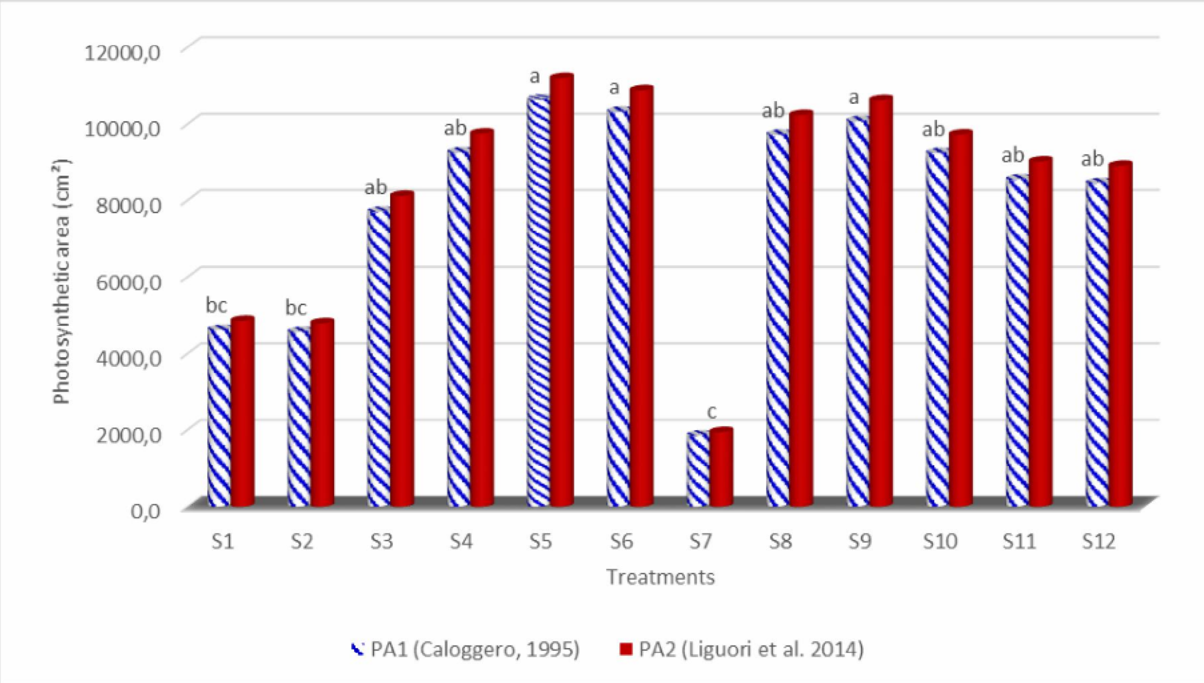


Figure 3. Photosynthetic area for the different treatments according to two methods of estimation (PA1 and Pa2 cf. Methodology). The values with the same letter are statistically not significantly different according to SNK test.

Root growth. The analysis of roots showed very highly significant differences between treatments (Table 5). In fact, S12 was the best treatment in term of root growth and root mass production. The root length (tap root) reached 30 cm, side roots reached 180 cm and a dry matter of 180 g after four years for the S12 depth. However, we note in the aboveground part analysis that plants of this treatment had significant better count of cladodes compared to the other treatments at time of measurement. In addition, S7 was the worst treatment registering the lower performances for root growth. Nevertheless, if we analyze the growth of aboveground part to the root growth part, we found no statistical differences between treatments for rooting.

Fruit yield. Fruit weight and number (Figure 4 & 5) was better in year 3 (three after plantation) for S5 while in the following year the number of fruits and the yield was significantly ($p<0.05$) distinct for the S6 and S11 compared to the control (S4). S7 method produced the worst fruit yield. Size of cladode was almost not significant in the last timepoint for fruit number and production. While surprisingly for depth, S11 produced the best fruit number and weight, especially for the last timepoint. In addition, the orientation also influenced significantly the fruit yield in the last timepoint where S10 produced lower significant fruit weight.

Table 5

Comparison of root length and mass for different treatments

Treatment		*HP (cm) (ns)*	*DPG (cm) (ns)*	*NR (***)*	*PDAS (g) (***)*	*HR (cm) (ns)*	*DRG (cm) (**)*	*PDRS (g) (**)*
S1	Mean	60.0^{a}	107.0^{ab}	15.7^{b}	1,144.7^{b}	20.7^{a}	108.7^{ab}	74.1^{b}
	SD	±9.0	±22.5	±4.5	±486.8	±4.2	±22.0	±33.5
S2	Mean	61.0^{a}	134.3^{ab}	18.7^{b}	816.0^{b}	20.3^{a}	162.0^{ab}	94.2^{b}
	SD	±20.2	±25.0	±3.2	±552.7	±0.6	±29.9	±25.2
S3	Mean	64.0^{a}	141.7^{ab}	18.3^{b}	1,403.9^{b}	23.3^{a}	124.0^{ab}	86.6^{b}
	SD	±10.1	±37.7	±4.9	±200.4	±5.0	±13.1	±3.3
S4	Mean	76.3^{a}	148.3^{ab}	26.0^{ab}	1,941.9^{ab}	28.6^{a}	166.1^{ab}	130.3^{ab}
	SD	±16.0	±18.9	±4.7	±407.5	±4.3	±17.4	±24.8
S5	Mean	71.7^{a}	152.3^{ab}	27.3^{ab}	1,833.2^{ab}	27.0^{a}	159.3^{ab}	118.2^{ab}
	SD	±10.1	±29.5	±2.5	±343.2	±1.0	±11.0	±25.0
S6	Mean	70.0^{a}	147.7^{ab}	23.7^{ab}	1,728.3^{ab}	30.0^{a}	175.0^{a}	111.8^{ab}
	SD	±6.0	±28.6	±1.5	±276.3	±6.2	±13.2	±19.5
S7	Mean	53.0^{a}	102.7^{b}	14.7^{b}	695.6^{b}	24.0^{a}	98.0^{b}	51.6^{b}
	SD	±18.4	±68.4	±10.3	±737.6	±10.6	±54.1	±65.8
S8	Mean	66.3^{a}	142.3^{ab}	26.0^{ab}	1,660.3^{ab}	28.0^{a}	157.0^{ab}	108.7^{ab}
	SD	±5.5	±22.5	±1.0	±56.6	±6.0	±2.6	±12.3
S9	Mean	57.7^{a}	181.0^{a}	22.7^{ab}	1,422.3^{b}	23.0^{a}	161.7^{ab}	99.9^{ab}
	SD	±9.5	±28.2	±3.8	±64.4	±5.6	±7.6	±10.1
S10	Mean	66.7^{a}	146.3^{ab}	19.7^{b}	1,292.0^{b}	27.0^{a}	121.7^{ab}	86.4^{b}
	SD	±2.9	±7.1	±6.4	±510.1	±5.2	±55.3	±52.8
S11	Mean	61.0^{a}	125.3^{ab}	19.7^{b}	1,362.8^{b}	29.0^{a}	138.3^{ab}	84.5^{ab}
	SD	±14.1	±3.2	±3.8	±285.6	±6.1	±23.6	±25.9
S12	Mean	77.7^{a}	153.3^{ab}	33.7^{b}	2,714.3^{a}	30.7^{a}	179.3^{a}	179.6^{a}
	SD	±11.9	±3.5	±6.5	±1,150.0	±3.5	±31.0	±65.6

Note. - (Mean ± Standard deviation (SD), df=16 except for S1 n=13 (tree plant died));
The values in the same column followed by the same letter are statistically not significantly different according to SNK test (*** $p<0.001$; ** $p<0.01$; ns not significant);
S1 to S12 (cf. table 1).

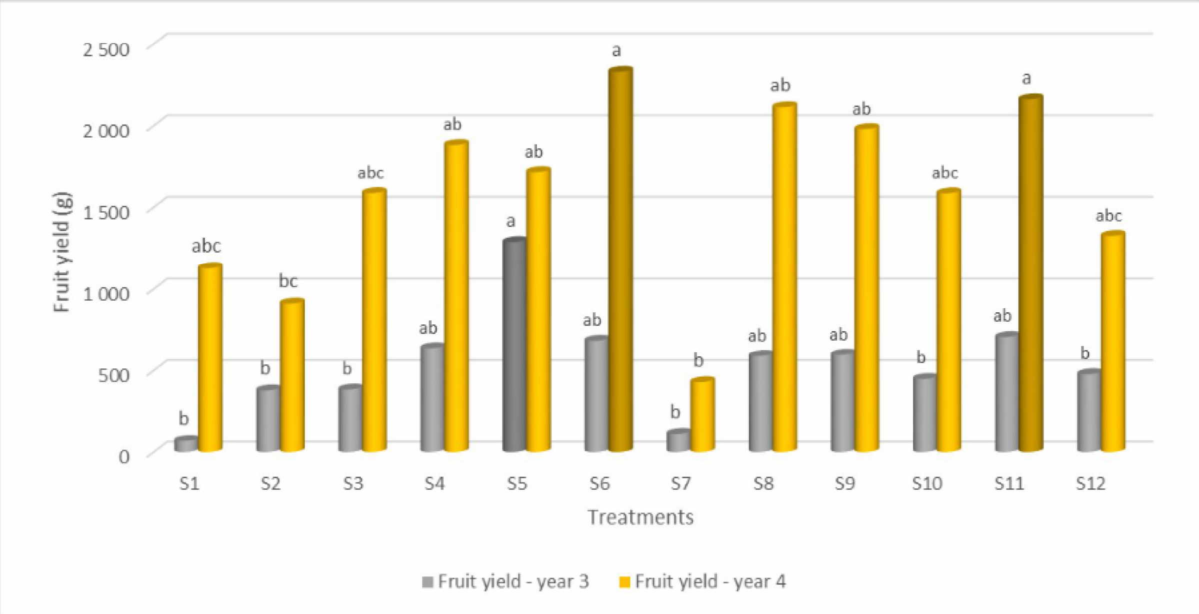


Figure 4. Fruit yield during year 3 and 4 from planting. The values with the same letter are statistically not significantly different according to Duncan test.

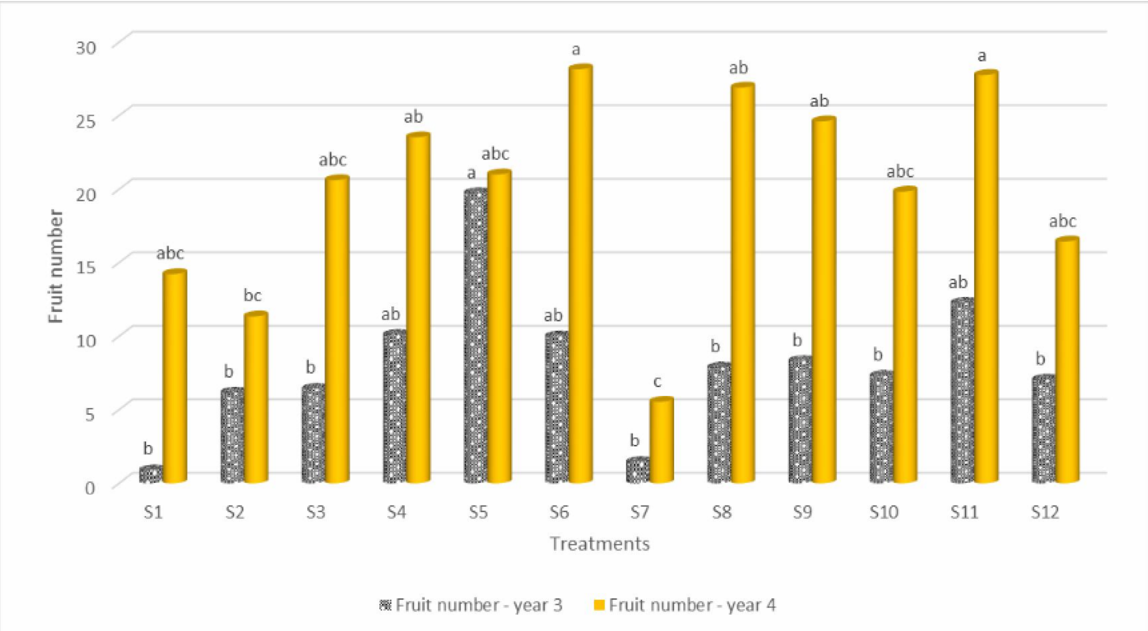


Figure 5. Fruit number during year 3 and 4 from planting. The values with the same letter are not significantly different according to Duncan test.

Discussion

Size of the cladodes. The results indicated that cladode size positively influenced the growth rate and dry matter production of the plant. However, when we compare the RGR, the case is inverted for the growth height rate. This could be explained by the additional threats of adaptation that possess small cladodes for light interception and rapid growth. Somehow, small ones invest a relatively greater proportion of the assimilated carbon in growth height to reach the big ones, while big ones allocate more resources to stem elongation and production so that the RGR for diameter, cladode number and dry matter accumulation was better accordingly to the cladode size. As plants are getting bigger, RGR usually decrease, making thus the comparison of plant individuals with different sizes difficult (Rees et al 2010). Resource allocation in the

Cactaceae has been studied at the philological level (e.g., Nobel 1988; Inglese et al 1999). RGR is a complex parameter determined by a number of physiological, morphological and biomass-allocation components. Mondragón-Jacobo et al 2001 stated that in areas in which Opuntia cultivation is traditional, healthy, vigorous branches with two to three pads are the best choice (Mondragón-Jacobo et al 2001). Fractionated cladodes are the best choice when the availability of material is spread poor to high cost transportation (Mondragón-Jacobo & Pimienta 1995). In this case, if we have to plant pieces of cladodes, our results showed that two-thirds single cladode is the optimal choice. It was better than half single cladode, this last was also better than third single cladode basically in term of dry matter production. In Argentina, also double cladode plants reached a greater photosynthetic area and total cladode number than the single cladode plants (Caloggero & Parera 2004). Franck (2000) and Sudzuki et al (1993) recommend also the use of double or triple cladodes since this leads to accelerate the formation of the vegetative plant structure and earlier fruit production than when single cladodes, and may even have some fruit during the first season (Caloggero & Parera 2004). However, this requires much material, which could be a limiting factor when you want to plant large areas. The production and growth of new cladodes are essentially influenced by the size of basal cladodes planted, which act as a carbon source for the new shoots (Luo & Nobel 1993). For CAM plants like cacti, the CO_2 fixation performed during night depends essentially on the photosynthetic area and the active radiation intercepted during the day. This was demonstrated for the size in our case by the Figure 1 on which size played an important role in determining the final photosynthetic area (double cladode was better than single cladode also better than two-thirds single cladode and so on).

Position of cladodes in planting. Even if we plant cladode in the horizontal side, or upside-down positions like in our case, the next daughter cladodes were vertically configured. In spite of that, our results demonstrated that horizontal side position gave the best starting results in term of growth, dry matter and fruit production, while the upside-down position registered the worst performances. These results could be explained by an equilibrated number of areoles in above and below ground in horizontal position compared to the other positions. In addition, we noted an equilibrated cladode charge over the first horizontal cladode compared to others. This position permitted also the best root-growing diameter and mass. In this case, this method affected also the cumulated photosynthetic area and as a consequence the finale growth and production results. Therefore, this would an originality of this work because we did not found in the literature any work done before comparing horizontal side and upside-down position. For the upside down direction, the modest results registered could explained by direction of Sap in the initial cladode that took a reversed direction, but this hypothesis should be confirmed. In fact, there is another method in Mexico called the flat position or horizontal on top soil that was not tested in this work. This method is suitable for rainy seasons and not recommended for warm, sunny and windy regions (Sortibran et al 2005).

Exposition or orientation of the cladodes to the sun. Our results indicated the east – west as the best initial planting direction, especially in terms of number of cladodes produced, dry matter and fruit production followed by the north west-south east direction. In reality, we observe that the daughter cladodes of the East/West turned gradually to North/South direction. This could be explained by the avoidance of direct sun at midday for small cladodes in East/West direction (the flat side was placed perpendicular to the path of the sun in the morning). Additionally, this direction is also confirmed as the most beneficial according to Becerra-Rodriguez et al (1976) and Pareek et al (2003). This direction permitted greater uptake of direct sunlight (more efficient in capturing light) and thus, we have a better photosynthetic area, fruit production, dry matter accumulation and great numbers of roots. Cladodes are frequently oriented east–west direction in intertropical latitudes, allowing them to intercept additional radiation during the year than north–south faced cladodes (Nobel 1980, 1981; Cano-Santana et al 1992). In Central Mexico, east-west facing cladodes of *Opuntia amycleae* received more photosynthetical active radiation and had greater dry matter accumulation than north-south facing ones (Becerra-Rodriguez et al 1976). In Israel, OFI was found faced in all directions equally (Konis 1950). *Opuntia chlorotica* was found facing north-south in the Mojave Desert and east-west in the Sonoran desert (Nobel & Bobich 2002). Consequently, the radiation environment of both sides of a cladode must be considered to predict its productivity. Nevertheless, in very warm regions (where temperatures are very high) like our region, Pimienta-Barrios (1990) recommended to invert the direction to avoid cladodes soil burning. At higher latitudes, the tendency is to expose cladodes to north–south due to the favorable growing season occurring in winter season (Nobel 1982). Inglese (1999) mentioned that the distance between rows should be considered to avoid shading between plants.

Finally, in arid regions with frequent frosts and wind, it was recommended to place the cladode edge where the winds direction blow dominant because light is not considered as a limiting factor in arid regions (Nobel 1988).

Planting depth and root mass. Cladodes initiate the rooting process soon after they come in contact with soil. The initial roots are essentially supported by the water stored in the cladode. With respect to depth, no big differences were registered between the three depths. However, our results were in contrast with Pareek et al (2003) under arid conditions in India, in our case, planting the cladodes by keeping their 1/3 portion underground produced lower average dry matter production (Table 3 & 4) but surprisingly it had the best lateral growth and fruit production in the last timepoint. Our results were conversely in harmony with Gutiérrez et al (1994) that suggested burying two third parts of the cladode volume, as not to, there is a risk to be broken by the prevailing wind (Gutiérrez et al 1994). This depth permitted the best absolute dry matter production (Table 3 & 4) but equally well as the control (S4) for growth and fruit production. The main differences were registered in the side root growth. Besides, lateral roots of Opuntia species are formed during periods of soil drying where lateral roots emerge in response to rainfall and as soil dries (Nobel et al 1991). S12 permitted the best rooting emergence because of placing more areoles in the soil and therefore more roots were developed. By the way, the basic meristematic unit of Opuntia is the areole that can develop either branches, flowers (Boke 1980; Sudzuki 1995) or roots (Gibson & Nobel 1986). If the cladode is superficially planted, the photosynthetic active surface will be superior, but it may be affected by wind and its root system may be very shallow, whereas burring pad more than 70%, could be not good for sprouting and root development because the photosynthetic active surface will be greatly reduced (Inglese 1999).

The initial cladode size affected also rooting, in fact, roots were more important for normal and double cladodes than fractioned cladodes. Differences in root development from the areoles can be attributed to the different shapes and sizes of the cladodes of OFI (Snyman 2006). However, according to Mondragón-Jacobo & Pimienta (1995), the size of the cladode does not affect the ability to form shoots or roots, but the size of the cladode was correlated positively to the number and size of the new shoots. The upside down position (S7) affected negatively the growth of roots because maybe of the reversed sap direction while exposition of the pad to the sun had no big effect on root mass and growth (except for S10).

The root system of the succulent *O. ficus-indica* is a complex parameter to follow because it spreads predominantly in the upper layers of the soil, where the soil-water content is both temporally and spatially heterogeneous (Sudzuki 1995; Nobel 2001; Snyman 2004, 2006). For root length (height), our experiment showed no differences between treatments. According to Snyman (2004), root length and mass of OFI change according to water stress (sensitive to water stress). In our case all plants were equally irrigated.

Fruit production. Fruit production was better for S5 method in the third year. This was in Caloggero & Parera (2004) that found that the double cladode system produced earlier fruits and the highest yields from the second year onwards. Nevertheless, in the fourth year, we note a regression for the S5 method in comparison with S6 and S11, which they were the best methods. De Cortazar & Nobel (1992) showed that an increase of dry matter allocated to the fruit was accompanied by a reduction in cladode count and dry weight accumulation. This was the case for S5 method whose fruit production in the third affected dry matter production for the following year. Once again, S6 method has proved to be one of the best-adapted planting methods for dry regions that produced the best fruit production with the S11 method in this trial. Fruit productivity in *O. ficus-indica* can also be increased by increasing the number of fertile or one year old-fruiting cladodes per plant and/or by increasing the plant population (Inglese et al 2002). The greater increase seen in the number of cladodes in the S6 system have been accompanied by a high accumulation of dry weight, leading to greater fruit harvest.

In summary, although there are researches in progress to obtain a better understanding of spineless *O. ficus-indica* behavior to different climatic conditions in Morocco, there is still a lack of knowledge on the best planting methods according the climatic context and permitting the best starting production. The results obtained from this study are very important for farmers in the way they permit to clarify how to plant *O. ficus-indica* in arid region to obtain good results quickly.

Normally several planting were good enough as showed in Principal Components Analysis (Figure 6). Only planting systems S1, S2 and S7 should be avoided.

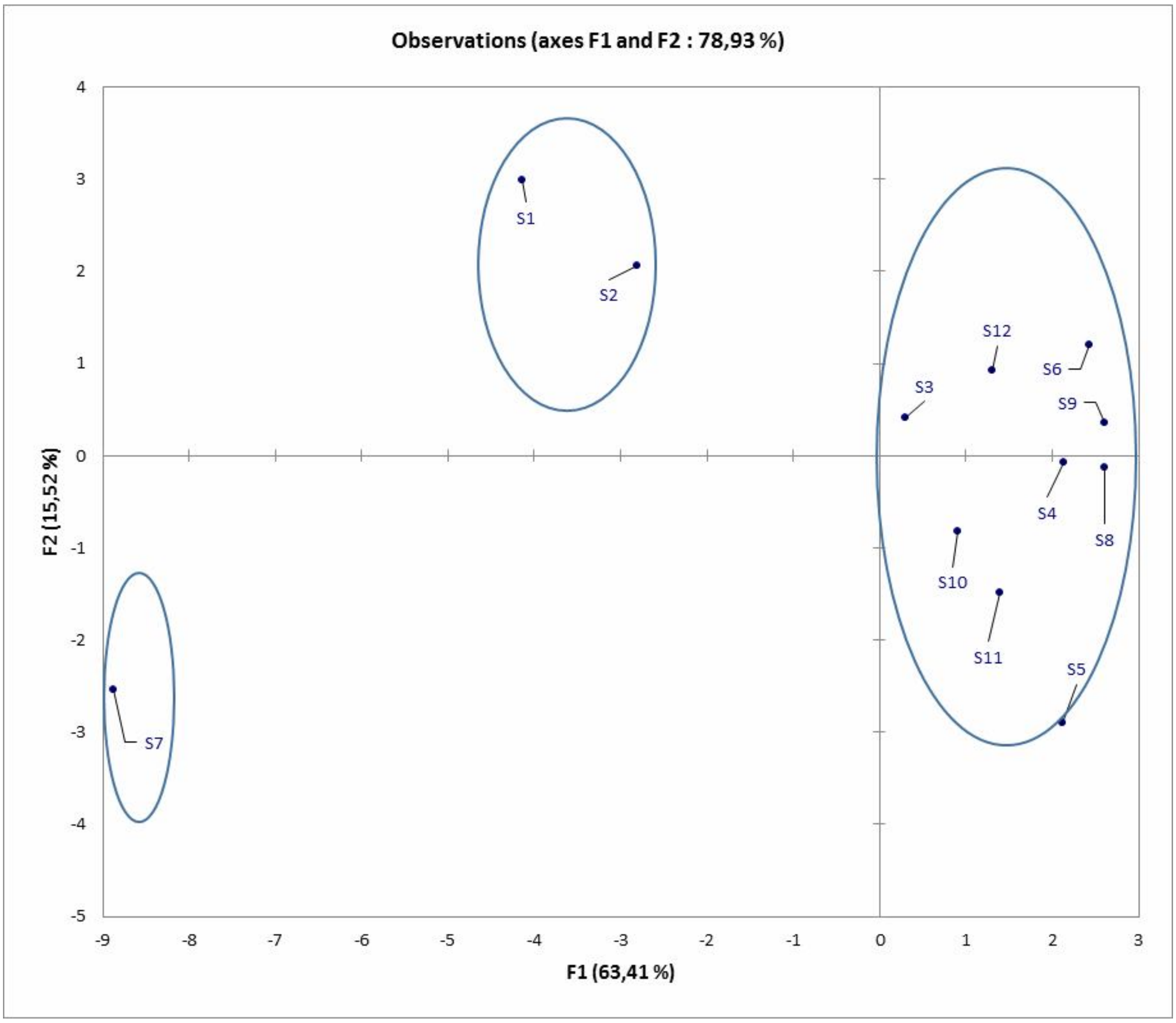


Figure 6. PCA analysis of planting systems including all traits studied.

Conclusions. The common recommendation that *O. ficus-indica* should be planted in the upright position of full cladode does not gave necessarily best results as in the South east of Morocco, under no limiting temperature and water availability conditions, morphological and architectural features. In fact, the horizontal side plantation gave the best starting growth rate (for aerial part and root part) and production performances. This method was found to be the most suitable for arid regions and could be adopted as standard method for the next plantations.

For normal upright cladode plantation, we should adopt an East-west direction (face cladode to the sun) that gave the best dry matter and fruit production. Regarding the planting depth, not significant differences were registered among the three depths tested (S4, S11, S12) but we recommend to bury two-thirds cladode in the ground that produced the best rooting and also to avoid breaking of cladodes by wind. At that point, treatments were done only for the upright position, whereas additional interactions should be studied for the horizontal position. Finally, this study had only taken care of phenotypic observations; therefore, further physiological studies should be carried out to provide more clarifications.

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