Original article

Effects of nitrogen and phosphorus fertilization on fruit yield and quality of cactus pear *Opuntia ficus-indica* (L.) Mill.

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Summary

Introduction – **In order to optimise the nitrogen (N) and phosphorus (P) fertilization of cactus pear in arid regions, we decided to determine its effects on the yield and fruit quality as well as on the plant phenology.** *Materials and methods* – **Five N-P dressings were compared on the spineless cv. Moussa in the Agadir area: 0–0, 0–80, 40–40, 60–0, and 60–80 (in kg N ha^{-1} – kg P_2O_5 ha^{-1}) over two consecutive growing seasons (2011 and 2012). Yield components and physico-chemical characteristics of the fruit were recorded at harvest.** *Results and discussion* – **Although in 2011 the applications of N and P had no effect on fruit yielding, in 2012 the dressings 60N or 80P alone increased the yield by +3.0 and 6.1 kg plant^{-1}, respectively, compared with the control. Combining both N and P at the same rate resulted in a maximum yield of 14.9 kg plant^{-1}. Fertilization had positive effects on flowering rates, fruit size and fruit number, and did not modify the content of pulp, the juice content, peel thickness, the juice dry matter, the pH, titratable acidity, total sugars and soluble solids. It also did not modify the dates of flowering and of ripening. Nitrogen dressings significantly increased the number of emitted buds and emitted shoots on one-year cladodes by four fold.** *Conclusion* – **Relevant N-P fertilization significantly improved fruit yield, the number of fruits per plant and fruit size in particular. Long term and postharvest effects shall be further studied.**

Keywords
Morocco, cactus pear, *Opuntia ficus-indica*, agronomic yield, crop management, fruit quality, phenology

Significance of this study

What is already known on this subject?

- Studies on mineral fertilization of cactus pear were carried out in some countries where cactus pear is cultivated. Several authors reported that mineral fertilization increased fruit yield, but some of them have indicated that fruit quality could be affected by fertilization.

What are the new findings?

- Obtained results showed that nitrogen and phosphorus mineral fertilization improved fruit yield, mainly fruit size (weight and dimensions). Fruit quality was not significantly affected. Mineral fertilization also increased the emission of buds and of shoots.

What is the expected impact on horticulture?

- Understanding the effects of nitrogen and phosphorus mineral fertilization on fruit yield and quality of cactus pear. The improvement of cactus pear managing practices, mainly the application of fertilizers, pruning and harvesting. The improvement of the socio-economic life of the farmers and the rural populations in the arid and semi-arid regions, notably in Morocco.

Résumé

Effets de la fertilisation azotée et phosphorique sur les composantes de rendement et la qualité des fruits du figuier de Barbarie *Opuntia ficus-indica* (L.) Mill.

Introduction – **La fertilisation azotée (N) et phosphorique (P) du figuier de Barbarie a besoin d'être optimisée en zone aride. Cette étude vise à en évaluer les effets sur le rendement et la qualité des fruits et à en décrire les effets sur la phénologie de la plante.**

Matériel et méthodes – **Cinq fumures N-P ont été comparées pendant deux années sur la variété inerme 'Moussa' dans la région d'Agadir: 0–0, 0–80, 40–40, 60–0, et 60–80 (en kg N ha^{-1} – kg P_2O_5 ha^{-1}). Les composantes du rendement et les caractères physico-chimiques des fruits ont été enregistrés à la récolte.** *Résultats et discussion* – **En 2011, les différent niveaux de fertilisation n'ont pas eu d'effet sur le rendement alors qu'en 2012, l'interaction entre N et P était très significative. En comparaison avec le témoin, l'apport de 80P ou de 60N a augmenté le rendement de +3,0 et +6,1 kg plante^{-1}, respectivement, et le traitement 60N + 80P de +14,9 kg plante^{-1}. Les traitements fertilisants ont eu des effets positifs sur le nombre de fleurs et le nombre de fruits formés, ainsi que sur le calibre des fruits; en revanche, ils n'ont pas eu d'effet significatif sur la teneur en pulpe et en jus de fruits, l'épaisseur du tégument, la teneur en matière sèche du jus, le pH, l'acidité titrable, les sucres totaux et matières sèches solubles. Ils n'ont pas nettement modifié les dates de floraison et de maturation des plantes. Cependant,**

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l'apport d'azote a augmenté le nombre de bourgeons émis par cladode et le nombre de pousses sur les cladodes d'un an, jusqu'à le multiplier par 4 environ. *Conclusion* **– Une fertilisation N-P appropriée permet d'améliorer de façon significative le rendement en fruits des cultures de figuier de Barbarie en condition aride, en particulier le nombre de fruits par plante et le calibre des fruits. Les effets dans la durée et en post-récolte doivent encore être étudiés.**

Mots-clés
Maroc, figuier de Barbarie, *Opuntia ficus-indica*, rendement agronomique, gestion de la production, qualité du fruit, phénologie

Introduction

The growing market demand for cactus pear fruits is pushing producing countries to increase their surface areas devoted to this crop and its productivity. Therefore, new plantations of cactus pear are increasing in several Mediterranean countries (Nerd and Mizrahi, 2010; Inglese, 2010; FAO, 2013) and particularly in Morocco. However, the recorded yields in Morocco are still very low due to extensive cultivation and almost no application of mineral fertilization.

Cactus pear is cultivated since a long time in Morocco for its edible fruits and its pads as fodder for cattle. The area occupied by cactus pear evolved in a remarkable way during these last decades to reach currently more than 120,000 ha. Thousands hectares of aligned plantations with a density of plantation of 1,000 plants ha^{-1} (5 m between rows × 2 m between plants) devoted to fruit production and fodder for cattle are carried out in the areas of cactus pear within the framework of the Moroccan Green Plan. The production of cactus pear in Morocco is still traditional, the techniques of production are still empirical and crop production and fruit quality are weak. The production is sold at low prices on the local market and the possibility of exporting fresh fruits with a great size is scarce. The development of this crop in Morocco requires an improvement of the cultural practices, mainly the irrigation and the mineral fertilization, subject of the current article, with aim to improve the yield and fruit quality and to ensure a good selling price on the local and overseas market.

Several authors have shown a positive effect of fertilization on fruit yield and fruit quality (Inglese, 2010; Ochoa and Uhart, 2006; Mimouni *et al*., 2013; Jorge Zegbe *et al*., 2014). Application of nitrogenous and phosphoric fertilizers at 120 kg N ha^{-1} and 100 kg P_2O_5 ha^{-1} on an 8-year old plantation of cactus pear increased fruit yield by more than 80% in comparison with non-fertilized plants (Inglese, 2010). Claassens and Wessels (1997) reported that the best fruit yield from a 4-year old plantation of cactus pear was obtained with the application of a N-P fertilizer with 60N (kg N ha^{-1}) and 16P (kg P_2O_5 ha^{-1}); however, no effect on fruit quality was recorded under this fertilization. Jorge Zegbe *et al.* (2014) reported that the application of 90N, 30P and 30K (kg K_2O ha^{-1}) on an adult plantation of cactus pear during three consecutive seasons increased fruit yield significantly: 9.6 t ha^{-1} in year 1, 13.1 t ha^{-1} in year 2 and 21.6 t ha^{-1} in year 3. This mineral fertilization had however, no effect on fruit quality and the application of potassium alone had no effect on fruit yield (Jorge Zegbe *et al*., 2014).

On a 7-year-old plantation of cactus pear, Ochoa *et al.* (2006) showed that the application of a nitrogenous fertilizer increased fruit yield significantly. In the second cropping season fruit yield was 1,346 g m^{-2} on plants receiving 100 to 150 kg N ha^{-1} against 594 g m^{-2} for the control without N. However, fruit weight was higher in the treatment without N (27.1 g in dry weight) than in the treatments receiving N. Mimouni *et al.* (2013) showed that application of an [N-P-K-Mg] fertilizer on 14 selected productive ecotypes increased the fruit yield by more than 27% and had a positive effect on the fruit quality of these ecotypes.

Karim *et al.* (1998) reported that application of a nitrogenous fertilizer combined with phosphorus and potassium at a rate of 100 kg ha^{-1} for each element on a 3-year-old plantation of cactus pear had no significant effect on fruit yield and fruit quality, but significant correlation existed between fruit yield and the contents of cladodes tissue in mineral elements. Galizi *et al.* (2004) also noted the absence of effects on fruit yield and fruit quality with application of an [N-P-K-Mg] fertilization of 100-50-100-50 kg ha^{-1} on an 8-year-old plantation of cactus pear with a density of 4 × 4 m. These results could be due to the high fertility of the soil.

Fruit quality is a complex concept evaluated on the basis of the appearance of fruit on the market (Barritt, 2001), mainly fruit size and color (FAO, 2013; Callahan, 2003). In Italy, cactus pear fruits are classified into five sizes: extra (>200 g), great (151 to 200 g), medium (121 to 150 g), small (80 to 120 g) and very small calibre (<80 g) (Chessa and Nieddu, 1997). In South Africa, the varietal evaluation for a commercial product based on the following minimal criteria: fruit weight >140 g, total soluble solids (TSS) >13 °Brix, percentage of pulp >50% and peel thickness <6 mm (Potgieter, 2007; De Wit *et al*., 2010). Karababa *et al.* (2004) and Bekir (2006) suggested that the size and weight of cactus pear fruit are influenced by locality, season and environment. Fruit quality is also influenced by orchard management and may change from year to year (Ochoa *et al*., 2006; Mokoboki *et al*., 2009). Whereas Felker *et al.* (2002) reported that fruit size was not determined by environmental or edaphic factors, but genetic factors. The chemical composition of fruit determines its global quality. Thus, in cactus pear, fruit quality is evaluated on the basis of its color, weight and contents of the pulp and sugars (FAO, 2013) and in edible fresh matter (Mashope, 2007). Maataoui-Belabbes and Hilali (2004) reported TSS = 11.9 °Brix, pH = 5.9 and a titratable acidity (TA) of 0.02% in a fruit juice of prickly pear with a yellow orange color, and Arba and Sharoua (2013) reported a juice rate of 49.9 to 57.3%, TSS of 12.3 to 12.5 °Brix and TA of 0.041 to 0.069% in the var. Mles [*Opuntia ficus-indica* (L.) Mill.] and Draibina (*O. megacantha* Salm-Dyck) grown in the central area of Morocco. In clones of *Opuntia* with fruit of various color, TSS of the edible core varied from 7.5 to 13.8 °Brix, TA from 0.01 to 0.30% and pH from 4.3 to 6.1 (FAO, 2013).

The first objective of our study is to evaluate the effects of nitrogen and phosphoric mineral fertilization on fruit yield and fruit quality in order to have a scientific basis for advising the cactus pear producers. The second objective is to describe the possible effects of the N-P fertilization on the morphological development of the plants by monitoring the growth phases, including the dates of the different stages such as floral bud emission, flowering or fruit maturation. Our first hypothesis is that N-P fertilization could modify the time for ripening – by earliness or lateness – offering some commercial advantage. Our second hypothesis is that mineral fertilization would stimulate an intense renewal of cladodes, the young cladodes being more prolific in fruit.

Materials and methods

The site of trials and plant material used in the study

Our studies were carried out at the experimental station of the Hassan II Institute of Agronomy and Veterinary Medicine, Horticultural Complex of Agadir, located at 17 km in the South East of Agadir city, latitude 30°36' North and longitude 9°36' East and 32 m altitude. The site of experiment is characterized by mean monthly temperatures ranging from approximately 8 °C in January to 31 °C in July, with maximum daily temperature reaching 45 °C in June-August.

Experiments were set in an orchard planted in 1998 with cactus pear (*O. ficus-indica* (L.) Mill., cv. Moussa) where plant spacing was 3 × 1 m apart. The cv. Moussa is a spineless variety of *Opuntia ficus-indica* with yellow-orange fruit at maturity.

The soil of the experimental site has a sandy silt texture with 18.51–23.30% coarse sand, 30.00–34.70% fine sand, 18.60–22.09 coarse silt, 19.96–21.45% fine silt and 5.45–7.45% clay. The chemical composition of the soil prior to the application of fertilizers was as follows: poor in available nitrogen (4.5–12.4 ppm), medium in available P (0.094–0.168‰), good or high in Ca (1.456–3.360‰), in K (0.347–0.694‰) and in Mg (0.260–0.940‰). The content of soil in organic matter was low to passable, the electrical conductivity (at 25 °C) was passable (0.13–0.16 mmhos cm^{-1}) and the pH (at 1:2.5 soil:water) was average to alkaline (8.4–8.6).

The experimental design

The following N-P combinations of nitrogen (N) and phosphorus fertilizer (P_2O_5) as units (kg ha^{-1}) were applied: T1: 0–0; T2: 0–80; T3: 40–40; T4: 60–0; and T5: 60–80. The experimental design was a complete randomized block with 4 blocks, each containing the 5 plots or experimental units corresponding to the fertilization treatments. Fertilizer doses in soluble form were injected in the irrigation system. They were applied once a week during the period of flowering when all the experimental plots received irrigation. Thirty mm irrigation water were applied at a rate of 4 mm per application during the period of April–May 2011, and 60 mm were applied at a rate of 8 mm per application during February 2012.

Fruit yield was determined based on the production of 2 plants per fertilization treatment and per block, which means 8 plants by treatment. It was expressed in kg fruit $plant^{-1}$ or kg ha^{-1} considering a density of planting of 3,300 plants ha^{-1}.

Physico-chemical analyses of the fruits

The evaluation of fruit quality was related to (i) fruit size: fruit and pulp weight, peel weight, fruit dimensions (fruit length and diameter at mid-length) (ii) the organoleptic and chemical characteristics of the fruit: the content of juice, soluble solids (in °Brix), titratable acidity, pH, total sugars and dry matter in the juice. The physical measurements were done on a sample made of 20 fruits per treatment and per block. The analytical qualitative features were determined on an average sample made of 5 to 6 mixed fruits per treatment and per block.

The content of juice is the percentage of juice contained in the fruit pulp; it was determined by separating pulp from the peel. The juice is extracted from the pulp by grinding and centrifugation (1 min) and juice collection (1 min). The measure was recorded 3 times per juice sample of fertilization and block.

The measurement of the juice pH was done by potentiometric method using a pH-meter calibrated on pH-4 and pH-7 buffer solutions. The measurement was done three times by fertilization treatment and by block on agitated fruit juice.

The titratable acidity was determined by the volume of solution of NaOH 0.111 N necessary to make fire the solution of juice to a pH of 8.1. It is expressed in g L^{-1} citric acid. Measurement was repeated three times at least per treatment and per block.

The TSS was determined by using a digital refractometer (ATAGO DBx 55, Japan). Measurement was repeated 5 times for each treatment of fertilization and per block.

To determine the dry matter content of the juice, a 100-mL beaker containing a glass rod and about 25 g sea sand washed with sulfuric acid was placed in an oven at 70 °C for at least 30 min and weighed after cooling in a desiccator. A test sample of approximately 5 g of juice was added into the beaker. Using the glass rod, the sample was homogenized with the washed sea sand with sulfuric acid then the set was placed in an oven at 70 °C for 24 h and weighed after the beaker was cooled in a dryer until it returned to room temperature. The dry matter content of the juice is computed as follows:

$$DM\% = 100 \times \frac{(m2-m0)}{(m1-m0)}$$

where m_0 is the mass of the beaker with glass rod and washed sea sand, m_1 is m_0 + 5 g of juice before drying and m_2 is m_1 dried in the oven after homogenizing the sample of juice with sea sand. The measurements were replicated 3 times per treatment and per block.

The analysis of sugars was realized according to AOAC methods (AOAC, 2002). Total sugars were proportioned after freeze-drying of the juice and hydrolysis with hydrochloric acid. The hydrolyzed solution was neutralized by a concentrated solution of sodium hydroxyde and deproteinized with the solutions of Carrez I-II. According to the sugar content of the product an aliquot of filtrate was added to the reactants of Bertrand I and II and the mixture was brought to boiling and then cooled rapidly. After decanting, the supernatant liquid (blue) was vacuum filtered in as interred glass crucible and the precipitate was washed several times with freshly boiled water. The copper oxide precipitate was then dissolved with a ferric solution, rinsed and titrated with a potassium permanganate solution (permanent pink color). Titration was repeated twice per treatment of fertilization and block.

The phenology of flowering and fruiting of the plants

To study the effects of the mineral fertilization on the phenology of the plants during the two successive years, 10 one-year-old cladodes per plot (treatment and block) have been selected and labelled, These cladodes were monitored about every ten days from buds emission (February) until end of fruit maturation (September), via the shoots emission and flowering stages.

Statistical analyses

Statistical analyses of data consisted mainly of analyses of variance (ANOVA) and when the values are different at a level of probability ($P < 0.05$) the least significant difference (LSD) between these values was computed. The intensity of the relation existing between two variables at a level of probability was assessed by the coefficient of correlation.

Table 1. Effect of five N-P dressing treatments (T1–T5) on cactus pear (cv. Moussa) fruit yield (kg plant^{-1}) over two years in Agadir area, Morocco.

Years		T1	T2	T3	T4	T5	F-test	Lsd
	N-P	0–0	0–80	40–40	60–0	60–80		(P < 0.05)
2011		16.52	14.64	13.46	17.37	19.59	*	4.67
2012		16.49	19.44	21.19	**22.54**	**31.26**	**	5.26

*: significant difference at P < 0.05; **: significant difference at P < 0.01.
Lsd: least significant differences at the corresponding level of significance.
In bold: values that are significantly different (at P < 0.01 level) from the T1 value in 2012.

Results and discussion

The results obtained during the two seasons (2010/2011 and 2011/2012) are presented in two sections, the effects of fertilization (i) on fruit yield and fruit quality and (ii) on the phenology of flowering and fruiting.

Fruit yield and quality

Fruit yields for the two years of production are displayed in Table 1. Plants of the control (T1) without any fertilizer recorded similar yields (16.5 kg plant^{-1}) for the two years. In 2011, fertilization treatments had minor effects on the yield, the only significant difference being recorded between T3 (40–40) and T5 (60–80). The absence of significant effects in the first year can be related to late application of the fertilizers during the crop cycle and the high vegetative growth of the 14-year old plants.

In 2012, fertilizations had significant effects on the yields, in particular for treatments T4 (60N-0P) and T5 (60N-80P). Our data analysis highlighted a significant interaction between the two elements nitrogen and phosphorus: in fact, the control treatment that received no fertilization recorded the lowest yield, while applying 80P increased the yield by +3.0 kg and applying 60N increased it by +6.1 kg. The simultaneous application of 60N + 80P had a significant effect on the yield with an increment of +14.9 kg, showing a positive interaction evaluated at 5.8 kg plant^{-1}. Similar results have also been reported by several authors who showed that mineral fertilization, in particular nitrogenous and phosphoric, has a positive effect on fruit yield (Inglese, 2010; Ochoa and Uhart, 2006; Mimouni *et al*., 2013; Jorge Zegbe *et al*., 2014; Claassens and Wessels, 1997). The effect of N appears more pronounced than that of P. The main reason is due to the fact that nitrogen is well known for its rapid and intense action on the yield. However, P has a weaker effect on yield except in severe primary deficiency in the soil. In addition, phosphorus has typically a slower mobility in the soil and in the plant, and could be subject to immobilization in calcareous or alkaline soil (the content of $CaCO_3$ in the soil of the experiment site can reach 6.5% and the pH = 8.4–8.6). Finally, the mobility of P-ions in the plant is slower than that of N-ions. The existence of a positive interaction between N and P – at least at the low doses studied – opens the way to a finer study for optimising N-P fertilization.

As Galizzi *et al.* (2004) reported that the K and Ca content of cactus pear fruits and pads are higher than other fruits and vegetables and despite several other authors reported that the application of K fertilizer had no effect on fruit yield of cactus pear (Jorge Zegbe *et al*., 2014; Claassens and Wessels, 1997) it could have been possible that the plants requirements for Ca and K nutrients were not met. A chemical analysis of one year pad tissues collected in October 2013 showed that the nutrient contents of pads in T5 were (in g kg^{-1} for each of the nutrients): N = 10.5, P = 1.3, K = 30.0, Na = 0.4, Ca = 52.2 and Mg = 9.5. The chemical composition of the non-fertilized control (T1) was (in g kg^{-1}): 9.8, 1.2, 28.0, 0.3, 46.7 and 9.8, respectively. The best mineral nutrient concentrations for maximum fruit yield in cactus pear according to Valdez-Cepeda *et al.* (2013) were (in g kg^{-1}): N = 11.4 ± 5.2; P = 3.4 ± 0.7; K = 42.3 ± 8.6; Ca = 42.5 ± 14; and Mg = 16.2 ± 4.4. Thus, in our case, all the optimum nutrient concentrations were reached with T5 as well as with the control (T1), except for P with a slightly weak content for T1 (1.2 g kg^{-1}) as well as for T5 (1.3 g kg^{-1}) when the limits of confidence according to Valdez-Cepeda *et al.* (2013) are between 2.0 and 4.8. Analytical results on other secondary elements and microelements (Na, Mn, Cu, Fe, Zn) (not detailed here) showed the absence of any deficiency in these elements. All these results confirm that aside of nitrogen, phosphorus is the right nutrient to give a priority.

Although in 2011, mineral fertilization had no significant effect on the average fruit weight (Table 2), in 2012 however, a positive effect on the fruit weight was recorded (Table 3) contributing greatly to the recorded yield increases. The number of fruits was also very significantly correlated with the yield (Table 4). Both components (number and weight) explained in a similar intensity the recorded fruit yields.

In 2012, fruit size resulting from fertilized plots were systematically higher than those of non-fertilized plots. For all treatments and in both years, the proportion of pulp in the total fruit weight was remarkably stable at 54–55%, and higher than what is reported as a quality standard (> 50%). Peel thickness always lies between 1.8 and 2.2 mm. These results correspond to the standards of quality for commercial production in South Africa (Potgieter, 2007; De Wit *et al*., 2010). According to the Italian classification system (Chessa and Nieddu, 1997), fruits from fertilized plots can be considered as large size fruits (151–200 g).

Even though we recorded an increase in the fruit yield and average fruit weight, fertilization did not modify the content of pulp in the fruit, nor the peel thickness (Tables 3 and 4).

The chemical analyses of fruits from the 5 treatments over two years indicate that fruits content 70 to73% juice, with no significant difference between treatments or between years (Table 5). The dry matter of the juice ranged 4.07 to 4.60%, appearing slightly higher in 2011 than in 2012. The pH was significantly lower in 2012, and the titratable acidity was higher. Total sugar contents were higher in 2011 whereas the total soluble solid contents (TSS) were lower than in 2012, indicating these traits highly sensitive to the environmental conditions.

Several authors also reported that fruit quality changes from year to year (Ochoa *et al*., 2006; Mokoboki *et al*., 2009).

TABLE 2. Effect of five N-P dressing treatments (T1–T5) on cactus pear (cv. Moussa) fruit size in 2011 in Agadir area, Morocco.

Fruit size parameters		T1	T2	T3	T4	T5	ANOVA
	N-P	0–0	0–80	40–40	60–0	60–80	
Fruit weight (g)		132	142	142	134	146	ns
Pulp weight (g)		73	76	76	72	79	ns
Peel weight (g)		62	68	68	63	70	*
Pulp:fruit ratio (%)		55	54	54	54	54	ns
Fruit length (cm)		7.3	7.4	7.6	7.4	7.5	ns
Fruit diameter (cm)		5.3	5.3	5.4	5.2	5.5	ns
Peel thickness (mm)		1.8	2.1	2.2	2.0	2.1	ns

*: significant differences at $P < 0.05$; ns: no significant difference.

TABLE 3. Effect of five N-P dressing treatments (T1–T5) on cactus pear (cv. Moussa) fruit size in 2012 in Agadir area, Morocco.

Fruit size parameters		T1	T2	T3	T4	T5	ANOVA
	N-P	0–0	0–80	40–40	60–0	60–80	
Fruit weight (g)		121	160	150	148	176	**
Pulp weight (g)		65	87	81	81	95	**
Peel weight (g)		56	72	69	69	78	*
Pulp:fruit ratio (%)		55	54	54	54	54	ns
Fruit length (cm)		7.1	7.8	7.7	7.7	8.3	*
Fruit diameter (cm)		5.0	5.6	5.5	5.4	5.8	*
Peel thickness (mm)		1.8	2.0	2.2	2.2	1.9	ns

*: significant differences at $P < 0.05$; ns: no significant difference.

TABLE 4. Effect of five N-P dressing treatments (T1–T5) on cactus pear (cv. Moussa) fruit yield components in 2012 in Agadir area, Morocco.

Fruit yield components		T1	T2	T3	T4	T5	R^2 (3)
	N-P	0–0	0–80	40–40	60–0	60–80	
Fruit yield (kg plant^{-1})		16.49	19.44	21.19	22.54	31.26	
Fruit weight (g)		121	160	150	148	176	0.84
Number of fruits plant^{-1} (1)		136	122	141	152	178	0.90
Number of fruits per ten cladodes (2)		82	78	89	105	107	0.81

(1) number calculated by the average fruit yield and average fruit weight relationship.
(2) observed number (see paragraph on phenology).
(3) coefficient of correlation with yield.

TABLE 5. Effect of five N-P dressing treatments (T1-T5) on cactus pear (cv. Moussa) fruit organoleptic traits in 2011 and 2012 (Agadir area).

Organoleptic traits	Years of harvest	T1	T2	T3	T4	T5	ANOVA
Content of juice (%)	2011	73.28	72.12	69.57	73.49	70.83	ns
	2012	70.21	71.98	71.68	72.54	69.87	ns
pH	2011	6.14	6.27	6.21	6.24	6.02	ns
	2012	5.99	5.88	5.99	6.06	6.01	ns
Titratable acidity (g L^{-1})	2011	0.46	0.43	0.45	0.46	0.47	ns
	2012	**0.50**	0.83	0.81	0.75	0.83	*
Total soluble solids (°Brix)	2011	13.5	14.5	13.1	13.4	13.5	ns
	2012	14.4	14.4	14.0	14.3	14.2	ns
Total sugars (%)	2011	62.1	64.0	60.3	60.5	62.0	ns
	2012	54.8	49.9	58.0	53.1	53.1	ns
Dry matter content of the juice (%)	2011	4.40	4.43	4.60	4.51	-	ns
	2012	4.35	4.32	**4.07**	4.38	4.43	*

ns: no significant difference; * : significant difference at $P < 0.05$.
In bold: values that are significantly different.

According to the varietal evaluation of the commercial production in South Africa (Potgieter, 2007; De Wit *et al.*, 2010), the TSS contents of fruit during the two years were similarly >13 °Brix and met the commercial standards of quality. Fruit quality was mainly affected by the year, and applying mineral fertilizers to the crop had no significant effect on the fruit quality components (Table 5).

Effects of fertilization on the phenology of flowering and fruiting of plants

In the first year of observations, fertilization applied in April had no influence on the beginning of the phenological phases. Thus, the observations were aggregated for all the treatments and replications. They constitute a reference for the cv. Moussa, without applying any mineral fertilization.

In 2011 (Table 6) the vegetative and floral buds appeared from March 2 to June 8 (98 days) and the floral buds formed from March 11 to June 23 (104 days). The time for flowers to mature (stage anthesis) took 15 to 20 days after the formation of floral buds. A floral bud is considered formed when it takes a spherical form, which makes it easy to distinguish from a vegetative bud having a flattened form (Nerd and Mizrahi, 2010; FAO, 2013; Mashope, 2007; Arba *et al.*, 2015). The emission and formation of buds are important in April. Many authors have also indicated that in the Mediterranean region emission of the principal series of buds occurred in the spring, in March–April, when temperature rises and day length increases (Nerd and Mizrahi, 2010; FAO, 2013; Arba *et al.*, 2015; Reyes-Aguero *et al.*, 2006; Segantini *et al.*, 2010). The period when blossomed flowers appeared was long (110 days, from March 26 to July 14). It extended from the first blossomed flower appearance in a plot to the last blossomed flower appearance in the same or another plot (noted by numbering the blossomed flowers). Several authors have also confirmed the length of the blossoming period due to non-synchronization of flowering in cactus pear (Nerd and Mizrahi, 2010; FAO, 2013; Arba *et al.*, 2015; Reyes-Aguero *et al.*, 2006; Segantini *et al.*, 2010).

The period of time between the early blossoming and the starting date of fruit maturation ranged from March 26 to June 18, and the period of fruit ripening was from June 18 to September 20 (94 days long). N-P fertilization had no significant effect on these dates. We did not observe any effect of fertilization, particularly N application, on the emission of a second series of flowers, which could result in late fruiting in autumn. This phenomenon of "re-flowering" has been observed by several authors (Nerd and Mizrahi, 2010; Inglese, 2010) when applying mineral fertilization after the summer harvest.

The fruit development period (FDP) is the time extending from the beginning of the formation of floral buds until fruit maturation (50% of fruits in maturity) (Mashope, 2007; Arba *et al.*, 2015). In our study, the FDP was 142 days long.

In 2012, the phase of emission of vegetative and floral buds lasted about 100 days (from January 20 to April 30) and the floral bud differentiation period was very similar, with a minor shift of approximately 5 days (Figure 1). These two phases perfectly overlapped each other, the second starting with a few days of delay, and resulted in a number of formed floral buds representing 90 to 95% of the total buds. The number of vegetative and floral buds was significantly higher with N fertilization (12 floral buds per cladode for both T4 and T5) than without N fertilizer (fewer than 9 floral buds per cladode for both T1 and T2).

The flowering phase began on March 10 and finished around June 10. This phase overlapped the bud emission phase which was 50 to 60 days long. Fertilization had no significant effect on the starting or ending dates of this phase, but significantly increased the total number of flowers formed, whereas the proportion of flowers in comparison to floral buds was not modified (Figure 2).

The fruit ripening phase has been around 120 days long. It started slowly from May 10 to June 10, then speeds up until August 1 and continued until early September. It can be considered that the period of "full production" is situated between the beginning of June and the end of August, representing approximately 90 days. Fertilization had no significant effect on these dates, neither in precocity, nor in lateness, although it had a highly significant effect on the number of fruits formed.

For all the fertilization treatments FDP was 180 days long, extending from February 1 until July 30. It was longer and earlier than in 2011 (duration: 142 days; starting date: March 11). In 2012, as in 2011, fertilization had no significant effect on the FDP.

The highest yields recorded in the complete N-P fertilization treatments are particularly related to the highest daily rate of fruit maturation during the following two periods: the beginning of maturation starting late May and the medium/end of this phase in the second half of July (Figure 3). There are possible effects of N-P fertilization on the vegetative growth that will generate the new cladodes for the next season. Our observations took place on the one-year-old cladodes only, although two-year-old cladodes or older can also generate vegetative shoots. In 2011, the emission of shoots (Figure 4a) was intense at the end of June and again in July. Compared to the control with no N fertilizer, it was earlier (June 8) and more intense in N treatments (the

Table 6. Starting and ending dates of the growth phases of cactus pear (cv. Moussa) and their duration (in days) in 2011 (Agadir area).

Plant development phases	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Duration (days)
Emission of vegetative and floral buds										98
Formation of floral buds										104
Flowering										110
Fruit maturation										94
Fruit development period (FDP)										142

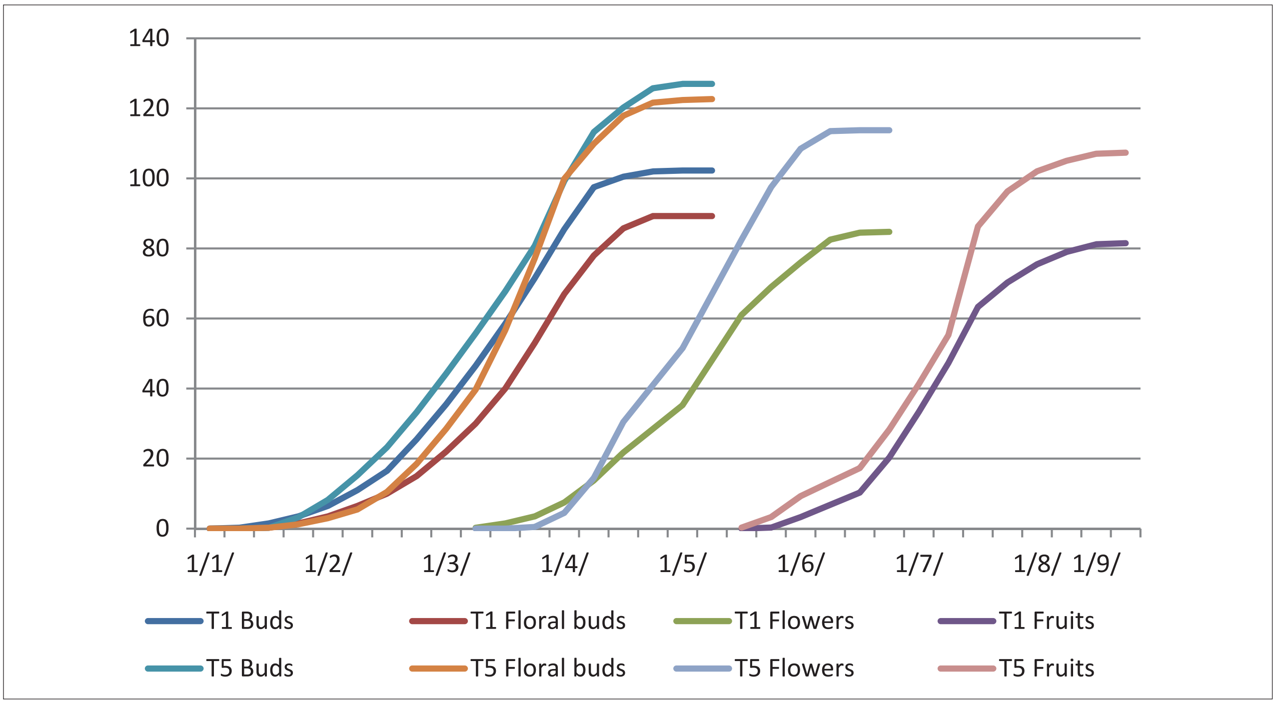
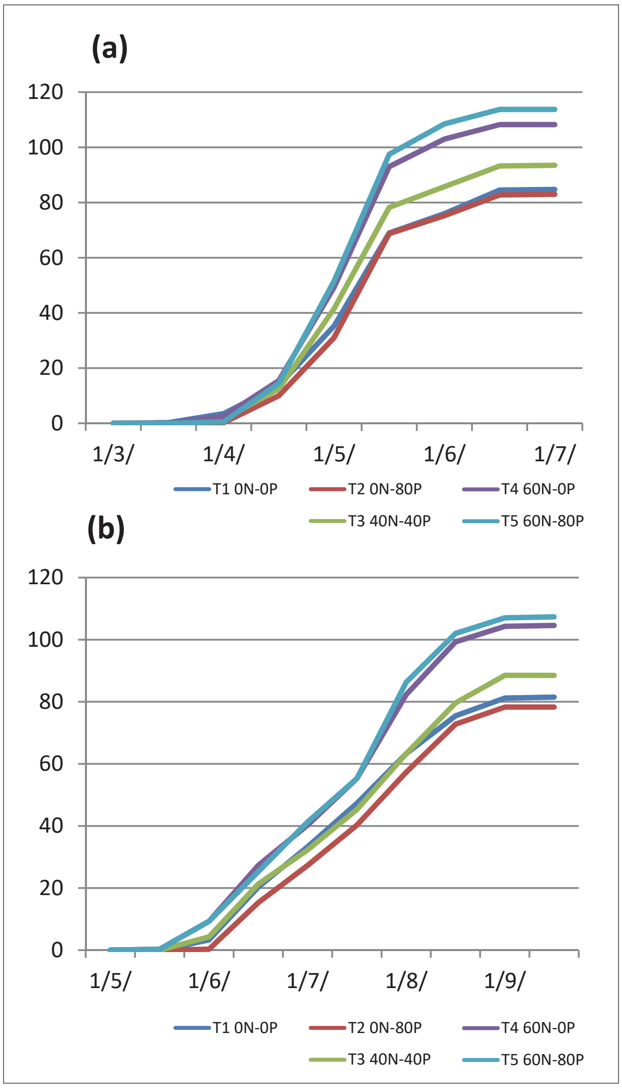


FIGURE 1. Phenology of cactus pear cv. Moussa in 2012 for N - P fertilization treatments T1 (0 – 0) and T5 (60 – 80) in Agadir area, Morocco. Data values are the cumulative numbers of organs per ten cladodes for each treatment.



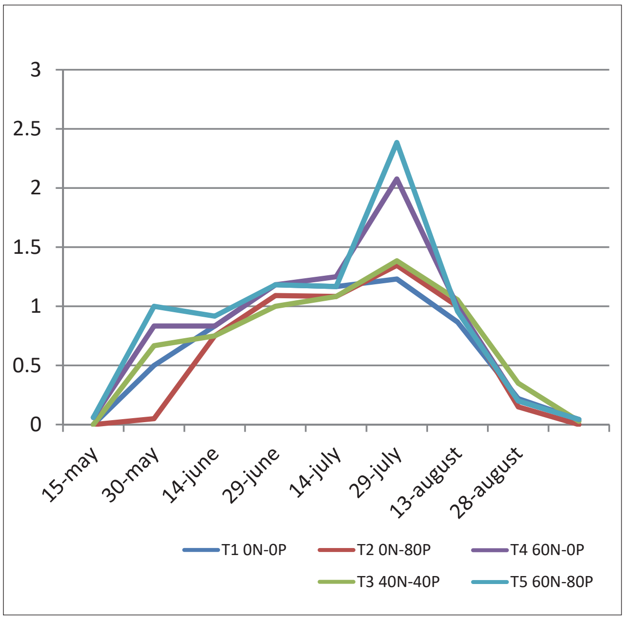


FIGURE 3. Dynamics of cactus pear cv. Moussa fruit ripening according to N - P fertilization (T1 to T5) in 2012. Values are expressed in number of mature fruits per ten cladodes and per day.

FIGURE 2. Flowering (a) and fruit ripening (b) phases of cactus pear cv. Moussa for the five N - P fertilization treatments in 2012.

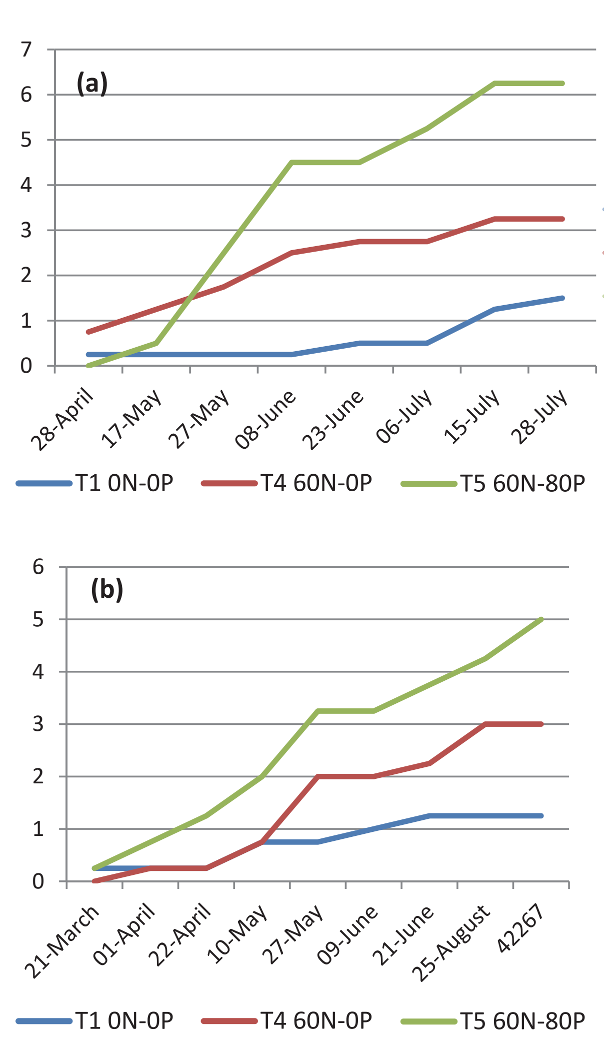


Figure 4. Phenology of shoot emission in cactus pear cv. Moussa according to N-P dressings for 2011 (a) and 2012 (b). Values are the numbers of formed shoots per ten cladodes for each treatment.

number of shoots per cladode increased by +0.2 in T4 and +0.4 in T5). The shoot number per cladode was globally higher for T4 and T5, with more than 0.30 and 0.60, respectively, in comparison with 0.15 for T1 (control). This trait was the only one significantly affected by N-P fertilization in 2011. In 2012 the emission of shoots (Figure 4b) began earlier (March 21) and finished later (September 21). As in 2011, N fertilization increased very significantly (four times) the number of shoots compared to the control. This effect has been reported by several authors (Mimouni *et al.*, 2013; Arba *et al.*, 2015).

Conclusion

The use of nitrogenous and phosphoric fertilizers on the prickly pear cactus crop proved to be effective since it improved yield and fruit quality, mainly the fruit size which is an important criterion in the marketing of fruit on the national or international market. During the season of production in Morocco, the selling price of a prickly pear fruit case (30 kg) of small caliber can reach 30 DH MAD, whereas a fruit case of great caliber can value more than 150 DH MAD. The improvement of yield and fruit quality and the market value of prickly pears should contribute to improve grower's income. The use of N fertilization and its application on prickly pear cactus should be better known in Morocco, so that its introduction in the best production practices would stimulate the development of this crop in Morocco.

N-P dressings also stimulated the formation of a greater number of organs, notably flower buds, flowers and vegetative shoots per cladode. The N-P fertilization did not deteriorate any parameters of physical or chemical fruit quality. N-P dressings did not have significant effects on the earliness or duration of the successive phases of the plant development. However, some sensitive responses to nitrogen make this element to be considered a monitoring tool of the physiological development of the plants. The response to phosphate dressing, well known to be slower to appear, deserves further observations.

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