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DYNAMIC PLANTATIONS: INTRASPECIFIC VARIABILITY IN GROWTH OF FIVE VARIETIES OF ZIZIPHUS MAURITIANA (POMME DU SAHEL) AND DEVELOPMENT TRAJECTORIES IN THE SAHELIAN REGION OF NIGER

RABIOU Habou[1]*., TOUGIANI Abasse[2]., DAN GUIMBO Iro[3]., ISSAHAROU-MATCHI Issiaka[1]., John C. WEBER[4]., Hamza DADÉ[3]., KATKORÉ Boubacar[2]., MOUSSA Boureima[2] and Ali MAHAMANE[1, 3]

[1]Département de production végétale, Faculté des Sciences Agronomiques, Université de Diffa, Niger
[2]Institut National de la Recherche Agronomique du Niger, Niger
[3]Université Abdou Moumouni de Niamey, Niger
[4]World Agroforestry Centre (ICRAF) / Montpellier, Languedoc-Roussillon, France

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ABSTRACT

Natural resources play a crucial role in terms of socio-economic life of people, especially in rural areas. In order to improve the living conditions of these populations, agro-forestry initiatives have been undertaken. In Niger, techniques of domestication of different agro forestry species have been undertaken, including cultivation of the jujube tree *Ziziphus mauritiana* Lam. This work aims to establish growth models of five *Z. mauritiana* cultivars that describe the growth of trees in their stands and identify the varieties that perform better. Experimentation was carried out in the field of arboriculture of the agro-sylvo-pastoral garden of INRAN in Maradi on an experimental design consisting of two (2) lines of each variety and each line consists of 19 plants. Thus 190 trees were planted and corresponding to 38 plants per variety. The study was carried out on five (5) improved jujube cultivars. *Z. mauritiana* trees were grafted with Indian strains. After three years of plantation, measurements were performed weekly and for 10 weeks on nine (9) single tree samples of each variety. Thus, for the monitoring of growth parameters, measurements were made on the height, diameter and two perpendicular diameters of the crowns of the plants. To establish the correlation between growth parameters and fruiting, fruit dynamics were followed at three individuals of each variety on a sample consisting of 20 flower buds. Indeed, the analysis of variance shows that there are no significant differences between varieties in terms of growth per week. However, the Seb variety shows an important vegetative development at the expense of fruit production, contrary to the variety Kaitlhi which produces many fruits but with a lower vegetative development. The Umran variety is characterized by the production of larger fruits but with lower growth in diameter. Both Gola and Ben Gurion varieties produce small fruit with larger diameter development at the collar. The study showed how varieties allocate resources during their development.

INTRODUCTION

Agroforestry is known as a natural resource management system through the integration of trees in the landscape (Adamou, 2009). It provides a sustainable and diversified production and also provides farmers with socio-economic and environmental benefits. Also, it offers multiples services to rural producers allowing them to cope with various problems. The choice of species to be introduced should be based on their productive potential (Yossi, 1997). Thus domestication techniques of different agro-forest species have been undertaken including the culture of jujube *Z. mauritiana* Lam. Improved cultivars of jujube

Corresponding author:* **RABIOU Habou
Département de production végétale, Faculté des Sciences Agronomiques, Université de Diffa, Niger

have higher content of various nutrients (vitamins C and A, carotene, calcium and magnesium) have been successfully introduced in Niger. The flowering and fruiting period of these cultivars is six months after grafting and that period varies from two to three years for the local variety. They produce much larger fruits (over 25 grams) than the local variety (less than 2 grams)(Clark and Clark, 1999). Higher productivity is the result of good growth conditions. It has been shown that the growth of individual trees is a major process of plantations dynamic (Bullock, 1997). Growth understanding is essential for modeling the dynamics of tree plantations or even natural forests (Brehima *et al*., 2009). In Niger as well as in the sub Saharan region several studies were carried out on the socio-economic aspect of the Sahel apple (Ibrahim *et al*., 2015) but none of them addressed the growth dynamics of these cultivars in order to select cultivars with better performance in terms of growth (height, diameter, crown diameter perpendicular) in relation to productivity.

Z. mauritiana is a small tree native to northern China, but now widely cultivated in dry regions of Africa and South Asia. It is a drought, flooding, salinity and wilting tolerant tree(Clark and Clark, 1999). It occurs in arid as well as semi-arid environment. *Z. mauritiana* was introduced in West Asia, Africa and in the Western Mediterranean region where it would be naturalized [(Clark and Clark, 1999; Christian *et al*., 2000; Ghosh and Mathew, 2002; Lal and Dhaka, 2007; Ismail and Almarshadi, 2013). Improved varieties of *Z. mauritiana* (Pomme du Sahel) were successfully introduced in Niger. Some of these varieties have significant vegetative developments while others are known for producing the quantity of fruits and can be used as food. The current paper aims to establish growth patterns of five cultivars of *Z. mauritiana* that describe the growth of trees in their populations and to identify varieties with the best performance.

MATERIAL AND METHODS

Study site

The experiment was conducted in the field of arboriculture of agro-forestry-pastoral garden INRAN / Maradi located at 13° 27'816 "N, 007° 06 '489'E and at 357 m. This experimental site consists of a plot of 0.64 ha. Mean annual temperature is of 32 ° C and Mean annual precipitation is of 498.025 mm (Dalling *et al*., 2001)

Rootstock

The study was focused on five (5) improved cultivars of jujube. *Z. mauritiana* were grafted with Indian stubs on the site of INRAN / Maradi three years after their plantation (Brehima *et al*., 2009):

Ben Gurion: Variety Indian. The leaf is oblong. The end of the style is crooked and oblique. One kilogram (1 kg) contains 23 fruits. Tree produces an average of 24 kg per year at three years of age.

Gola: Variety Indian. The fruit is round, oblong or the hickory leaf. One kilogram (1 kg) contains 22 fruits. Three years after planting, the tree produces an average of 26 kg of fruit per year. Under irrigation condition, the tree does not seem to stop growing during the year.

Kaithli: Variety Indian. The sheet is elongate, the tip style is round; the end of the leaf may also be acute. One kilogram (1 kg) contains 24-27 fruits and are oval. The tree produces 18-23 kg after three years of planting.

Seb: Variety Indian. The shape of the tree is straight, round fruit, oval leaf. The end of style is as flat as the depression of an apple. One kilogram (1 kg) contains 36 fruits. At three years of planting, the tree produces 43 kg of fruit per year on average. In the Sudan region, the fruit is cracked.

Umran: Variety Indian. It has Oval leaf, round end of style, subacute end of leaf. One kilogram (1 kg) contains from 24 to 25 fruits. The tree produces on average 21 kg of fruit per year, after three years of planting in Sahel(Adamou, 2009).

Data collection

The experimental design consists of two lines of each variety and each line consists of 19 plants. A total of 190 trees were planted and distributed in 38 plants per variety. These varieties have been planted since August 8, 2007 at a distance of six meters between plants and between varieties. The experiment involved a sample of nine trees of each variety selected randomly after numbering from one to n among the living plants. In each block a plant sample was selected based on the type of studied parameter. And for the monitoring of growth parameters, the measurements were focused on the height (m), Diameter at breast height (cm) and the diameter perpendicular to the crown (m) of the plants, of the nine (9) tree of each variety, using a metric ruler of three meters, a caliper and a tape measure of 20 m respectively,. A total of nine individuals per variety were being monitored for 10 weeks. The measures were done each week implying 90 observations per variety. To verify the correlation between growth and fruit productivity, dynamic appearance of the fruit has been monitored in a sample of 20 fruiting buds in three trees of each variety and their average weights were measured on first harvested fruits.

Data analysis

Data analysis was performed using Minitab 16 software. Two factors ANOVA (General Linear Model) taking into account three parameters (height, diameter, and crown) was done. To compare varieties, one-way ANOVA was used. Allometric relationships were analyzed using linear regression model. Indeed three main tests are used to check the quality of the regression. The coefficient of determination R2 is the percentage of the variation in the dependent variable due to variation in the explanatory variable. The compliance test was used to test the coefficients a and b. Finally the significance test shows the model fit. An average of nine measurements was performed by variety per week to reduce bias and increase the quality of regression. For the comparison of regression lines at these five varieties, directors' coefficients were compared using the condition of equality of residuals.

$$b = \Delta Y / \Delta X$$

b: Coefficient director of the regression lines
ΔY: Variation in the dependent variable

ΔX: Change in the explanatory variable.

Conditional equal residuals, if b is low it means that Δy growing faster than Δx and vice versa.

RESULTS

Growth variation in diameter crown

Table 1 shows the monitoring of plant growth using two diameters crown for ten weeks. The analysis of variance shows that there are no significant differences in terms of growth in crown diameter between varieties by weeks (P> 0.05).

much increased its diameter of approximately 0.82 m followed by varieties Kaithli and Ben Gurion with 0.55 and 0.54 m respectively (Figure 1).

Highest increase in diameter was observed from the variety Gurion Ben with 1.04 cm in ten weeks, followed by Gola and Kaithli varieties with 0.96 and 0.82 cm respectively (Figure 2).

The highest increase in height was observed in Seb variety with 36.8 cm in ten weeks. This variety is followed by varieties Gola and Kaithli with 34 and 19.16 cm respectively (Figure 3).

Table 1 Growth Variation in diameter crown (m); W: Week

Varieties	Ben Gurion	Gola	Kaithli	Seb	Umran	Probability
W_1	2.03±1.13	1.91±0.96	2.30± 0.84	2.02±1.04	2.60±0.98	0.597
W_2	2.16±1.18	1.93±0.99	2.27±1.18	2.23±1.18	2.66±0.98	0.711
W_3	2.20±1.18	2.02±0.92	2.40±1.03	2.47±1.10	2.70±0.99	0.698
W_4	2.18±1.21	2.07±0.94	2.47±1.04	2.50±1.08	2.74±0.99	0.681
W_5	2.27±1.25	2.14±0.97	2.56±1.06	2.57±1.05	2.80±0.99	0.705
W_6	2.36±1.23	2.19±0.98	2.64±1.04	2.66±1.04	2.86±0.97	0.694
W_7	2.42±1.24	2.24±0.99	2.71±1.03	2.73±1.03	2.93±0.95	0.671
W_8	2.49±1.24	2.29±1.01	2.76±1.03	2.76±1.04	2.97±0.95	0.684
W_9	2.52±1.25	2.32±1.01	2.80±1.04	2.80±1.05	2.91±1.03	0.771
W_10	2.57±1.26	2.37± 1.01	2.85±1.07	2.85±1.05	3.08±0.96	0.675

Variation of the diameter growth

Table 2 summarizes the average diameter growth of five varieties per week for ten weeks. Analysis of variance shows that there are no significant differences between varieties (P> 0.05).

Allometric relationship between diameter and height of five varieties

In general, a very higher correlation was found between diameter and height.

Table 2 Change in diameter growth (cm); W: Week

Varieties	Ben Gurion Gurion Gurion	Gola	Kaithli	Seb	Umran	Probability
W_1	2.24±1.22	2.33±1.70	3.59±1.45	3.08±1.47	3.97±1.31	0.057
W_2	2.52±1.31	2.81±1.83	3.97±1.56	3.19±1.41	4.14±1.27	0.109
W_3	2.90±1.56	3.04±1.68	4.13±1.55	3.27±1.40	4.20±1.23	0.218
W_4	3.02±1.60	3.10±1.70	4.16±1.54	3.31±1.38	4.27±1.21	0.244
W_5	3.10±1.66	3.17±1.74	4.22±1.55	3.34±1.39	4.44±1.21	0.214
W_6	3.15±1.66	3.20±1.75	4.28±1.55	3.42±1.38	4.51±1.19	0.199
W_7	3.20±1.66	3.22±1.75	4.33±1.54	3.48±1.40	4.58±1.20	0.192
W_8	3.25±1.66	3.20±1.81	4.36±1.54	3.51±1.41	4.60±1.20	0.192
W_9	3.28±1.67	3.29±1.78	4.38±1.54	3.54±1.41	4.63±1.19	0.212
W_10	3.29±1.67	3.30±1.78	4.41±1.55	3.57±1.43	4.67±1.19	0.194

Variation in height growth

Table 3 shows the values of the average growth of varieties in height. It appears that the average height growth of varieties is not different except for the first week (P = 0.022).

Statistical models of simple linear regression explain these allometric relationships between height and diameter of all varieties. The coefficient of determination, the director of compliance coefficient test and the constant b, the model significance test performed on height data and diameter of five varieties highlights the results shown in Table 4.

Table 3 Change in height growth (m); W: Week

Varieties	Ben Gurion Gurion	Gola	Kaithli	Seb	Umran	Probability
W_1	1.12±0.50	0.77±0.41	1.58±0.73	1.05±0.35	1.12±0.31	0.022
W_2	1.16±0.49	0.83±0.35	1.21±0.34	1.30±0.20	1.16±0.32	0.080
W_3	1.18±0.49	0.87±0.35	1.23±0.37	1.24±0.37	1.19±0.33	0.235
W_4	1.19±0.49	0.90±0.37	1.32±0.35	1.26±0.36	1.23±0.35	0.211
W_5	1.22±0.50	0.95±0.38	1.35±0.35	1.28±0.39	1.28±0.37	0.270
W_6	1.26±0.49	1.01±0.39	1.39±0.30	1.33±0.39	1.31±0.38	0.300
W_7	1.28±0.49	1.04±0.39	1.42±0.30	1.35±0.39	1.33±0.39	0.345
W_8	1.31±0.47	1.07±0.39	1.43±0.29	1.38±0.40	1.34±0.40	0.367
W_9	1.32±0.47	1.09±0.38	1.46±0.29	1.40±0.39	1.37±0.38	0.334
W_10	1.34±0.49	1.11±0.37	1.47±0.29	1.42±0.39	1.40±0.38	0.334

Increasing of dendrometric parameters for five varieties

Concerning the increase which explains the difference between the average diameter of crown in the tenth week and in the first week, it appears that the variety Seb has

The statistical regression models show strong determination coefficient R^2. Indeed, it shows the best quality of adjustment especially for Seb and Umran varieties with 99.2 and 97.8% respectively meaning that the growth continued during the observation period.

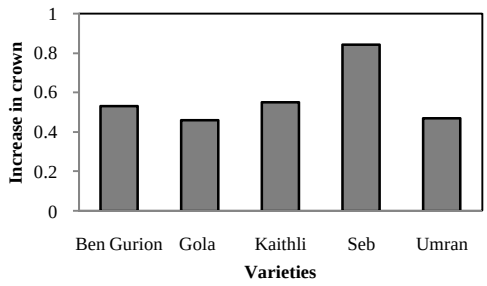

Figure 1 Increased average diameter of five varieties of crown

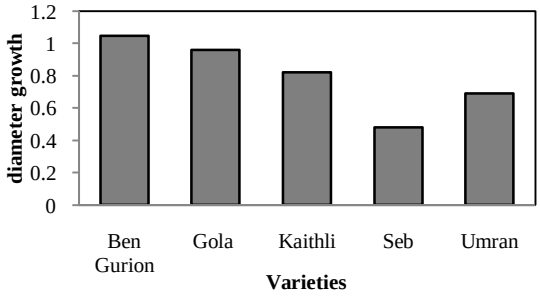

Figure 2 diameter increment of five varieties

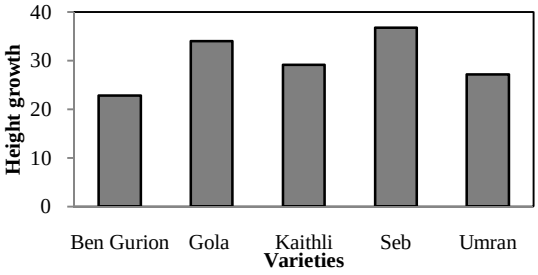

Figure 3 increase in height of five varieties

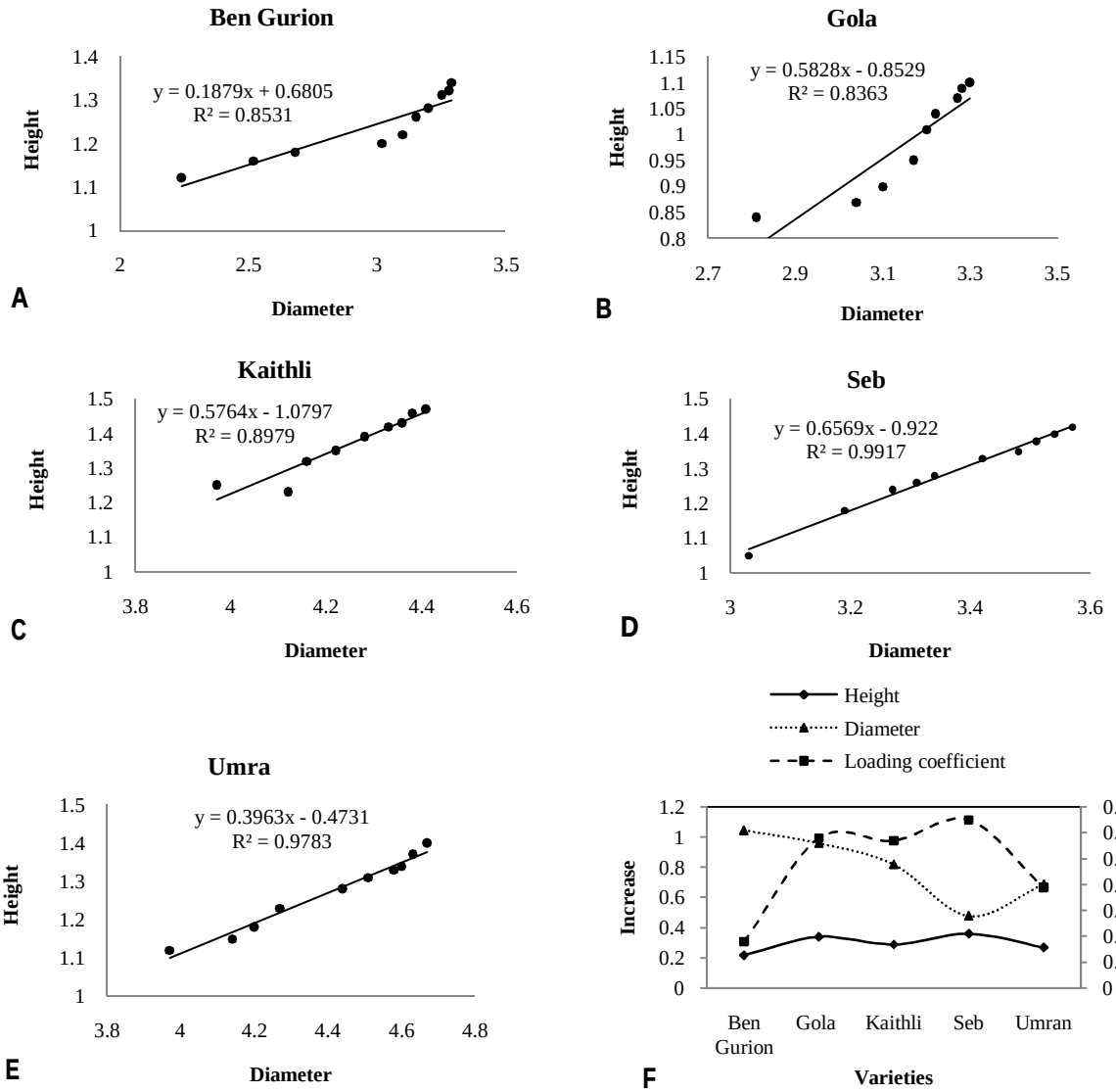

Figure 4 The regression curves between height and diameter. Ben Gurion in A; Gola in B; Kaithli C; Seb D; Umran in E and relationship manager illustration coefficient of the regression lines, height and diameter F

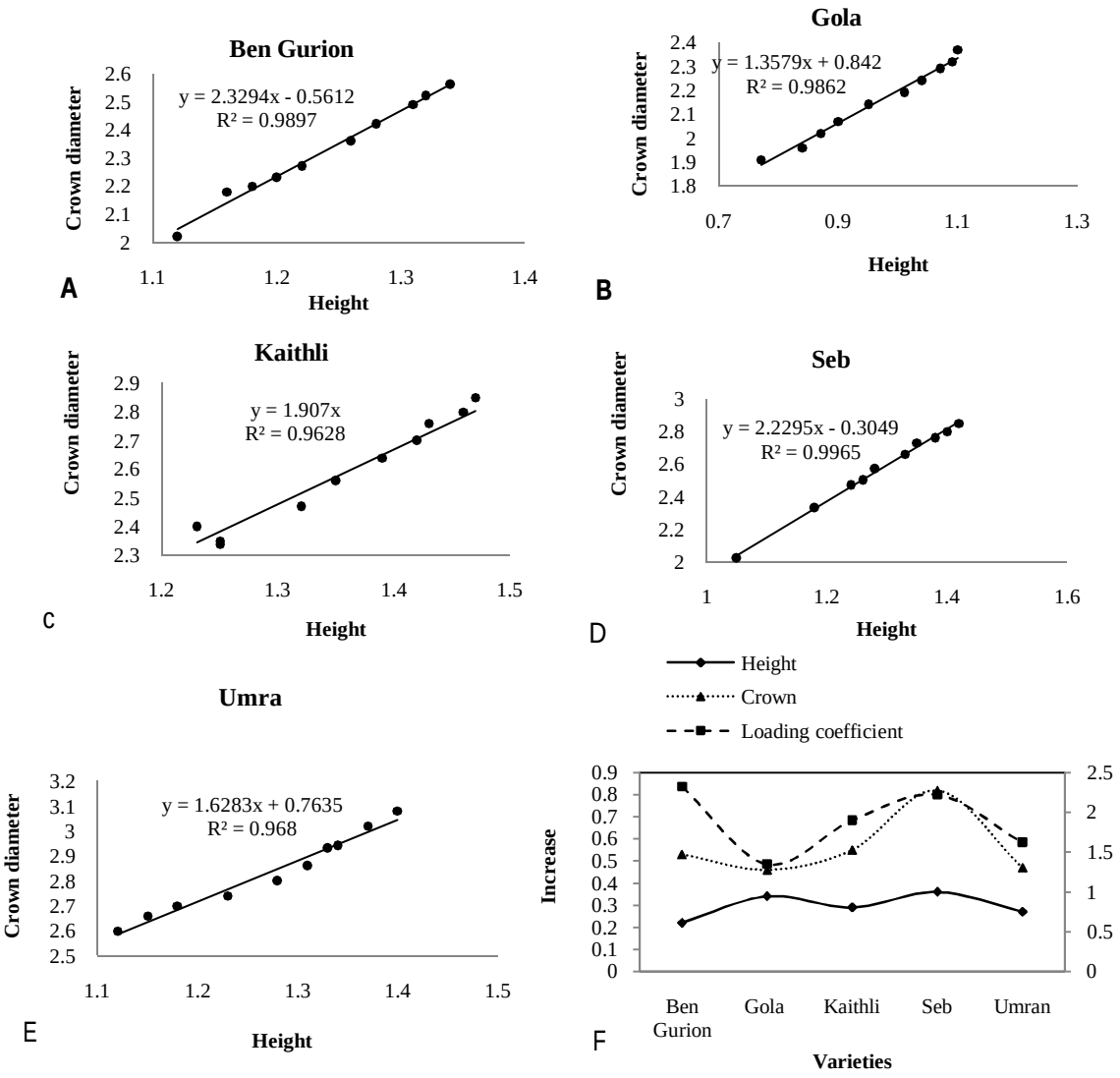

Figure 5 Regressions curves between height and crown. Ben Gurion in A; Gola in B; Kaithli C; Seb D; Umran in E and relationship manager illustration coefficient of the regression lines, height and crown diameter F

The adequacy test shows the consistency of models with probabilities <0.001 for all varieties. The compliance test shows the consistency of the coefficients a and b for all varieties, the probabilities associated with this test are <0.001 which explains the quality of linear model of y = a + bx. These tests confirm the degree of adjustment explained by the higher coefficient of determination R^2 and all results are recorded in table 3. So in general, there is a higher correlation between height and diameter for all varieties of *Z. mauritiana* (apple Sahel) in the study site.

Allometric relations between the crown and height of five varieties

As shown previously, it was proposed to establish for the five varieties of jujube some regression models between the average crown diameter and the height (table5).

The good correlation between the crown diameter and height is explained by an increase of coefficient of determination R^2 for all five varieties. The adequacy test certifies the reliability of the models with p<0.001 for all varieties. But the compliance test shows the consistency model for all varieties with p <0.001 except for the Kaithli variety which has an equation y = bx. These models show that we can predict the evolution of average diameter of crown and the recovery of the five varieties from the height and possibly productivity apple Sahel to future years.

The regression curves between height and diameter and between crown and height

Analysis of regression curves shows straight relationship between height and diameter and between crown and height. However these curves have different coefficients directors. Indeed, there is a difference in height growth depending on diameter on one hand and on the other hand the increase in average crown diameter depending on the height. The principal factor analysis gives indications of the subsidiary on the growth curves. Seb variety has the greatest director coefficient (0.656) followed by Gola (Figure 4). So these varieties are growing faster in height at the expense of diameter. However, varieties such as Ben Gurion and Umran have a much faster growth in diameter than in height.

Figure 4 (F) shows the relationship between height growth, diameter growth and the director coefficient. Further, the varieties that have higher height growth are indeed those who have a strong director coefficient which is the slope of the line. These are of Seb and Gola

varieties. Those with lower height growth are those with lower regression slope. Gola and Seb varieties increase their height at the expense diameter.

Table 4 Regression results (Allometric relationships between diameter and height); H: height; Diam; Diameter

Variétés	model adequacy test du model P-Value	R^2 (%)	Equations
Ben Gurion	<0.001	85.3	H = 0.18 Diam+ 0.68
Gola	<0.001	83.6	H = 0.58 Diam - 0.85
Kaithli	<0.001	89.8	H = 0.57 Diam - 1.08
Seb	<0.001	99.2	H = 0.65 Diam - 0.92
Umran	<0.001	97.8	H = 0.39 Diam - 0.47

Table 5 Relationship between Allometric and crown height; H: height; Crw: Crown

Varieties	model adequacy test P-Value	R^2 (%)	Equations
Ben Gurion	<0.001	99	Crw = 2.33 H - 0.56
Gola	<0.001	98.6	Crw = 1.36 H + 0.84
Kaithli	<0.001	96.8	Crw = 1.91 H
Seb	<0.001	99.7	Crw = 2.23 H - 0.30
Umran	<0.001	96.8	Crw = 1.63 H + 0.76

Regarding to average diameter of crown based on height (Figure 5) the Ben Gurion variety showed the greatest director coefficient (2.329) followed by Seb variety with 2.22. These varieties therefore grow faster in terms of tree cover according to height. But in general and based on three parameters (height, diameter, and crown), crown Kaithli variety is most efficient. The variety Umran has higher diameter and a good tree cover but characterized by a lower height.

Figure 5 (F) summarizes the relationship between the increase in crown and increase in height and the slope of the regression line. Varieties that have a strong growth in crown are characterized by a strong slope of the regression line. These are Gurion Ben and Seb. This figure also shows that these varieties are slightly increasing in height apart from Umran variety with a lower vegetative development.

Relationship between dendrometric growth parameters

The principal component analysis summarizes all dendrometric relations, fruit production in terms of number and as well as their size.

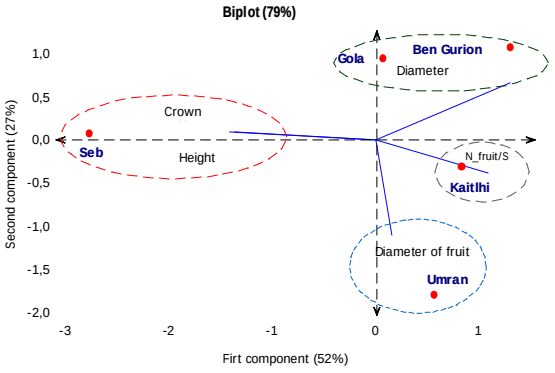

Figure 6 Summary of relationship between increases and production of fruit per week.

The first two factorial axes explain 79% of the total variance where Axis 1 explains 52% and axis 2 explains 27%. It appears from the analysis of this graph that Seb variety is characterized by a large vegetative development, but produces lower quantity of fruit with small size.

Varieties Gola and Ben Gurion are characterized by higher increase in diameter and produce a lot of fruit but with small size. Kaithli variety which is characterized by a lower vegetative development produced higher quantity of fruits. Ben Gurion variety produces larger fruit but has a weak development in diameter (Figure 6).

DISCUSSION

The average growth of one species does not necessarily reflect its potential. While potential growth of Seb variety is clearly higher than for other species. Indeed, variety Seb allocates all its resources basically to vegetative propagation, strong increase in height and a strong recovery in growth. However, the Kaithli variety with a lower crop development uses its resources to the production of fruits in quantity and in average quality. The lowest vegetative development was observed in the variety Umran, with lower diameter growth, height and recovery but characterized by higher production of fruits which are usually large. This vegetative growth at the expense of fruit production has already been reported by several authors, among others (Yamada *et al.*, 2005; Bloor and Grubb, 2004; Madelaine *et al.*, 2007). Varieties Ben Gurion and Gola are also close but characterized by lower growth potential. The diameter- height relationship may significantly be different from one species to another and even within a species from one variety to another. This relationship reflects the dynamics of trees' growth, as well as additional element of comparison of the five analyzed varieties of *Z. mauritiana*. The determination and characterization of the fundamental processes regarding the dynamics of population of plantation are crucial for the modeling and the management of stands. Yet they are crucial in the sylvicultural treatment of plantations. Indeed according to the species, there is a physiological phenomenon that determines the growth in terms of height, diameter and recovery and in the meristem dominance. According to (Bloor and Grubb, 2004), the ecological strategy of a species concerns all its specific adaptations that allow the maintenance of the species in a community. The variety Umran strengthens its diameter and recovery, and reduces its height to better withstand the weight of its branches. The plantations of the trees studied in this paper were performed with a spacing of 6 m, while for the same variety having a large overlap (Umran) the average ray does not reach 1.5 m three years after planting, which reduces the competition between the trees. The growth strategy is defined as the preferential allocation of resources to growth in diameter or height of the trunk and / or the lateral or vertical extension of the crown (Aulakh and Kumar, 2005). But these strategies differ from one species to another or even from one variety to another at intra-specific level. The study of allometric relationships between the different dimensions of a tree can address indirectly the notion of differential allocation of biomass produced for growth of tree (Lal and Dhaka, 2007; King, 2005; Niklas and Enquist, 2001;

Rondeux, 1999). For a given species, this strategy may change during ontogenesis (Yamada *et al*., 2005; Bloor and Grubb, 2004) and according to local conditions (Madelaine *et al*., 2007). According to several authors including (Bonou, 2007; Rabiou *et al*., 2014; Pelissier, 1995) allometric relationships between height and diameter are not necessarily linear under natural conditions. Some authors have hypothesized the existence of a point of release in the tree growth trajectory (Madelaine *et al*., 2007). This point corresponds to the transition from a developing competition phase where the diameter increases slightly compared to the level and development phase after the free passage of trees above a well-developed stratum to avoid excessive inter-individual competition. But as part of this work, competition is limited by the distance of six meters between individual trees leaving each individual to free development. Furthermore, it also explains a stronger linear correlation with higher coefficients of determination close to 1 and a good fit models of $p < 0.05$ for all varieties.

CONCLUSION

The study of the growth dynamics of five improved varieties of Jujubier (Ziziphus mauritiana) was successfully used to distinguish varieties with better morphological and phenological potentialities. The study allowed understanding the mechanism of allocation of resources. Indeed, varieties with higher vegetative growth are those that produce low fruit yields. For all varieties, the increase in diameter is negatively correlated with the increase in crown. Ben Gurion and Gola varieties showed higher increase in diameter but smaller increase in crown, contrary to the Seb variety, which showed higher increase in crown and height but smaller increase in diameter. Furthermore, the increase in height is negatively correlated with fruit production. Varieties which are characterized by higher increase in height produce small fruit. These are the Gola and Seb varieties. The last two varieties may be recommended for pastoralisms whereas the Kaithli and Umra varieties may be recommended for fruit production.

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