World Journal of Agricultural Research, 2019, Vol. 7, No. 1, 8-13
Available online at http://pubs.sciepub.com/wjar/7/1/2
Published by Science and Education Publishing
DOI:10.12691/wjar-7-1-2

The Critical Period for Thinning Carrot (*Daucus carota* L.)

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Received November 17, 2018; Revised December 28, 2018; Accepted January 10, 2019

Abstract Field experiment was carried out at Impala Research station, in Botswana, aiming at investigating critical period for thinning of carrot (*Daucus carota* L.). The experiment was laid out in a complete randomized block design (CRBD), replicated three times and was repeated four times at different sowing dates. Seeds were sown at the same rate (3 kg ha^{-1}) in all plots to obtain an equal plant population at initial stage, thereafter thinned at different times (2^{nd}, 3^{rd}, 4^{th}, 5^{th} and 6^{th} weeks after emergence) to 30 cm between rows and 5 cm between intra rows to maintain constant population across the experiment. Days to maturity were constant from sowing to harvest in all the sowing dates. Plant height and yield significantly declined as thinning time was delayed. Number of leaves developed, root diameter and root length were not influenced by the thinning time. Vegetative growth and yield declined with the late sown experiments. It can be concluded that thinning time significantly increase plant height and yield, especially at earlier stages and carrot yield best when sown earlier in the season.

Keywords: *carrot, thinning time, storage root, growth, yield*

Cite This Article: Gagopale Bosekeng, "The Critical Period for Thinning Carrot (*Daucus carota* L.)." *World Journal of Agricultural Research*, vol. 7, no. 1 (2019): 8-13. doi: 10.12691/wjar-7-1-2.

1. Introduction

Carrots (*Daucus carota* L.) originate from Asia, and currently cultivated worldwide. It belongs to the family of Umbelifers and is a cool season vegetable crop. It is grown for its enlarged storage (tap) root as an essential vegetable playing a role in the human nutrition as a source of vitamin A, B and C [1]. Carrots roots are also processed to produce juice rich in nutrition, concentrates, dried powder, canned and pickles [2]. This vegetable provide carotenoids and B-carotene [2,3]. Besides being food, components of carrot parts like seeds and leaves are used for medicinal purposes. Carrot seeds are useful the treatment of kidney diseases and are prescribed for subsiding uterine related pains [4].

In Botswana, carrot is ranked as a second valuable crop in terms of income, after tomato. During 2015/16 carrot generated a revenue of about P 7.4m, whilst tomato generated P15m [5]. Regardless of the good ranking of carrot in Botswana, annual production (2 317.31 tons) is not sufficient as its importation is being noted [6]. Another factor leading to low supply is amount of yield attained annually, carrot yields in Botswana (20 to 30 t ha^{-1}) are very low, falls even far below the targeted 40 t ha^{-1} by the local Department of Crop Production. Comparatively, yields ranging from 26.3 to 74.7 t ha^{-1}, 64.9 to 69.2 t ha^{-1} and 38.13 to 51.22 t ha^{-1} were attained by [7,8,9].

The performance of any crop depends on genetic factors interacting with environmental factors and cultural practices [10]. In carrot production, there are a number of outstanding cultural practices that have been exploited and showed to have an impact on the growth and yield of carrot. These include, sowing date, thinning, fertilization, irrigation, fumigation, weeding as well as harvesting. Work have been done and documented on these practices regarding their precise time of executions in carrot production, except thinning, though it is commonly practiced by carrot producers (small scale farmers) in this country. Thinning is a selective uprooting of seedlings from overcrowded plants resulting from closely seeded plants. Recommended plant spacing, plant density, plant stand as well as evenly distribution of plants are attained through thinning. These contribute to optimal utilization of soil moisture, nutrients and sunlight by plants for better growth and yield. Since thinning of carrot is a practice to embark on for better plant stand and density, which in return a better yield, producers have no choice but to execute this practice although with no precise time of carrying it out. Some researchers on carrot studies [4,9,11], varied on the time of executing thinning, though they were not investigating the time of thinning nor outlining the impact of the time of thinning in their findings. [11] carried out thinning at three to four weeks after emergence (WAE), whereas [12] and [4] thinned carrot at two WAE. [3] and [13] in their experiments, thinned carrot at the first true leaf stage. [14] when investigating the influence of moon rhythms on the yield of carrot, thinned carrot at 27

days after germination. [15] and [9] executed thinning several times form the same area. [16] thinned at 20 days after sowing.). [17] thinned after complete emergence. In a study conducted by [18], thinning was done whenever the need arises. To avoid thinning, pneumatic precision seed drill can be used [8]. However, pneumatic machinery comes with costs.

Variations in thinning time of carrot is due to scant data available on the critical thinning time (stage), though the importance of thinning has been observed. This research therefore, was undertaken to investigate the critical time (stage) for thinning on growth, root qualities and yield of carrot using a single carrot variety 'Cape market', with the following specific objectives:

1. To determine the effect of thinning time/ stage on the growth and the yield of carrot using a single carrot variety 'Cape market'.
2. To determine the effect of thinning time/stage on quality parameters of storage root using a single carrot variety 'Cape market'.

2. Materials and methods

2.1. Experimental Site Description

A field trial was conducted in 2018 at Impala Horticulture farm (21°08 – 21°11S', 21°35' – 27°37' E) which is adjacent to the city of Francistown, in North East part of Botswana. The area is flat with an altitude of 1020 m above sea level. The area is occasioned by local climatic conditions of low rainfall and dry periods (between April and October) and wet season (between November and March). The annual rainfall is about 630 mm. The soils are classified as haplic lixisol, a typical sodic type and characterized by clay [19]. Monthly metrological data during the trial are indicated in Table 1.

Table 1. Average monthly temperatures and rainfall during the period of field experiment [20]

Month	Temperature (°C)			Precipitation (mm)
	Maximum	Minimum	Average	
March	27	21	24	0
April	26	18	22	0
May	24	13	19	0
June	22	10	16	0
July	21	9	15	0
August	30	12	21	0

2.2. Field Procedures

The experiment was laid out in a randomized complete block design (RCBD), with three replications. Cape market variety was used and thinned at five different leaf stages which were 2, 3, 4, 5 and 6 true leaf stage, which ended up being at 2nd, 3rd, 4th, 5th and 6th WAE respectively as for this study. The entire block area was 45 m^2. The distance between plots and replications was 1.0 m and 1.5 m respectively. Each replication consisted of five unit plots (1.5 m x 1.2 m) and each plot per replication thinned at its allocated time (week after emergence). Seeds at a rate of 3 kg ha^{-1} were sown directly at a depth of 1 cm in each unit plot which had five rows. Thinning operations were done on intra-row spacing and in each unit plot to remain with a seedlings standing of 30 cm between rows and 5 cm intra rows. This experiment was repeated four times on different dates (12 April, 19 April, 26 April and 03 May) during 2018 cropping season. Irrigation was done daily using drip irrigation system. Fertilization was done at two weeks prior to sowing (50 kg ha^{-1} N, 75 kg ha^{-1} P and 50 kg ha^{-1} K) and top dressed with 52 kg ha^{-1} N at eight weeks after emergence using urea. Carrot was harvested from the net plot (1.08 m^2) of each plot unit when matured.

2.3. Data Collection

Collection of data was done on all parameters measured. Growth parameters were conducted on ten randomly selected (tagged) plants from each unit plot. Data was collected on vegetative growth and storage roots quality parameters as follows;

2.4. Vegetative Growth

2.4.1. Number of Leaves

Active leaves were counted on tagged plants. This was done weekly at 6 WAE after the last thinning in all the plots.

2.4.2. Plant Height

Plant height was measured from the ground to the tip of the tallest leaves of tagged plants using a standard ruler. This was done weekly starting at 6 WAE immediately after the last thinning stage in all the plots.

2.5. Storage Root Quality Parameters

2.5.1. Root Diameter

The root diameter was measured at 1 cm from the crown of the same ten selected plants from which vegetative growth parameters were measured. Measuring was done using a digital caliper. This was done after harvest on the ten tagged plants from which vegetative growth measurements were collected.

2.5.2 Root Length

Root length was measured from the apex to the base of the root using a digital caliper. This was done after harvest on the ten tagged plants from which vegetative growth measurements were collected.

2.5.3. Root Yield

The fresh mass of ten selected roots where vegetative growth parameters were measured together with the mass of all roots harvested from the net plot size were expressed as kg m^{-2}, and then converted to t ha^{-1} in order to indicate carrot yield. Roots were separated from leaves before weighing them.

2.6. Data Analysis

Analysis of variance was done on all measured parameters to determine significance of differences between means of treatments using SAS program, and Tukey's test for LSD ≤ 0.05, except where stated.

3. Results and Discussions

3.1. Vegetative Growth Parameters

3.1.1. Number of Leaves

Thinning time did not significantly influence number of leaves but sowing date did (Table 2). Number of leaf development declined significantly. The first sown experiment (12 April) produced significantly more leaves (8.79) which then retarded significantly in the last three subsequent sowings (19 April, 26 April and 03 May).

3.1.2. Plant Height

The time of thinning significantly influenced plant height (Table 2). When thinning was done at 2nd and 3rd WAE, carrot produced significantly taller plants than when thinning was done at 5th and 6th WAE. There was no significant difference on plant height when thinning was carried out at 2nd, 3rd and 4th WAE. Though, 4th WAE performed the same as 2nd and 3rd WAE, it also performed the same with 5th WAE which was significantly different from 2nd and 3rd WAE. Thinning at 4th WAE resulted in significantly taller plants (34.51 cm) than when plants were thinned at 6th WAE (30.88 cm). In subsequent experiments as an experiment was repeated (19 April, 26 April and 03 May), plant height declined significantly (Table 2).

This study indicates that the time of thinning dictated the ultimate vegetative growth particularly plant height which carrots plant reaches, the earlier thinned plants being taller than the late thinned ones up until harvesting. Carrots thinned at an early stage (2nd and 3rd WAE) produced significantly taller plants (36.09 cm and 36.33 cm respectively), and more leaves though the leaves were not significantly different than when thinned at a later stage (5th and 6th WAE). Thus, the vegetative part of carrot plants at this stage (2nd and 3rd WAE) thrived more since it was relieved from water and nutrients competitions with the storage root as they were not yet initiated nor vigorously active. [21] reported that before carrot plants could be 25 days old, its shoots would record way far more weight than its roots and their studies highlighted that, root enlargement occurs after 25 days from sowing. The same was highlighted by [22] who observed that thickening of carrot root is only evident at 42 days old. In concurring that vegetative part develop first, [23], highlighted that the first organ to be active in carrot plant is leaves. At a delayed thinning (5 and 6 WAE), leaf growth declined due to competition of nutrients between the vegetative part and storage root as they grow simultaneously at this stage. Although plants thinned at 2nd and 3rd WAE were the tallest in this study, they were shorter than plants (41.86 cm to 52.99 cm) thinned at 2nd WAE as reported by [12], when investigating growth and yield response of carrot (*Daucus carota* L.) to different green manures and plant spacing. This might be attributed to the type and amount of fertilization as well as the type of cultivars used as these factors have been reported to play a role in the growth of carrot [18,24]. The record values of the number of leaves and the plant height of early sown plants are significantly more than when sown late. This might be due to temperature differences, noted during the experiment. [25] also recorded taller plants and more leaves at the first sowing date and lower at the late sowing date.

3.2. Storage Root Quality Parameters

3.2.1. Root Diameter

Thinning time did not significantly influence carrot diameter but sowing date did play a significant role (Table 3). The results also indicated that the root diameter declined significantly as sowing was delayed. The initial experiment sown on the 12th of April, yielded significantly thickest (28.29 mm) roots compared to 21.28 mm diameter of roots from experiment sown on the 3rd of May. The root diameter of carrots sown on the 19th of April and the 26th of April did not differ significantly from each other but they were significantly thinner than those of plants sown on the 12th of April and significantly thicker than those of plants sown on the 3rd of May.

3.2.2. Root Length

Thinning time did not significantly influence root length of carrot but sowing date did play a significant role (Table 3). The results indicated that the root length declined significantly as sowing was delayed. The initial experiment sown on the 12th of April, yielded significantly longer roots (176.14 mm) compared to 154.79 mm from experiment sown on the 3rd of May. The root length of carrot sown on the 19th of April and the 26th of April, were not significantly different from each other but were significantly shorter than of plants sown on the 12th of April and longer than that of plants sown on the 3rd of May.

Table 2. Influence of thinning time on number of leaves and plant height of carrot, variety 'Cape market' from 2nd to 6th weeks after emergence

Thinning time (WAE)	Number of leaves					Plant height (cm)				
	Date sown				Average (Tt)	Date sown				Average (Tt)
	12 April	19 April	26 April	03 May		12 April	19 April	26 April	03 May	
2	8.30	7.90	8.20	8.37	8.19^{a}	39.30	34.88	36.10	34.07	36.09^{a}
3	8.67	8.57	8.27	7.50	8.25^{a}	39.18	37.90	38.12	30.13	36.33^{a}
4	9.03	8.27	7.63	8.72	8.41^{a}	38.65	35.07	33.27	31.03	34.51^{ab}
5	9.10	7.30	7.70	8.50	8.15^{a}	34.58	31.23	32.73	29.77	32.08^{bc}
6	8.87	7.50	8.37	7.90	8.16^{a}	33.75	29.85	30.72	29.20	30.88^{c}
Average (SD)	8.79^{A}	7.91^{B}	8.03^{B}	8.20^{B}		37.09^{A}	33.79^{B}	34.19^{B}	30.84^{C}	
$LSD_{T(0.05)}$	Tt = ns SD = 0.56 Tt*SD = ns					Tt = 2.58 SD = 2.25 Tt*SD = ns				

Means followed by different small letter(s) in the same column differ significantly. Means followed by different capital letter(s) in the same row differ significantly. **$LSD_{T(0.05)}$** = least significant difference. **Tt** = Thinning time, **SD** = sowing date, **ns** = non significant, **Tt*SD** = thinning time interaction with sowing date and **WAE** = weeks after emergence.

Table 3. Influence of thinning time on root diameter and root length of carrot, variety 'Cape market' from 2nd to 6th weeks after emergence

Thinning Time (WAE)	Root diameter (mm)					Root length (mm)				
	Date sown				Average (Tt)	Date sown				Average (Tt)
	12 April	19 April	26 April	03 May		12 April	19 April	26 April	03 May	
2	27.39	23.00	25.61	21.02	24.26^{a}	156.50	167.38	173.68	150.72	162.07^{a}
3	28.46	25.72	29.01	20.54	25.93^{a}	165.34	171.40	172.42	143.50	163.17^{a}
4	29.65	24.11	23.67	23.08	25.13^{a}	222.94	164.37	169.68	159.06	179.01^{a}
5	28.20	22.67	25.18	22.16	24.55^{a}	160.34	173.56	161.55	156.96	163.10^{a}
6	27.75	24.44	23.67	19.60	23.87^{a}	175.56	171.58	160.46	163.72	167.83^{a}
Average (SD)	28.29^{A}	24.00^{B}	25.43^{B}	21.28^{C}		176.14^{A}	169.66^{AB}	167.56^{AB}	154.79^{B}	
$LSD_{T(0.05)}$		Tt = ns	SD = 2.16	Tt*SD = ns			Tt = ns	SD = 20.41	Tt*SD = ns	

Means followed by different small letter(s) in the same column differ significantly. Means followed by different capital letter(s) in the same row differ significantly. $LSD_{T(0.05)}$ = least significant difference. Tt = Thinning time, SD = sowing date, ns = non significant, Tt*SD = thinning time interaction with sowing date and WAE = weeks after emergence.

Table 4. Influence of thinning time on root yield of carrot, variety 'Cape market' from 2nd to 6th weeks after emergence

Thinning time (WAE)	Root yield (t ha^{-1})				Average (Tt)
	Date sown				
	12 April	19 April	26 April	03 May	
2	33.03	29.01	20.99	23.15	26.55^{a}
3	35.50	29.63	24.69	23.46	28.32^{a}
4	29.32	31.17	19.44	18.83	24.69^{ab}
5	23.46	23.46	23.46	13.27	20.91^{b}
6	18.82	20.06	10.49	12.65	15.51^{c}
Average (SD)	28.03^{A}	26.67^{A}	19.81^{B}	18.27^{B}	
$LSD_{T(0.05)}$			Tt = 4.15	SD = 3.71	Tt*SD = ns

Means followed by different small letter(s) in the same column differ significantly. Means followed by different capital letter(s) in the same row differ significantly. **$LSD_{T(0.05)}$** = least significant difference. **Tt** = Thinning time, **SD** = sowing date, **ns** = non significant and **Tt*SD** = thinning time interaction with sowing date and **WAE** = weeks after emergence.

3.2.3. Root Yield

The time of thinning significantly influenced yield of carrot and as thinning executions is delayed, yield significantly declined (Table 4). Although the yield of carrot thinned at 2nd and 3rd WAE, were not significantly different from each other, they were significantly different from yield of carrot thinned at 5th and 6th WAE.

Thinning at 4th or 5th WAE did not differ significantly regarding the yield and this was the same between thinning at 3rd and 4th WAE. As sowing was delayed, the yield declined by close to 10 t ha^{-1} (Table 4). Carrot sown early (12th April) produced significantly more yield (28.03 t ha^{-1}) than late sown (3rd May) carrot which yielded 18.27 t ha^{-1}. However, when sown on the first and the second sowing dates (12th April and 19th April), the yield produced was not significantly different. The same was on carrot sown on the third and the fourth sowing dates (26th April and 3rd May). But when sown on the 12th of April and the 19th of April, the yield differed significantly from those sown on the 26th of April and 3rd of May.

From this study, it appears that storage roots depend on the vegetative parts for assimilates and the greater the vegetative parts, greater was the storage roots in both diameter and length. Thus, the quantity of photosynthetic material scaled the size of the storage root. As the date of repeating the experiment delayed, storage roots reduced in size. This might be due to the decline in vegetative part as a results of the decrease of temperatures noted on the late sowing dates. This is in line with [26], who highlighted that as vegetative growth is promoted, root length increases. In supporting study, [27], reported a significant decline in root diameter at late sown dates when studying the performance of carrots (*Daucus carota* L.) genotypes under different sowing dates. However, [28], when evaluating baby carrot cultivars and their growth patterns, highlighted that the rate of root elongation either longitudinal or radial depend on the cultivar. The root size of carrot attained from this study ranged between 21.28 and 28.29 mm in diameter and between 154.79 to 179.01 mm in length, thus meeting the fresh market requirements for large, class 1 and 2. According to the local grading system for fresh produce markets, all the storage root greater than 40 mm in diameter are graded as large. Whereas the ones that are greater than 125 mm in length are of class 1 and 2 [29].

High yields (26.55 t ha^{-1} to 28.32 t ha^{-1}) in this study were attained when carrot were thinned at early stages where significant higher growth in vegetative sector was recorded. [30] highlighted that storage root yield depends on the quantity of vegetative part accumulated at early stage, suggesting that large photosynthetic capacity should be promoted as soon as the first true leaf is initiated. This is in agreement with [31] who also stated that greater yield is associated with greater plant stand. However, comparable studies where carrot were also thinned at 2nd WAE, [26] and [12] reported gross yield of 12.4 t ha^{-1} and 28.73 t ha^{-1} respectively, which is lower than of the current study. Early sowing date also yielded more (26.67 t ha^{-1} to 28.03 t ha^{-1}) and this is in supportive of several studies that reported decline in yield as sowing date is delayed [25,32,33]. This might be due to decline of temperatures from 24°C to 15°C (mean temperatures) in this study. This is in agreement with [34] when stating that sowing crops at appropriate time when temperatures are favourable is critical for uttermost crop performance and higher yields.

4. Conclusions and Recommendations

From the findings of this study, it can be concluded that the time at which thinning is done, significantly affect growth and yield of carrot. Thinning early helps carrot plant to develop sufficient vegetative organs needed for gathering assimilates for storage roots. Yield of a great recompense of reward will be attained if thinning is done at 2nd and 3rd weeks after emergence which is the period before storage root could be vigorously active. The sowing date also shown to be playing a role in carrots growth. Both vegetative growth and yield progressively declined as sowing date was delayed. Thus, thinning can be done when plants are two to three weeks old with sowing done early in the growing season in the North East of Botswana. However, further investigations on thinning time of carrots with different varieties or type of fertilizers can be of great importance.

Acknowledgements

I am grateful to the Department of Agriculture Research for availing the facilities and materials used for this work. Credits also to Ms L. C. Bosekeng, Mr K. Mogotsi and Mr Z. Madzonga for valuable discussions during the proposal stage of this work and all the field assistants (FA's) under the supervision of Ms D. Kaisara. I am also expressing my gratitude to Mr M. Ithuteng for statistical analysis.

Declaration of Interest

The author declare no conflict of interests.

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