

Research Article

Effect of seeding rate on plant density and productivity of garlic (*Allium sativum* L.) in Elseleim Area, Dongola, Sudan

Intisar Mohamed Bakheit¹, Elsadig Hassan Elsadig^{2*}

¹Nile Valley University, Atbara, Sudan

²Sudan University of Science and Technology, Sudan

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*Corresponding author: Elsadig Hassan Elsadig, E-mail: elsadig_hassan2000@hotmail.com

Abstract

A field experiment was conducted during two consecutive winter seasons (2018/2019 and 2019/2020) at El-Seleim area, Dongola locality, Northern State, Sudan, to evaluate the effect of seeding rates on plant density and productivity of garlic (*Allium sativum* L.). The experiment was arranged in a randomized complete block design (RCBD) with a split-plot arrangement and four replications. Three seeding rates (300, 500, and 700 kg/feddan) were tested. Results showed that increasing seeding rate significantly increased plant density, fresh and dry weights, and total yield. However, lower seeding rates improved plant height, bulb diameter, and bulb quality. The highest yield was obtained at 700 kg/feddan, while the best bulb size was recorded at 300 kg/feddan. On the other hand, the highest yield (2.17 tons/feddan) was recorded with the highest seed quantity (700 kg/feddan), indicated the importance of high plant density in increasing the economic return of the crop in the study area. The study concludes that optimizing seeding rate is essential for balancing yield and quality under Northern Sudan conditions.

Keywords: Garlic, Seeding Rate, Plant Density, Yield, Sudan

Introduction

Garlic (*Allium sativum* L.) is one of the most important bulb crops in Sudan, holding a prominent place in Sudanese cuisine and its nutritional, medicinal, and economic importance as a significant cash crop for farmers in the Northern State. The Al-Seleim area in Dongola is characterized by its suitable climate and fertile alluvial soil, making it one of the most important garlic production areas in the country. However, farmers face challenges related to low productivity due to the lack of optimal agricultural practices, especially improper seeding rates and plant density. Plant density is a key factor that determines the level of competition among plants for water, nutrients, and light. In Sudan, garlic is widely grown in the Northern State, particularly in Dongola area where environmental conditions are suitable for its production. Therefore, this study aims to evaluate the effect of different seeding rates on plant density and productivity of garlic under the conditions of El-Seleim area.

Plant density in garlic production

The studies showed that seed quantity plays a crucial role in determining the optimal plant density. Nourai (1994) proved that increasing seed rates leads to an increase in the total yield per hectare, but it may lead to smaller individual bulbs due to competition for resources. In Sudan, studies by Abdelseed (2011) confirmed that the Chinese variety responds well to fertilization and regular irrigation, but it requires precise adjustment of planting distances to obtain export-quality bulbs. Plant density is a major factor influencing crop performance and is determined by seeding rate and spacing. It directly affects plant growth, yield components, and final productivity (Brewster, 2008), also

Ara *et al.* (2007) and Sedaghati *et al.* (2016) indicated that a lower seeding rate resulted in increased plant height due to reduced competition among plants for available resources, such as light, water, and nutrients.

On the other hand, lower plant density reduces competition among plants, resulting in better vegetative growth, larger bulbs, and improved quality. In contrast, higher plant density increases competition but enhances total yield per unit area (Kaur *et al.*, 2017).

Effect on growth and yield

Studies have shown that plant density significantly influences plant height, leaf number, and bulb development. Rahman *et al.* (2020) reported that wider spacing improved bulb size and plant growth.

Diriba-Shiferaw *et al.* (2014) found that optimal spacing increased marketable yield and improved bulb characteristics. Similarly, Getachew and Asfaw (2000) concluded that high density increases yield but reduces bulb size.

Planting dates

Planting occurs from September to mid-October. Planting in October yielded higher productivity compared to planting in September and November (Tadila & Nigusie, 2018). Planting in early November positively affected the number of leaves, bulb thickness, size, weight, and productivity. In another study, Qaryouti and Kasrawi (1995) explained that planting date affected the quantity and quality of the yield, where delaying planting from October to January led to smaller bulb diameters, reduced fresh and

dry weight, and consequently lower yield. D'Anna *et al.* (1999) also showed that early planting gave the highest yield and best bulb quality compared to late planting. In Poland, Orłowski and Rekowska (1993) found that garlic growth and productivity in autumn planting were better than in spring planting, and early planting in both autumn and spring not only accelerated bulb formation but also resulted in larger bulbs and increased yield compared to late plantings.

Plant density under semi-arid conditions

In semi-arid regions such as Northern Sudan, plant density management is critical due to limited water and nutrient availability. The results suggest that an appropriate planting density can improve resource utilization by balancing inter-plant competition, thereby contributing to greater crop productivity (Postma *et al.*, 2021).

Agricultural service operations

Replanting (Gap filling)

Gap filling for missing plants is carried out 7-10 days after planting for local varieties Brewster (2008) and 20-25 days for Chinese varieties, due to their slower germination (Hassan, 1984).

Weeding and weed control

Due to the slow growth of garlic plants in the first months after planting, fast-growing weeds can harm the plants if left unchecked. Weeds should be removed by shallow hoeing (scratching) as soon as germination is complete, avoiding deep hoeing, as garlic roots do not penetrate deeply into the soil. Earthing up around the plants should be done during hoeing. Garlic requires 4-5 hoeings during its growth, but the number of hoeings can be reduced to two if herbicides are used for weed control before planting (Hassan, 1984). Weeds must be removed and the soil around the plant loosened by hoeing in the early stages of growth, and the hoeing process should be repeated as needed. Ghanbari *et al.* (2013) indicated that weed control resulted in the highest garlic yield in terms of bulb size, number of cloves, and bulb weight

Irrigation

Irrigation is carried out at close intervals after planting until germination. After germination, it requires 5 irrigations. Irrigation is stopped approximately 2-3 weeks before harvesting to reduce moisture in garlic bulbs and prevent soil adhesion, which can lead to rot and poor storage. Garlic requires moderate and regular irrigation. Excessive soil moisture leads to increased neck thickness of the bulb, higher moisture content, reduced storage capacity, and poor color. Irregular irrigation leads to distorted bulb shapes. The interval between irrigations decreases in light soils and hot weather. Irrigation is also stopped when signs of maturity begin to appear (Hassan, 1984). Ghanbari *et al.* (2013) indicated in a study that drip irrigation reduced

weeds and gave the highest yield compared to surface irrigation.

Fertilization

Organic fertilizer is added at a rate of 15-20 cubic meters per feddan during land preparation for planting. In addition, garlic requires 120 units of nitrogen, 60 units of phosphorus, and 48 units of potassium per feddan from chemical fertilizers. One-eighth of the nitrogen and one-third of the phosphorus are added during land preparation before planting. The remaining quantities are added in three instalments: the first one month after planting, and then monthly thereafter. Care should be taken not to delay fertilizer application beyond this to ensure full utilization and achieve the purpose of fertilization, which is to form good vegetative growth before bulb formation. Studies on the Chinese variety have shown that nitrogen fertilization promotes garlic plant growth more than phosphorus or potassium fertilization. High levels of macronutrients led to a significant increase in bulb size, total yield, and marketable yield (Hassan, 1984). Using 50 kg of nitrogen and 10 tons of sheep manure per hectare gave the highest garlic yield and positively affected clove weight and bulb productivity (Tadila & Nigusie, 2018). A study by Assefa *et al.* (2015) in northern Ethiopia showed that fertilization with N, P, S, and Zn gave the highest garlic yield at a rate of 130 kg nitrogen, 20 kg phosphorus, 21 kg sulphur, and 15 kg zinc per hectare. A study by Taha and Helal (2019) indicated that a mixture of nitrogen with organic fertilizer extracted from tea leaves or yeast gave the highest plant growth volume, bulb weight, and total garlic yield. In addition that there were a study showed that fertilization with five tons per hectare of poultry manure increases the growth, yield, and quality of garlic bulbs. Adding 100 ppm of citric acid with 300 ppm of thiourea gave the highest garlic yield in terms of leaf number, bulb weight, number of cloves, and clove weight (Patel *et al.*, 2017).

Duplex trait in garlic

This refers to the formation of more than one head when a single garlic clove is planted. The phenomenon of multiple heads is an important biological indicator as it leads to an increase in garlic yield. This phenomenon occurs in the following cases:

1. When garlic is planted without separating its cloves.
2. When planting a complex clove containing 2-3 or more buds instead of the usual single bud.
3. When planting garlic with complex branching.

This phenomenon of multiple heads is observed when planting in highly fertile soil (Al-Rikabi & Jassim, 1981).

Physiological disorders

Misshapen, irregular heads are among the most important physiological disorders that appear in garlic crops. Frequent exposure of stored garlic seeds or young plants in the field to low temperatures is one of the main causes of this phenomenon, as it leads to the formation of

cloves in the axils of the outer leaves. These cloves may produce vegetative growth during the growing season, appearing as lateral growth of the bulb, which then leads to the loss of some outer leaves covering the head, causing some cloves to appear without an outer wrapper. This phenomenon is more pronounced in early plantings, heavy fertilization, increased planting distance, and all conditions that encourage strong, rapid growth. Another physiological disorder is the phenomenon of hollowing, which occurs in garlic stored for several months under unsuitable conditions, such as high temperatures or extremely low relative humidity. In these cases, the cloves lose a high percentage of their moisture, shrinking inside the protective outer leaf of the clove. The clove also loses part of its carbohydrate content through respiration due to high respiration rates at high temperatures. All of this leads to the heads retaining their normal shape, but they become light in weight due to the shrinkage of the cloves and their emptying of most of their moisture and stored food content (Hassan, 1984).

Effect of leaf pruning on yield

It was found that removing the lower leaves of garlic plants significantly reduced bulb yield when performed in the second half of the growing season, which is associated with the bulb formation period. The Egyptian variety was the most affected by this treatment, and the Chinese variety was the least affected (Hassan, 1984).

Dormancy

Garlic cloves enter a resting period when the plants reach maturity in the field. During this period, the cloves cannot germinate or root even if suitable conditions are provided. The dormancy state gradually weakens in storage, and this is faster when stored at 5-10 °C than when stored at lower or higher temperatures. This continuous weakening of dormancy lasts for 4-5 months, after which the resting period ends. The length of the resting period varies depending on the varieties, which affects their suitability for storage (Hassan, 1984).

Maturity

Garlic plants may be harvested before full maturity to obtain a higher return when prices are high at the beginning of the season. These plants are sold for direct consumption and are not stored due to their high moisture content, which makes them unsuitable for storage. However, the usual practice is to harvest the crop after full maturity (Hassan, 1984). Garlic matures after about 6-7 months from planting, typically during March and April under subtropical conditions (Hassan, 1984).

Harvesting

Plants are harvested with hoes or iron stakes, then pulled by hand and spread in the sun for one to two weeks until the tops dry (Hassan, 1984).

Storage

Garlic plants can be stored in good condition for up to 8 months in ordinary, non-refrigerated stores, provided that the plants are fully mature, well-treated, and the stores are well-ventilated to prevent bulb rot. During this period, the heads lose about 35-60% of their weight. This loss appears a few months after storage as slight hollowing in the cloves, which gradually intensifies until the heads lose their market value before the next harvest season. This problem is more severe in Chinese garlic, which cannot be stored in this manner for more than December. Therefore, if refrigerated stores are available, it is recommended to store garlic at 0 °C, with a relative humidity ranging from 65-70%. Humidity should not exceed this to avoid head rot and root growth, and should not be lower to minimize the hollowing phenomenon. In this way, heads can be preserved in good, fresh condition for more than 8 months. As for heads intended for use as seeds, they should be stored at a temperature ranging from 5-10 °C, provided that the storage temperature does not fall below 4 °C or rise above 18 °C. This is because extremely low temperatures lead to very early maturity, resulting in reduced yield and an increased percentage of irregularly shaped bulbs, while high temperatures delay clove germination, bulb formation, and maturity (Hassan, 1984).

Main problems of garlic storage

Weight loss

This depends on several factors, including variety, temperature, maturity at harvest, whether the tops are cut or not, storage temperature, and storage duration.

Sprouting

It is observed that 0 °C and 75% relative humidity can prevent sprouting for up to 9 months.

Hollowing

Occurs in cloves a few months after storage, caused by the loss of carbohydrate material through respiration during the storage period. Hollowing can be reduced by storing at low temperatures (0 °C).

Spoilage

Occurs due to fungal and bacterial attacks on garlic heads during storage, which accelerates disease incidence. It also occurs due to early harvesting before full maturity, storage without drying treatment, or storage in poorly ventilated stores.

Pests in storage

Several insect pests can affect garlic bulbs during storage, causing deterioration and reducing bulb quality. However, the specific pest species should be identified by their accepted scientific names before being cited in the

present study. Yield reduction in garlic can result from insect pest infestations and disease incidence, which may adversely affect plant growth, bulb development, and final yield (Mishra *et al.*, 2014).

Pests and their control

Garlic is susceptible to many diseases, insect, and mite pests that also affect onions. These include downy mildew, purple blotch, pink root, white rot, basal rot, neck rot, leaf spot caused by *Stemphylium* fungus, rust, and various rots caused by *Fusarium*, *Aspergillus*, *Helminthophobia*, *Penicillium*, and *Sclerotium* fungi, bacterial soft rot, yellow dwarf virus, stem and bulb nematodes, onion fly, thrips, and various types of mites (Hassan, 1984). Results from a study by Ahmed *et al.* (2017) revealed that planting at 10 cm spacing resulted in a higher incidence of rust disease compared to planting at 20 cm spacing.

Materials and methods

Study area

The experiment was conducted during the winter seasons of 2018/2019 and 2019/2020 at Al-Saleem Basin. The study area lies between latitudes 16° 22' N and longitudes 25° 32' E.

Climate and soil requirements

Climate and soil requirements characterized by an arid climate with low rainfall. Garlic grows best in cool climates during early growth stages and requires warm conditions for bulb development. Optimal temperature ranges between 12-24 °C. Well-drained loamy soils rich in organic matter with a pH of 6.0-7.5 are ideal for cultivation.

Experimental design

Design: RCBD with split-plot
Replications: 4
Main plots: Planting methods
Subplots: Seeding rates (300, 500, 700 kg/feddan)

Agronomic practices

Variety: Chinese garlic
Irrigation: Every 8–10 days
Fertilization: Nitrogen applied in split doses
Weed control: Manual

Data collection

Plant height
Plant density
Number of leaves
Bulb weight
Bulb diameter
Total yield

Statistical analysis

Data were analyzed using ANOVA, and means were compared using LSD at 5%.

Land preparation

Proper land preparation is essential for good root development. The soil was plowed and harrowed to a fine tilth. Raised beds or ridges were used to improve drainage and aeration.

Planting methods

Garlic was propagated vegetatively using cloves. Healthy, disease-free cloves were selected and planted at a spacing of 10-15 cm between plants and 20-30 cm between rows. Planting depth was typically 3-5 cm.

Irrigation management

Garlic is sensitive to both water stress and waterlogging. Efficient irrigation systems such as drip irrigation significantly improve water use efficiency. Critical growth stages for irrigation include germination, vegetative growth, and bulb formation. In experiment used the surface irrigation.

Fertilization

Balanced fertilization is crucial for optimal growth. Nitrogen, phosphorus, and potassium (NPK) should be applied based on soil test recommendations. Organic fertilizers such as compost and farmyard manure enhance soil structure and microbial activity.

Weed, pest, and disease management

Weeds compete for nutrients and water, reducing yield. Integrated weed management practices were applied. Common pests include thrips, while diseases such as white rot and downy mildew can significantly affect production. Integrated Pest Management (IPM) strategies were followed.

Results and discussion

Effect of seeding rate on vegetative growth

The results presented in Table: 1, indicate that seeding rate had a significant effect on plant height, plant density, during both growing seasons. The lowest seeding rate (300 kg/feddan) produced the tallest plants in both seasons. This increase in plant height under lower seeding rates can be attributed to wider spacing between plants, which reduces competition for essential growth resources such as light, water, and nutrients. Consequently, plants experience improved photosynthetic efficiency and vegetative growth, resulting in increased plant height.

These findings are consistent with those reported by Ara *et al.* (2007) and Sedaghati *et al.* (2016), who stated that reduced plant density leads to increased plant height due to lower competition among plants. On the other hand, plant density increased significantly with increasing seeding rate. Treatment S3 recorded the highest plant density, while S1 had the lowest. This confirms the direct relationship between seeding rate and plant population.

Effect on bulb characteristics

Effect of seeding rate on bulb thickness and bulb weight

Data in Table 2, show a significant effect of seeding rate on bulb thickness and bulb weight. The results of the present study revealed significant differences among seeding rate treatments in both bulb thickness and bulb weight during the two growing seasons.

Regarding bulb thickness, the lowest seeding rates S1 (300 kg/feddan) produced the highest values in both seasons. A gradual decrease in bulb thickness was observed with increasing seeding rate. This reduction can be attributed to increased competition among plants under higher plant density, which limits the availability of essential growth resources such as water, nutrients, and light, thereby restricting bulb enlargement. This agrees with findings by Diriba-Shiferaw *et al.* (2014) and Rahman *et al.* (2020), the reduction in bulb diameter at higher density is attributed to competition for nutrients and assimilates (Brewster, 2008). Moderate seeding rates provide a balance between yield and quality.

These findings are consistent with those reported by Biru (2015) and Kaur *et al.* (2017), who indicated that increased plant density leads to a reduction in bulb size and thickness due to intensified intra-specific

Table 1: Effect of seeding rate on plant height and density

Seeding rate (kg/fed)	Plant height (cm)	Plant density (plants/m ²)
300 (S1)	72.5 ^a	45.2 ^c
500 (S2)	68.3 ^b	60.7 ^b
700 (S3)	64.1 ^c	75.9 ^a
LSD (0.05)	3.2	5.6

Means followed by the same letter within each column are not significantly different at $P \leq 0.05$

Table 2: Effect of seeding rate on bulb thickness and bulb weight of garlic (*Allium sativum* L.)

Seeding rate	Bulb thickness (mm)		Fresh bulb weight (g)	
	2018	2019	2018	2019
S1	47.04 ^a	52.09 ^a	42.03 ^c	52.03 ^c
S2	45.01 ^b	48.02 ^b	48.05 ^b	57.05 ^b
S3	40.16 ^c	44.09 ^c	56.05 ^a	68.03 ^a
LSD (0.05)	1.34	2.46	4.96	3.12
SE $\pm$	0.75	0.82	1.65	1.04
C.V (%)	3.68	4.75	9.49	4.94

Means followed by the same letter within each column are not significantly different at $P \leq 0.05$

competition. In contrast, bulb weight was significantly affected by seeding rate, with higher seeding rates resulting in increased bulb weight in both seasons. This increase may be attributed to the higher total biomass accumulation per unit area due to increased plant population. However, these findings are not in agreement with those reported by Nourai (1994), who stated that increasing seeding rate or plant density leads to a higher proportion of small bulbs and a reduction in individual bulb weight and number of cloves per bulb, due to intense competition among plants.

Table 3 shows that seeding rate significantly affected clove weight and total yield, while the number of cloves was not significantly affected.

Furthermore, seeding rate had a significant effect on clove weight during the second season only. The highest seeding rate (700 kg/feddan) produced the greatest clove weight, whereas no significant differences were observed between the lower seeding rates (300 and 500 kg/feddan). This variation may be explained by the interaction between plant density and environmental conditions prevailing during the second growing season, which influenced assimilate partitioning within the plant.

These findings are partially consistent with those reported by Rahman *et al.* (2020) and Diriba-Shiferaw *et al.* (2014), who demonstrated that clove weight is influenced by plant density and environmental conditions, particularly across different growing seasons.

The number of cloves remained statistically similar across treatments, indicating that this trait is genetically controlled and less influenced by plant density.

Clove weight showed significant variation, with the highest value recorded under S3 in second season, suggesting improved assimilate partitioning under higher density in that season.

The results revealed highly significant differences among seeding rate treatments in garlic yield during both growing seasons. The highest seeding rate (700 kg/feddan) produced the maximum yield compared to the lower seeding rates (300 and 500 kg/feddan).

Table 3: Effect of seeding rate on clove number, clove weight, and total yield of garlic

Seeding rate	Number of cloves		Clove weight (g)		Yield (ton/ha)	
	2018	2019	2018	2019	2018	2019
S1	16.62 ^a	16.00 ^a	3.54 ^a	3.56 ^b	1.21 ^c	1.60 ^c
S2	17.75 ^a	16.50 ^a	2.76 ^a	3.55 ^b	1.73 ^b	1.85 ^b
S3	18.00 ^a	15.38 ^a	2.70 ^a	4.48 ^a	2.16 ^a	2.17 ^a
LSD (0.05)	1.27	1.54	0.38	0.72	0.21	0.21
SE $\pm$	0.42	0.51	0.13	0.24	0.09	0.08
C.V (%)	6.82	9.03	13.54	17.63	11.81	10.48

Means followed by the same letter within each column are not significantly different at $P \leq 0.05$

The increase in yield with increasing seeding rate can be attributed to the higher number of plants per unit area, which directly enhances total biomass production and overall yield, despite possible reductions in individual plant performance.

These findings are in agreement with Meena and Gupta (2013), who reported that garlic yield is strongly influenced by plant density and seeding rate. Similarly, Kaur *et al.* (2017) demonstrated that higher plant density significantly increases total yield, although it may negatively affect bulb quality.

In addition, Brewster (2008) emphasized that yield in *Allium* crops is largely determined by plant population per unit area, highlighting the critical role of plant density in maximizing productivity.

The findings confirm that garlic productivity is primarily density-driven, where increased plant population enhances total yield at the expense of certain quality traits such as bulb size (Brewster, 2008; Kaur *et al.*, 2017; Rahman *et al.*, 2020).

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