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RESEARCH ARTICLE

Impact of deficit irrigation management and growth retardants application on yield attributes and yield of groundnut (*Arachis hypogaea* L.) variety VRI8

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Abstract

Groundnut, an important oilseed crop, requires effective management such as maintaining less oil moisture content and providing growth retardant chemicals to prevent pre-harvest sprouting, which can adversely affect yield. A field experiment was conducted at the Agricultural College and Research Institute, Madurai, in the early summer of 2024 to evaluate the impact of growth retardants and deficit irrigation on the sprouting of groundnut kernels. The study included three irrigation strategies: conventional irrigation and two deficit regimes with irrigation withheld from 90 to 105 DAS (Days After Sowing) and 85 to 100 DAS. Additionally, growth retardants [maleic hydrazide (MH) @ 1250 ppm, cycocel (CCC) @ 1000 ppm, abscisic acid (ABA) @ 750 ppm and salicylic acid (SA) @ 750 ppm] were sprayed at 75 and 90 DAS. Results showed that MH @ 1250 ppm was the most effective treatment for inducing dormancy. A split-plot design was used. Withholding irrigation from 90 to 105 DAS also significantly increased pod yield by reducing pod loss due to field sprouting. The combination of MH @ 1250 ppm and no irrigation from 90 to 105 DAS resulted in a pod yield of 2776 kg ha^{-1}, which was higher than the control plot. The foliar application of MH @ 1250 ppm combined with irrigation withdrawal from 90 to 105 DAS emerged as the most effective method for inducing dormancy in groundnut, resulting in a substantial reduction in pod loss and enhanced pod yield, as well as seed storage potential. The reduction in soil moisture content during the harvest stage, combined with changes in hormonal activities, significantly impacts seed sprouting. These factors can lead to stress conditions that inhibit germination, ultimately affecting crop yields. Addressing these issues is crucial for ensuring optimal seed development and enhancing agricultural productivity.

Keywords

bunch type; dormancy; groundnut; growth inhibitor; pre-harvest sprouting

Introduction

A major legume crop from South America, groundnut (*Arachis hypogaea* L.) is a member of the Leguminosae family. Because of the ideal agro-climatic conditions for groundnut growing, India has become the world's leading producer of groundnut, with an annual production of 10.2 million tonnes and an average productivity rate of 2703 Kg ha^{-1}, across a cultivated area of 6.01 million hectares (1). Groundnut is mostly grown during the *kharif* season under rainfed conditions in India. It is also an irrigated crop in several states throughout the *rabi* and spring seasons. Grown on 0.41 million ha of land in Tamil Nadu, it yields 1.02 metric tons of production annually, with a productivity of 2.50 tonnes per hectare annually (2).

Groundnut seeds are rich in oil (42-52%) and protein (22 -30%). It also has a high calcium, magnesium, potassium and phosphorus concentration. The haulms of groundnuts are a healthy way to feed livestock. Compared to cereal fodder, they contain higher amounts of proteins (8-15%), lipids (1-3%), minerals (9-17%) and carbohydrates (38-45%) (3). Further, being leguminous, groundnuts help to improve soil fertility and health by incorporating organic residues into the soil.

A popular choice among farmers, the VRI 8 groundnut variety has a high yield potential, early maturity, disease resistance, adaptability, consistent pod features, nutritional quality, stress tolerance and simplicity of maintenance. In comparison to other groundnut cultivars, it is well known for having a comparatively high production potential with marketable bold seeds. When growing conditions are ideal and management techniques are followed, VRI 8 can yield an average of 2,000-3,000 kg ha^{-1} of pods (4). The oil content of VRI 8 groundnut typically ranges from 45% to 50% of the weight of the kernel (5). The main issue with this bunch-type groundnut variety is the non-dormant nature of the seeds. To address this situation, it is crucial to look for a way to induce seed dormancy in the majority of bunch-type groundnut growing areas to preserve the crop and prevent field sprouting.

Seed dormancy is a critical issue in agriculture, particularly in India, where it plays a significant role in crop establishment, yield and food security. Seed dormancy refers to the inability of seeds to germinate under favorable environmental conditions, which can lead to delayed or uneven crop emergence. This issue is particularly relevant in crops like groundnut (peanut), where dormancy can affect the timing and success of planting. Dormancy is a crucial element in the commercial production of groundnuts. It can be beneficial when dormancy prevents mature seeds from sprouting before harvest. However, if dormancy lasts for a long time, it can cause problems in seed germination after sowing (6). Lack of dormancy in bunch-type varieties has been described as an inherent property of seeds. Due to delays in harvesting, this issue becomes more apparent. It has been reported that in-situ germination in bunch-type groundnut varieties can result in yield losses of 20-40% (7). This investigation is about non-conventional methods of inducing dormancy in bunch types to save the produce and retain the seed quality. Deficit irrigation management during the maturity stage (8) and foliar application of different growth-retarding chemicals (9) have been successfully used.

With a focus on the pre-harvest sprouting in groundnut, the current study attempts to ascertain how growth retardant treatment and deficit irrigation affect groundnut in-situ sprouting mitigation. Understanding the interplay between water management, hormonal regulation and crop physiology is crucial for developing resilient cultivation methods that enhance productivity while minimizing environmental impacts such as drought and irregular rainfall patterns. So, the primary objective of this study is to reduce the *in situ* sprouting of groundnut seeds under higher soil moisture conditions during the harvest stage to improve the yield.

Materials and Methods

The present investigation was conducted during early summer 2024 in the Department of Agronomy, Agricultural College and Research Institute (Agricultural College and Research Institute), Madurai, situated at 9˚ 96′ N latitude and 78˚ 20′ E longitude. Groundnut variety VRI 8 was grown in a 3 × 4 m^2 plot with 30 cm × 10 cm spacing. VRI 8 is a bunch-type groundnut variety with more *in situ* sprouting problems. Thus, this variety was chosen. A split-plot design was used with three replications.

Weather and Climate

The recorded data of relative humidity, maximum temperature, minimum temperature, solar radiation, pan evaporation, wind velocity and rainfall were acquired from March 17 to July 27 (standard week of sowing to harvest) at the agro-meteorological observatory at ACRI, Madurai, Tamil Nadu.

During the experimental period, the maximum and minimum temperatures fluctuated from 36.67 °C to 23.42 °C, respectively. The rainfall received during the period was 254.2 mm. A relative humidity (RH) of 66.35% was recorded. The mean daily pan evaporation of 5.35 mm/day was obtained during the cropping period and the mean daily wind velocity was 4.25 km/hr. The weather parameters recorded during the experiment are presented in Fig. 1.

Methodology

The experiment was laid out in a split-plot design with three replications. The recommended cultivation methods were adopted to raise the crop. The experiment included three irrigation management strategies: normal irrigation and two deficit irrigation treatments where irrigation was withheld from 90 to 105 DAS (Days After Sowing) and 85 to 100 DAS. Additionally, foliar sprays of growth retardant chemicals such as maleic hydrazide (MH) @ 1250 ppm, cycocel (CCC) @ 1000 ppm, abscisic acid (ABA) @ 750 ppm and salicylic acid (SA) @ 750 ppm were applied at 75 and 90 DAS (10). Proper agronomic practices were followed throughout the crop growth cycle.

Irrigation practices

The experimental plots were irrigated immediately after sowing. Generally, groundnut crops require 10-12 irrigations. The first irrigation, called life irrigation, was given on 3 DAS to all the plots uniformly, regardless of irrigation scheduling treatment to ensure crop establishment. The subsequent irrigations were given based on the crop's requirements. Irrigations were stopped according to treatments to impose stress on the crops at 85 and 95 DAS in the selective treatment plots across all three replications.

Growth retardant application

Growth retardant chemicals, including MH at 1250 ppm, cycocel at 1000 ppm, abscisic acid at 750 ppm and salicylic acid at 750 ppm, were systematically applied to groundnut crops during the pod formation stage, specifically at 75 and 90 (DAS). For uniform and effective distribution of these chemicals, a

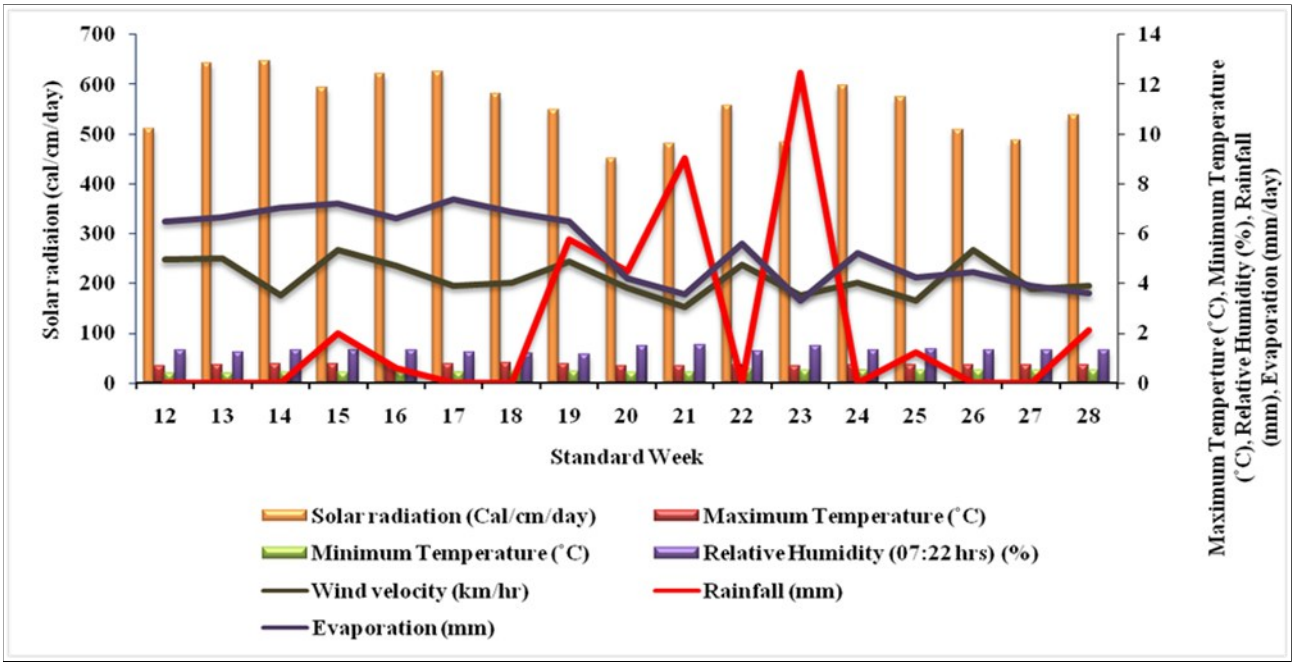

Fig. 1. Weather data regarding weekly mean temperature, rainfall during experiment, weekly mean solar radiation, wind velocity, evaporation and weekly mean Relative humidity

hand-operated knapsack sprayer equipped with a deflector-type nozzle was utilized, ensuring even coverage across the plants. To prepare the spray solutions, a precise method was employed: for 1 ppm concentration, 1 mg of the respective chemical powder was thoroughly mixed into 1 L of water. This meticulous preparation aimed to maximize the efficacy of the growth retardants, potentially enhancing the physiological responses of the plants and improving overall yield.

Observations

The yield parameters of the total number of pegs plant^{-1}, total number of pods plant^{-1}, peg to pod conversion percentage (%), 100 pod weight (g), 100 kernel weight (g), shelling percentage (%), pod yield (kg ha^{-1}) and haulm yield (kg ha^{-1}) were observed and presented in tables and figures. These parameters provide key insights into the plant's growth, reproductive success and overall productivity, as well as the quality of the final harvest.

Total number of pegs plant^{-1}

The total number of pegs plant^{-1} was counted at harvest from randomly selected five plants in each plot. The mean value was computed and expressed in numbers.

Total number of pods plant^{-1}

The total number of pods plant^{-1} was counted at harvesting from randomly selected five plants in each plot. The mean value was computed.

Peg-to-pod conversion percentage

Observations were made from five tagged plants of each treatment and the peg-to-pod conversion percentage was determined using the following equation (11).

$$\text{Peg-to-pod conversion percentage} = \frac{\text{Total no of pods plant}^{-1}}{\text{Total no of pegs plant}^{-1}}$$

Hundred pod weight

The dry weight of 100 two-seeded pods from each treatment was measured and expressed in g.

Hundred kernel weight

The dry weight of 100 kernels was weighed from each treatment and expressed in g.

Shelling percentage

The shelling percentage was calculated using the following equation and expressed as a percentage (12).

$$\text{Shelling percentage} = \frac{\text{Kernel weight}}{\text{Weight of pod}} \times 100$$

Pod yield

The harvested pods from each net plot area were shade-dried for three days to a uniform moisture level and their dry weight was measured and converted into kg ha^{-1}.

Haulm yield

After stripping out the pods from the harvested plants, the haulm yield from each net plot area was sun-dried and the dry weight of the haulm was recorded and expressed in kg ha^{-1}.

Statistical analysis

The data were subjected to statistical analysis by Analysis of Variance (ANOVA) using AGRES software (Version 1.5.1). Differences between mean values were statistically evaluated for significance using the least significant difference (LSD) at a 1% or 5% probability level (13).

Results and Discussion

Effect of deficit irrigation management and growth retardant chemicals application on total number of pegs plant^{-1} of groundnut

Deficit irrigation management and foliar application of growth retardant chemicals had influenced the total number of pegs plant^{-1} significantly. The individual and the combination treatment effects are briefly shown in Table 1. Among the main plot treatments, conventional irrigation (M_1) recorded a higher total number of pegs plant^{-1} (42.5). It was followed by withdrawal of irrigation from 90 to 105 DAS (M_2) with the 37.6 number of pegs plant^{-1} and the lower number of pegs plant^{-1} (35.3) was observed in the treatment with the withdrawal of irrigation from 85 to 100 DAS (M_3). Among the foliar application of growth retardant chemicals, the application of MH (S_3) had a notable effect and obtained the highest number of pegs plant^{-1} (44.6), followed by foliar application of abscisic acid (S_5) (40.9), while the lower level which was seen at control (S_1) (34.1). The interaction effect between deficit irrigation management and foliar application of growth retardant chemicals was significant and resulted in a higher number of pegs plant^{-1}. Conventional irrigation combined with foliar application of MH (M_1S_3) resulted in a higher number of pegs plant^{-1} (51.7), followed by conventional irrigation combined with foliar application of ABA (M_1S_5) (46.7). The lowest number of pegs plant^{-1} (30.0) was observed with the combination of irrigation withdrawal from 85 to 100 DAS and no foliar spray (M_3S_1). The drought at peg formation and peg-to-pod conversion significantly reduced the total number of the peg as well as pod plant^{-1}. At the reproductive stage of groundnut lower soil moisture leads to a harder soil texture which makes it difficult for pegs to penetrate the soil. Hard soils can inhibit peg growth, leading to reduced successful pod formation, as confirmed by previous research (14). Additionally, the foliar application of growth retardant chemicals, such as MH and ABA, mitigated the adverse effects of drought stress on yield components and increased the total number of pegs and pods plant^{-1} (15). MH can inhibit ethylene production, a hormone associated with fruit and flower drop. By reducing ethylene levels, MH can help maintain flower integrity and increase the drought stress tolerance and chances of successful pegging and pod development (16).

Total number of pods plant^{-1}

Deficit irrigation and foliar application of growth retardants significantly affected the total number of pods plant^{-1}. The individual and the combination treatment effects are briefly shown in Table 2. Among the irrigation management treatments, control (M_1) yielded the highest number of pods (30.4), followed by irrigation withdrawal from 90 to 105 DAS (M_2) with 24.4 pods and the lowest number of pods was recorded in the treatment with withdrawal of irrigation from 85 to 100 DAS (M_3) with 23.9 pods. Among the growth retardants application, MH application at 75 and 90 DAS (S_3) produced the highest number of pods (33.3), followed by the application of abscisic acid (S_5) with 29.7 pods and the lowest number of pods was observed at control (S_1) with 21.1 pods. Among the interaction effects, the best results came from conventional irrigation combined with MH application at 75 and 90 DAS (M_1S_3), which produced 41.7 pods, followed by conventional irrigation with the abscisic acid application (M_1S_5) produced 34.7 pods. The lowest value was observed with the combination of irrigation withdrawal from 85 to 100 DAS and no foliar spray (M_3S_1), resulting in 17.8 pods plant^{-1}. At the

Table 1. Effect of deficit irrigation management and foliar application of growth retardants at different intervals on total no. of pegs plant^{-1} of groundnut

Treatment	M1	M2	M3	Mean
S1	37.9	34.6	30.0	34.2
S2	39.0	35.1	32.8	35.6
S3	51.7	42.8	39.2	44.6
S4	40.2	37.8	36.9	38.3
S5	46.8	38.8	37.1	40.9
S6	39.9	36.7	35.6	37.4
Mean	42.6	37.6	35.3	**38.5**
	M	**S**	**M × S**	**S × M**
S. Ed	0.67	0.91	1.59	1.58
CD (p=0.05)	1.85	1.86	3.45	3.22

M_1 : Control (Continuous irrigation as per the recommendation)
M_2 : Withdrawal of irrigation at 95 DAS
M_3 : Withdrawal of irrigation at 85 DAS
S_1 : Control
S_2 : Foliar application of Water at 75 and 90 DAS
S_3 : Foliar application of Maleic Hydrazide @ 1250 ppm at 75 and 90 DAS
S_4 : Foliar application of Cycocel @ 1000 ppm at 75 and 90 DAS
S_5 : Foliar application of Abscisic acid @ 750 ppm at 75 and 90 DAS
S_6 : Foliar application of Salicylic acid @ 750 ppm at 75 and 90 DAS

Table 2. Effect of deficit irrigation management and foliar application of growth retardants at different intervals on total no. of pods plant^{-1} of groundnut

Treatment	M1	M2	M3	Mean
S1	24.6	20.9	17.8	21.1
S2	25.3	21.8	20.2	22.4
S3	41.8	28.2	30.0	33.3
S4	28.2	25.2	24.3	25.9
S5	34.7	26.2	28.2	29.7
S6	27.5	24.2	23.1	24.9
Mean	30.4	24.4	23.9	**26.2**
	M	**S**	**M × S**	**S × M**
S. Ed	0.37	0.74	1.23	1.28
CD (p=0.05)	1.02	1.51	1.58	1.62

M_1 : Control (Continuous irrigation as per the recommendation)
M_2 : Withdrawal of irrigation at 95 DAS
M_3 : Withdrawal of irrigation at 85 DAS
S_1 : Control
S_2 : Foliar application of Water at 75 and 90 DAS
S_3 : Foliar application of Maleic Hydrazide @ 1250 ppm at 75 and 90 DAS
S_4 : Foliar application of Cycocel @ 1000 ppm at 75 and 90 DAS
S_5 : Foliar application of Abscisic acid @ 750 ppm at 75 and 90 DAS
S_6 : Foliar application of Salicylic acid @ 750 ppm at 75 and 90 DAS

reproductive stage of groundnut lower soil moisture leads to a harder soil texture which makes it difficult for pegs to penetrate the soil. The foliar application of growth retardant chemicals, such as MH and ABA, reduced the adverse effects of drought stress on yield components and increased the total number of pegs and pods plant^{-1} (15).

Peg-to-pod conversion percentage

Deficit irrigation management and foliar application of growth retardant chemicals significantly influenced the peg-to-pod conversion percentage. The individual and the combined treatment effects are presented in Table 3. Among the main plot treatments, conventional irrigation (M_1) achieved the highest peg-to-pod conversion rate at 70.7%. This was followed by irrigation withdrawal from 90 to 105 DAS (M_2) with 67.3% and the lowest conversion percentage was observed for irrigation withdrawal from 85 to 100 DAS (M_3) with a rate of 65.2%. Among the foliar applications of growth retardants, MH (S_3) had the most significant effect, achieving a peg-to-pod conversion rate of 75.2%. Abscisic acid (S_5) reached a conversion rate of 72.6%, while the control (S_1) showed the lowest rate at 61.5%. Among the interaction effects, the best results came from combining conventional irrigation with foliar application of MH at 75 and 90 DAS (M_1S_3), which achieved an 80.8% conversion rate, followed by combination of conventional irrigation with abscisic acid application at 75 and 90 DAS (M_1S_5) at 74.3%. The lowest conversion rate was observed with the combination of irrigation withdrawal from 85 to 100 DAS and no spray (M_3S_1), resulting in a value of 59.4%. Limited irrigation during the critical peg development period has been shown to reduce peg-to-pod conversion efficiency (17). The decline in peg-to-pod conversion efficiency with earlier irrigation withdrawal is primarily due to the physiological stress induced by water deficit during critical stages of pod development (18). Additionally, research has confirmed that the use of growth retardants, such as cycocel can significantly increase peg-to-pod conversion percentages. MH can limit excessive vegetative growth by inhibiting the synthesis of certain hormones (like gibberellins). By moderating vegetative growth, MH can also improve nutrient allocation towards reproductive organs. This allows for better support of peg and pod development, improving the peg-to-pod conversion rate (19).

100-pod weight

The analysis of variance indicated significant variation among the main and subplot treatments, as well as their interaction effects (Table 4). Among the irrigation management practices, the highest (69.6 g) and the lowest (64.8 g) 100 pod weights were observed in the conventional irrigation (M_1) and irrigation withdrawal from 85 to 100 DAS (M_3), respectively. The effect of foliar application of growth retardant chemicals also showed significant variations in 100-pod weight, with values ranging from a low of 56.5 g for control (S_1) to a high of 74.8 g for MH application at 75 and 90 DAS (S_3). Among the interaction effects, the highest (80.5 g) was recorded for conventional irrigation with foliar application of MH at 75 and 90 DAS (M_1S_3), while the lowest value (54.3 g) was observed in the combination of irrigation withdrawal from 85 to 100 DAS with no spray (M_3S_1) respectively (Fig. 2). Withdrawal of irrigation during the maturity stage of groundnut has been shown to reduce the 100-pod weight due to the limited water availability during peg and pod formation stages (20). Conversely, foliar application of growth retardant chemicals has been found to produce pods with higher weight (21).

Table 3. Effect of deficit irrigation management and foliar application of growth retardants at different intervals on peg to pod conversion percentage of groundnut

Treatment	M1	M2	M3	Mean
S1	65.0	60.3	59.4	61.6
S2	65.0	61.5	62.2	62.9
S3	80.8	76.4	68.3	75.2
S4	70.1	65.8	66.7	67.5
S5	74.3	76.0	67.7	72.7
S6	68.9	65.0	66.0	66.6
Mean	70.7	67.4	65.2	**67.7**
	M	**S**	**M × S**	**S × M**
S. Ed	1.20	1.46	2.59	2.52
CD (p=0.05)	3.32	2.97	5.70	5.15

M_1 : Control (Continuous irrigation as per the recommendation)
M_2 : Withdrawal of irrigation at 95 DAS
M_3 : Withdrawal of irrigation at 85 DAS
S_1 : Control
S_2 : Foliar application of Water at 75 and 90 DAS
S_3 : Foliar application of Maleic Hydrazide @ 1250 ppm at 75 and 90 DAS
S_4 : Foliar application of Cycocel @ 1000 ppm at 75 and 90 DAS
S_5 : Foliar application of Abscisic acid @ 750 ppm at 75 and 90 DAS
S_6 : Foliar application of Salicylic acid @ 750 ppm at 75 and 90 DAS

Table 4. Effect of deficit irrigation management and foliar application of growth retardants at different intervals on 100-pod weight of groundnut

Treatment	M1	M2	M3	Mean
S1	58.8	56.4	54.3	56.5
S2	62.4	61.1	59.8	61.1
S3	80.6	72.5	71.5	74.9
S4	71.0	68.8	66.4	68.7
S5	76.7	71.2	70.9	72.9
S6	68.5	67.8	66.3	67.5
Mean	69.6	66.3	64.9	**66.9**
	M	**S**	**M × S**	**S × M**
S. Ed	0.65	0.87	1.53	1.51
CD (p=0.05)	1.81	1.79	3.33	3.09

M_1 : Control (Continuous irrigation as per the recommendation)
M_2 : Withdrawal of irrigation at 95 DAS
M_3 : Withdrawal of irrigation at 85 DAS
S_1 : Control
S_2 : Foliar application of Water at 75 and 90 DAS
S_3 : Foliar application of Maleic Hydrazide @ 1250 ppm at 75 and 90 DAS
S_4 : Foliar application of Cycocel @ 1000 ppm at 75 and 90 DAS
S_5 : Foliar application of Abscisic acid @ 750 ppm at 75 and 90 DAS
S_6 : Foliar application of Salicylic acid @ 750 ppm at 75 and 90 DAS

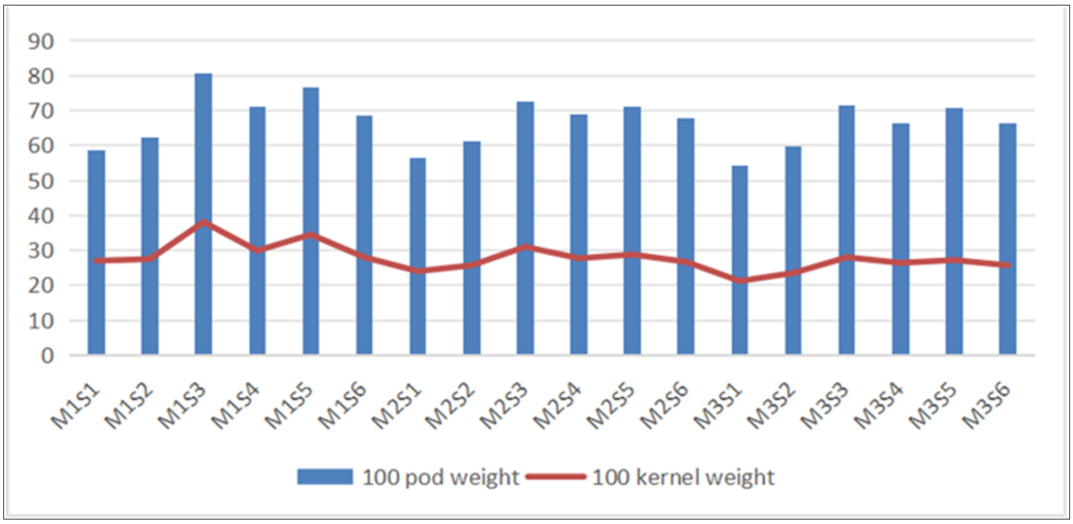

Fig. 2. Effect of deficit irrigation management and foliar application of growth retardants on different intervals on 100 pod weight and 100-kernel weight of groundnut.

100-kernel weight

The analysis of variance revealed significant differences among the main plot and subplot treatments, as well as their interactions. The individual and the combination treatment effects are presented in Table 5. Among the irrigation management practices, conventional irrigation (M_1) achieved the highest 100-kernel weight at 30.8 g, whereas irrigation withdrawal from 85 to 100 DAS (M_3) resulted in the lowest 100-seed weight of 25.3 g. Significant differences were also noted in the foliar application of growth retardant chemicals, with 100-seed weights ranging from 32.3 g for foliar application of MH at 75 and 90 DAS (S_3) to 24.1 g for control (S_1). Among the interaction effects, the combination of conventional irrigation with MH at 75 and 90 DAS (M_1S_3) produced the highest 100-kernel weight at 38.1 g. In contrast, the combination of irrigation withdrawal from 85 to 100 DAS with no spray (M_3S_1) resulted in the lowest weight at 21.2 g (Fig. 2). Limited water supply during critical periods, such as peg and pod formation, negatively impacts the hundred pod weight. Additionally, insufficient water availability can adversely affect kernel development, leading to smaller and lighter kernels (22). On the other hand, the application of growth retardant chemicals has been shown to improve both pod and kernel weight by optimizing resource allocation to pod development. Many growth regulators may improve the plant's resilience to environmental stresses, such as drought. Healthy plants under stress are better able to support pod formation resulting in the production of heavier kernels (23).

Table 5. Effect of deficit irrigation management and foliar application of growth retardants at different intervals on 100-kernel weight of groundnut

Treatment	M1	M2	M3	Mean
S1	27.0	24.0	21.2	24.1
S2	27.5	25.7	23.5	25.6
S3	38.1	31.0	28.0	32.4
S4	29.9	27.7	26.4	28.0
S5	34.5	28.8	27.2	30.2
S6	28.0	26.7	25.7	26.8
Mean	30.8	27.3	25.3	**27.8**
	M	**S**	**M × S**	**S × M**
S. Ed	0.58	0.70	1.25	1.21
CD (p=0.05)	0.60	1.43	2.75	2.48

M_1 : Control (Continuous irrigation as per the recommendation)

M_2 : Withdrawal of irrigation at 95 DAS

M_3 : Withdrawal of irrigation at 85 DAS

S_1 : Control

S_2 : Foliar application of Water at 75 and 90 DAS

S_3 : Foliar application of Maleic Hydrazide @ 1250 ppm at 75 and 90 DAS

S_4 : Foliar application of Cycocel @ 1000 ppm at 75 and 90 DAS

S_5 : Foliar application of Abscisic acid @ 750 ppm at 75 and 90 DAS

S_6 : Foliar application of Salicylic acid @ 750 ppm at 75 and 90 DAS

Shelling percentage

Deficit irrigation and foliar application of growth retardants significantly impacted on shelling percentage. The effects of individual treatments and their combinations are summarized in Table 6. Conventional irrigation (M_1) achieved the highest shelling percentage at 64.8%, while the lowest shelling percentage (55.7%) was observed for irrigation withdrawal from 85 to 100 DAS (M_3). Among the foliar applications of growth retardant chemicals, significant variation was observed, ranging from a higher shelling percentage of 67.01% for the MH application at 75 and 90 DAS (S_3) to a lower percentage of 52.1% for the control (S_1). The interaction effects revealed that the highest shelling percentage (76.3%) was achieved with the combination of conventional irrigation and foliar application of MH at 75 and 90 DAS (M_1S_3), while the lowest shelling percentage (50.7%) was observed for the combination of irrigation withdrawal from 85 to 100 DAS with no spray (M_3S_1). The shelling percentage was significantly higher with deficit irrigation management and was greater with irrigation application compared to conventional methods (24). The possible reason for this could be poor pod filing. Further, sufficient water application can reduce stress on the plants, which is crucial during critical periods such as flowering and pod filling. Reduced stress typically leads to higher quality and heavy pods and kernels. Previous studies have confirmed the effect of growth retardant chemicals on the shelling percentage of groundnut, noting that some PGRs were effective in significantly enhancing the shelling percentage. Plant growth regulators can effectively reduce the environmental stress on the plants and increase shelling percentage, thereby contributing to improved yield (25).

Table 6. Effect of deficit irrigation management and foliar application of growth retardants at different intervals on shelling percentage of groundnut

Treatment	M1	M2	M3	Mean
S1	53.4	52.3	50.7	52.1
S2	54.8	52.8	51.9	53.1
S3	76.4	63.8	60.9	67.0
S4	67.8	57.5	56.3	60.5
S5	71.0	60.0	58.7	63.2
S6	65.7	56.2	55.6	59.2
Mean	64.8	57.1	55.7	**59.2**
	M	**S**	**M × S**	**S × M**
S. Ed	0.80	1.35	2.28	2.34
CD (p=0.05)	2.23	2.76	4.87	4.78

M_1 : Control (Continuous irrigation as per the recommendation)

M_2 : Withdrawal of irrigation at 95 DAS

M_3 : Withdrawal of irrigation at 85 DAS

S_1 : Control

S_2 : Foliar application of Water at 75 and 90 DAS

S_3 : Foliar application of Maleic Hydrazide @ 1250 ppm at 75 and 90 DAS

S_4 : Foliar application of Cycocel @ 1000 ppm at 75 and 90 DAS

S_5 : Foliar application of Abscisic acid @ 750 ppm at 75 and 90 DAS

S_6 : Foliar application of Salicylic acid @ 750 ppm at 75 and 90 DAS

Table 7. Effect of deficit irrigation management and foliar application of growth retardants at different intervals on haulm yield of groundnut

Treatment	M_1	M_2	M_3	Mean
S_1	3452	4353	4398	**4068**
S_2	3922	4381	4433	**4245**
S_3	4853	5243	5055	**5051**
S_4	4319	4660	4515	**4498**
S_5	4715	5160	4988	**4966**
S_6	4304	4566	4325	**4398**
Mean	**4267**	**4727**	**4619**	**4538**
	M	**S**	**M × S**	**S × M**
S. Ed	64.1	93.0	160	161
CD (p=0.05)	177	189	346	329

M_1 : Control (Continuous irrigation as per the recommendation)

M_2 : Withdrawal of irrigation at 95 DAS

M_3 : Withdrawal of irrigation at 85 DAS

S_1 : Control

S_2 : Foliar application of Water at 75 and 90 DAS

S_3 : Foliar application of Maleic Hydrazide @ 1250 ppm at 75 and 90 DAS

S_4 : Foliar application of Cycocel @ 1000 ppm at 75 and 90 DAS

S_5 : Foliar application of Abscisic acid @ 750 ppm at 75 and 90 DAS

S_6 : Foliar application of Salicylic acid @ 750 ppm at 75 and 90 DAS

Haulm yield

The effects of irrigation management, growth retardant application and their combination effects on haulm yield showed significant variation, as summarized in Table 7. Among the irrigation practices, the highest haulm yield (4566 kg) was recorded for irrigation withdrawal from 90 to 105 DAS (M_2). This was followed by the irrigation withdrawal from 85 to 100 DAS (M_3) with a haulm yield of 4325 kg, while conventional irrigation (M_1) resulted in a lower yield of 4304 kg. Regarding growth retardant treatments, the lowest yield (4068 kg) was obtained with control (S_1). In contrast, the foliar application of MH at 75 and 90 DAS (S_3) resulted in a significantly higher haulm yield of 5051 kg. Examining the interaction effects, the combination of conventional irrigation with no spray (M_1S_1) produced the lowest yield of 3452 kg, while the combination of irrigation withdrawal from 90 to 105 DAS with MH spraying at 75 and 90 DAS (M_2S_3) achieved the highest haulm yield (5243 kg) (Fig. 3). Previous research supports these findings. Groundnut haulm yield improves with reduced moisture regimes, indicating that deficit irrigation can enhance crop performance. Controlled water stress might trigger physiological adaptations that enhance growth. Plants may become more efficient in using available resources, leading to improved overall growth and higher haulm production (26).

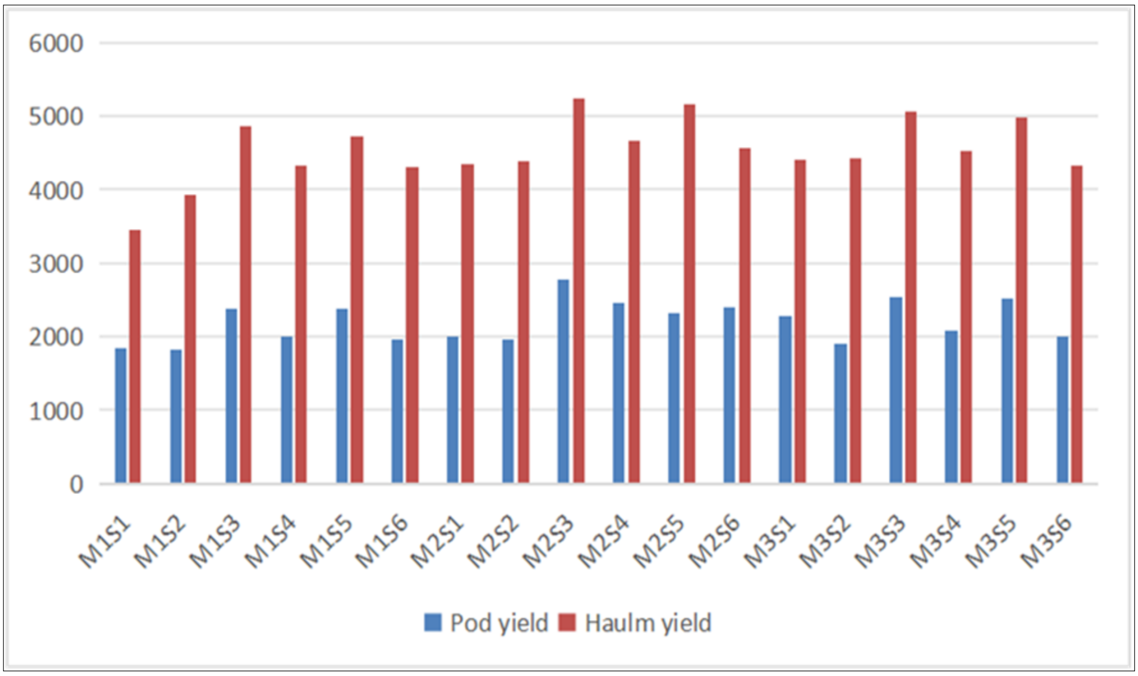

Fig. 3. Effect of deficit irrigation management and foliar application of growth retardants on different intervals on pod yield and haulm yield of groundnut.

Pod yield

The effects of irrigation management, growth retardant application and their combination effects of treatments showed significant variation in pod yield, as summarized in Table 8. Among the irrigation management practices, the highest pod yield (2317 kg) was recorded for irrigation withdrawal from 90 to 105 DAS (M_2). This was followed by irrigation withdrawal from 85 to 100 DAS (M_3) with a pod yield of 2219 kg and the lowest yield (2063 kg) was recorded for conventional irrigation (M_1). Among the foliar application of growth retardant chemicals, the lowest yield (1890 kg) was obtained from distilled water spray at 75 and 90 DAS (S_2), while foliar application of MH at 75 and 90 DAS (S_3) recorded a pod yield of 2563 kg. Among the interaction effects, the lowest yield (1816 kg) was obtained from the combination of conventional irrigation with distilled water spray at 75 and 90 DAS (M_1S_2). The combination of irrigation withdrawal from 90 to 105 DAS with MH spraying at 75 and 90 DAS (M_2S_3) recorded the highest pod yield (2776 kg) (Fig. 3). Research has shown that groundnut pod yield increases with reduced moisture regimes, suggesting improved crop performance under deficit irrigation (26). When irrigation water is reduced plants may increase their root development and efficiency in water use, leading to higher consumptive use as they adapt to the available moisture (27). In a previous study, plant growth retardants on groundnut revealed that two foliar sprays of growth retardant chemicals achieved higher pod yield (3855 kg ha^{-1}) and it was statistically superior over control and water sprays (28).

Table 8. Effect of deficit irrigation management and foliar application of growth retardants at different intervals on pod yield of groundnut

Treatment	M1	M2	M3	Mean
S1	1853	1999	2284	2045
S2	1816	1954	1901	1890
S3	2384	2776	2530	2563
S4	1994	2453	2081	2176
S5	2380	2314	2515	2403
S6	1954	2408	2003	2122
Mean	2064	2317	2219	**2200**
	M	**S**	**M × S**	**S × M**
S. Ed	64.8	87.4	152	151
CD (p=0.05)	180	178	331	309

M_1 : Control (Continuous irrigation as per the recommendation)

M_2 : Withdrawal of irrigation at 95 DAS

M_3 : Withdrawal of irrigation at 85 DAS

S_1 : Control

S_2 : Foliar application of Water at 75 and 90 DAS

S_3 : Foliar application of Maleic Hydrazide @ 1250 ppm at 75 and 90 DAS

S_4 : Foliar application of Cycocel @ 1000 ppm at 75 and 90 DAS

S_5 : Foliar application of Abscisic acid @ 750 ppm at 75 and 90 DAS

S_6 : Foliar application of Salicylic acid @ 750 ppm at 75 and 90 DAS

Conclusion

The present investigation was conducted during the summer of 2024 at Agricultural College and Research Institute, Madurai to study the impact of deficit irrigation management and foliar application of growth retardant chemicals induced dormancy on yield and yield attributes of groundnut. The experiment was laid in a split-plot design with three replications. In the main plot, different deficit irrigation management practices were followed. In the subplot, different growth retardant chemicals were sprayed at different concentrations. Significant variations among the treatments were observed in the total number of pegs plant^{-1}, total number of pods plant^{-1}, peg-to-pod conversion percentage (%), 100-pod weight (g), 100-kernel weight (g), shelling percentage (%), haulm yield (kg ha^{-1}) and pod yield (kg ha^{-1}). Among the irrigation management practices, irrigation withdrawal from 90 to 105 DAS combined with foliar application of MH @ 1250 ppm at 75 and 90 DAS (M_2S_3) recorded the highest pod yield compared to other treatments. This investigation indicates that foliar application of dormancy-inducing chemical, i.e., MH @ 1250 ppm at 75 and 90 DAS, combined with irrigation withdrawal from 90 to 105 DAS, enhanced pod yield by reducing the pod loss due to in-situ sprouting. Ultimately, these adjustments will help ensure the sustainability of groundnut production in the face of water scarcity, climate change and economic challenges, contributing to both food security and the economic stability of farming communities. The ability to manage water efficiently and maintain high levels of peg-to-pod conversion will be crucial for securing stable, long-term groundnut yields and supporting the livelihoods of farmers globally.

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Authors' contributions

The list of scientists given for authorship has equally contributed to planning, execution of research, preparation of manuscript and reviewing the content.

Compliance with ethical standards

Conflict of interest: The authors have declared that no competing interests exist.

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