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Effects of Fertilizers on Growth and Yield Parameters of Mirriah Pepper (*Capsicum frutescens* L.) in Zinder, Niger

IDI SAIDOU Sani [a,b*], MAAZOU Rahila [c], MAHAMAN ISSA Méno [d], RABIOU Abdou [e], ZANGO Oumarou [e], RABIOU Habou [a,b], MAHAMANE Ali [b,f] and BAKASSO Yacoubou [b,f]

[a] Department of Biodiversity and Plants Productions, Faculty of Agronomic and Ecological Sciences, University of Diffa (UDA) BP: 78 Diffa, Niger.
[b] Research Laboratory for the Management and Valorization of Biodiversity in the Sahel (GeVaBioS), Abdou Moumouni University, Niamey, Niger.
[c] Department of Forestry Engineering, Wildlife and Ecology, Higher Institute of Environment and Ecology, University of Diffa, Diffa, Niger.
[d] Department of Environmental Digitization, Faculty of Science and Technology, University of Dosso (UDO), Dosso, Niger.
[e] Department of Biology, Faculty of Science and Technology, André Salifou University of Zinder (UAZ), Zinder, Niger.
[f] Department of Biologie, Faculty of Technical Sciences, Abdou Moumouni University of Niamey (UAM) BP: 10960 Niamey, Niger.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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**Corresponding author: E-mail: ssaidouidi@gmail.com, saidousani@yahoo.fr;*

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Original Research Article

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Abstract

This study, conducted in the botanical garden of André Salifou University in Zinder, aims to evaluate the effects of mineral and organic fertilizers on the growth and yield parameters of the local variety of Mirriah long chili pepper (Zinder region). Factorial randomized block design and three replicates had use for experimentation. Two factors were studied. The factor (block) had three levels, b1 to b3, and the factor (fertilization or treatment) had seven levels (T0, T1, T2, T3, T4, T5, and T6). The collected data were analyzed using Minitab-v18 and Rv4.3.1 software. Comparison of average performance and Principal Component Analysis (PCA) showed significant differences between the different treatments on the variables studied. In addition, the results show variability between treatments. In fact, in terms of fertilization, organic fertilizers performed better than mineral fertilizers, which in turn outperformed the witness. Composted poultry manure (T3) recorded the most effective treatment averages for almost all of the parameters studied. T3 treatment improves yield more effectively than the witness in the study. However, this treatment should be widely adopted in order to obtain better yields for chili pepper cultivation.

Keywords: Effects; mineral and organic fertilization; mirriah pepper; Zinder; Niger.

1. Introduction

Peppers (*Capsicum* spp.) are vegetable crops that are of great nutritional and commercial interest worldwide. A species of the Solanaceae family, the pepper is an annual herbaceous plant (Rêgo et al., 2016) found on every continent (Eric et al., 2018). Global chili pepper production is 41,881,815.15 tons spread over an area of 3,666,266 ha (FAO, 2022). In Africa, chili pepper production is 4,581,740.98 tons spread over an area of 738,756. There are currently estimated to be more than 30 wild species of chili pepper, five of which have been domesticated (C*. frutescens* L., *C. annum* L*., C. baccatum* L., *C. pubescens* Ruiz & Pav., and C. chinense Jacq are the most widely cultivated in the world. Each species is distinguished by its wide diversity of traits in terms of vegetative parts and/or fruits (El-Ghorab et al., 2013 ; Akaza et al., 2022). Therefore, identifying these varieties is crucial for their conservation and promotion. The genetic resources of chili peppers are a vital source for diversifying varieties to meet food needs. Chili peppers have high nutritional value due to the presence of capsaicinoids, which are responsible for their spicy taste, carotenoids, phenolic compounds, vitamins C and E, and other chemical elements with antioxidant and hypoglycemic properties (Valencia et al., 2007 ; Zimmer et al., 2012; Lahbib et al., 2021). For the integrated pest management program for agricultural products, it acts as a biopesticide (Simo et al., 2019). Chili peppers also contain many compounds that are beneficial to the proper functioning of the human body, such as minerals and other substances with antibacterial, antiseptic, diuretic, sudorific, digestive, anticonvulsant, and antioxidant properties. It can be used as an environmentally friendly compound due to its repellent properties against mice, squirrels, and rabbits. In Niger, according to the final report of the survey on horticultural production, chili peppers are grown in all regions on an area of 3,033.58 ha, with production estimated at 31,824.47 T. The region with the highest production is Tahoua, with 1,692.98 ha and a production of 18,758.85 tons (58.94%), followed by the regions of Maradi and Zinder, which account for 21.67% and 7.68% of the area under cultivation, respectively. The other regions account for the remaining 11.71% of the area. However, numerous constraints still limit the development of these crops. These include the low productivity of local cultivars, high pest pressure, poor witness of technical itineraries, and above all, soil degradation and depletion, which remain at the heart of debates on rural development and the future of agriculture (N'Guessan et al., 2012). Fertilization is the lifeblood of modern agriculture (Abga (2013 ; Abdou et al., 2022 ; Shaaban et al., 2025). It ensures that plants receive the nutrients they need, which in turn influences crop yield and quality (Siene et al., 2020 ; Coulibaly et al., 2021). However, excessive use of chemical fertilizers is harmful to the environment (DeWitt et al., 1993 ; El-Ghorab et al., 2013 ; Aliyu (2000)

; Abdou et al., 2022 ; Shaaban et al., 2025). These risks make fertilization one of the most problematic agricultural practices today, especially for market gardening crops, which have very high nutritional requirements. This is why the use of organic fertilizers, which is one of the traditional methods, is currently being revived (Dada and Sayah, 2020 ; El-Ghorab et al., 2013). The traditionally question asked by producers is "how can we meet the demands of customers who are increasingly interested in organic products, while at the same time achieving high yields without over-relying on mineral fertilizers (Mohamedi, 2023)?" Furthermore, mineral fertilization has long been considered the essential means of improving fertility and soil amendments in Africa (Pypers et al., 2011 ; R'him et al., 2013). Experience shows that mineral fertilizers do not always produce the desired results (Aliyu, 2000 ; Jones and Jr, 2012). It is essential to apply the best fertilizer at the optimal dose, at the right time, and in the best place (Coulbaly et al, 2017). Thus, given the importance of chili peppers in our country's agri-food and agro-economic sectors, and with a view to providing producers with suitable chili peppers to address the issues of climate change, environmental pollution, and the selection of varieties with desirable characteristics, as well as the production of local seeds for the conservation of genetic heritage, these issues deserve special attention. It is important to emphasize that a better understanding of the genetic material of chili peppers is necessary in order to carry out variety selection programs (Kumar et al., 2009 ; N'Dri et al., 2011 ; Wahyuni et al., 2013 ; Glodjinon et al., 2021 ; Silva et al., 2021 ; Waongo et al., 2021). Several studies have focused on chili pepper cultivation in Africa, but few have examined the agromorphological characteristics and fertilization of chili peppers in Niger. In this context, the main objective of this study is to evaluate the effect of mineral and organic fertilization on a variety of chili pepper (Mirriah chili pepper) from the Zinder region. Specifically, this involves: (i) identifying the fertilizers best suited to chili pepper development and productivity in the Zinder region. The hypothesis assigned to this objective is: The growth of chili peppers depends on the type of fertilizer used.

2. Materials and Methods

2.1 Study Site

The trial was conducted in the experimental field (Fig. 1) of the Faculty of Science and Technology at André Salifou University in Zinder during the 2023 growing season. The FST/UAS experimental site, located between (Latitude : 13.84538° and Longitude : 8.984°), was created in 2016 on the university campus as part of biological science research. It covers an area of 2,045 m² and its purpose and missions are agricultural experimentation, seed conditioning and production, animal testing and experimentation, and participating in the dissemination of knowledge to users (farmers, pastoralists, etc.). Since its creation, several research projects have been carried out. This area includes plantations of annual crops, vegetables, and fruit plants, as well as a section set aside for poultry and small ruminants. The manure from these animals is used as fertilizer in the experiments. The soil in this experimental area is mainly sandy-clay (Mamadou et al., 2016 ; Malam et al., 2021). The climate in the city of Zinder is Sahelian, characterized by a short rainy season from June to September (Amadou et al., 2014) and a long dry season from October to May. The city of Zinder is located between the 350 and 450 mm isohyets. Average annual temperatures range from 21.6°C to 35.51°C. May is the hottest month with an average temperature of 40.6°C, while January has the lowest temperature with an average of 14.7°C (Mamadou et al., 2016 ; Malam et al., 2021). The monthly rainfall totals recorded during the trial period in 2023 are shown in Fig. 2. We can see that humidity rises during the rainy season, specifically in August with 166 mm, but it is low in May with 15 mm. The total shows us that the 2023 campaign was in surplus, as it exceeded the 500 mm threshold. It is also important to note that this year was disrupted by a drought lasting almost thirty days in August.

2.2 Plant Material

The plant material used (Table 1) in this study consists of the *Capsicum frutescens* variety known as "Mirriah pepper," collected from producers in the locality of Tessaoua, which is the pepper production area in the Zinder region.

2.3 Experimental Design

This study focused on a local variety of Mirriah long chili pepper. To this end, two (2) factors were studied : the factor (block) with three (3) levels b1 to b3, and the factor (fertilization or treatment). Thus, the factor (fertilization or treatment) comprises eight (7) levels :

Level 0 (T0) : Treatment without fertilizer application (witness) ;
Level 1 (T1) : Treatment with NPK application at a rate of 300 kg/ha ;
Level 2 (T2) : Treatment with urea application at a rate of 300 kg/ha ;
Level 3 (T3) : Treatment with composted poultry manure at a dose of 30 t/ha ;
Level 4 (T4) : Treatment with composted cow manure at a dose of 30 t/ha ;
Level 5 (T5) : Treatment with a combination of NPK + composted cow manure at a dose of 300 kg/ha (Segnou et al., 2012) for the mineral dose and 30 t/ha for the organic dose (ITCM, 2022 Cited by Dada and Sayah, 2020).

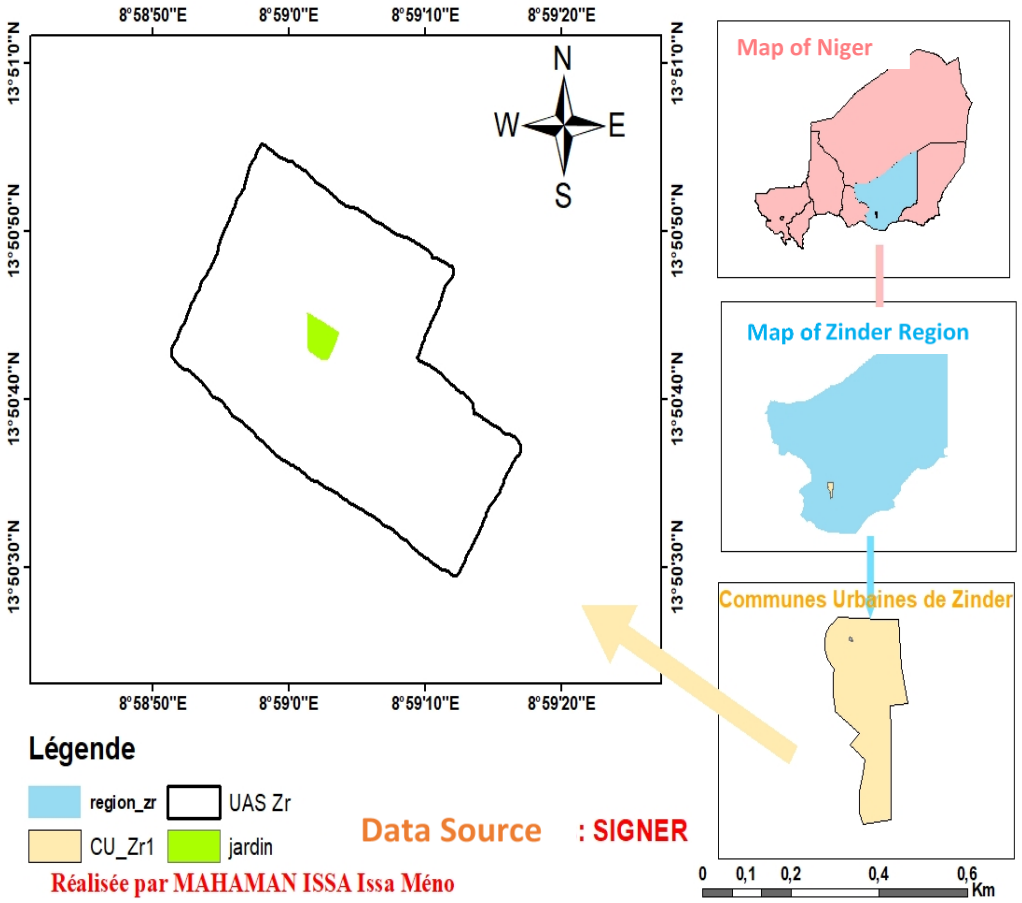


Fig. 1. Study site presentation

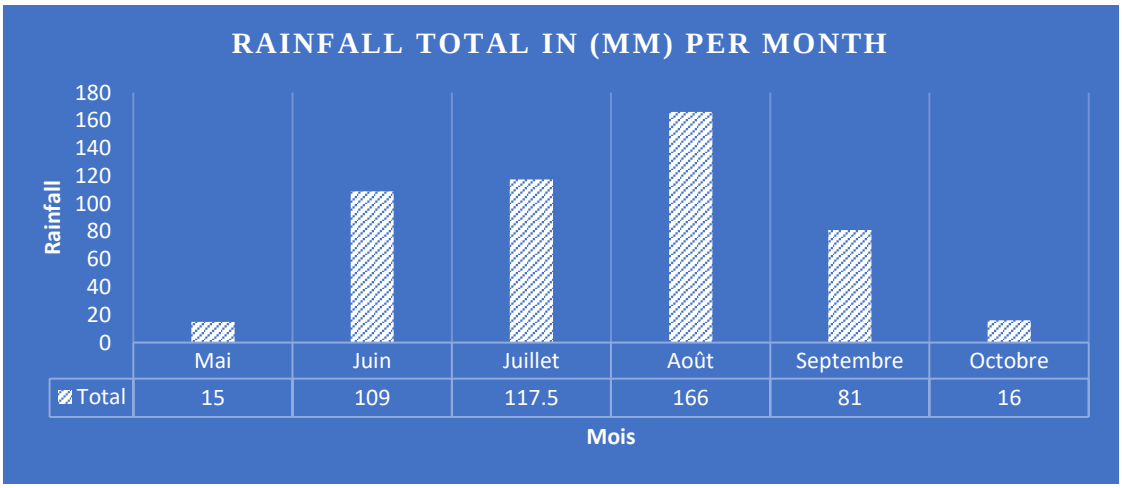


Fig. 2. Monthly rainfall totals for the 2023 season.

Table 1. Characteristics of the variety and its origin

Variety type	Variety	Origin	Characteristics of the fruit
Local	Long Chili Pepper	Mirriah	Elongated and pointed

Level 6 (T6) : Treatment with a combination of composted poultry manure + composted cow manure dung at a rate of 300 kg/ha (Segnou et al., 2012) for the mineral dose and 30 t/ha for the organic dose (ITCM, 2022 Cited by Dada and Sayah, 2020). Table 2 shows the list of different treatments applied and their recommended doses.

Each level of the first factor was combined with each level of the second factor, resulting in 3*7 = 21 treatments. Factorial randomized block design and three replicates had use for experimentation. The area of each plot was 1.5m² (1.5m x 1m), giving a total area of 10.5m² per block, or 31.5m² for the entire area. Each block also consists of seven plots, giving a total of twenty-four plots, and these blocks are also 1 m apart. Each plot has 12 holes spaced 40 cm apart. The choice of treatments in all blocks is random (Fig. 3).

Table 2. Treatments applied according to fertilizer doses used. (Choise quantities according (ITCM, 2022 Cited by Dada and Sayah, 2020) for organic doses and (Segnou et al., 2012) for mineral doses

Treatments	Organic fertilizers (T/hectare)	Mineral fertilizers (kg/ha)
T1	0	300kg/ha
T2	0	300 kg/ha
T3	30 tons per hectare of composted poultry manure	0
T4	30 tons per hectare of cow manure	0
T0	0	0
T6	30tons/ha	0
T5	30tons/ha	300 kg/ha

T1 : NPK, T2 : Urea, T3 : composted poultry manure, T4 : composted cow manure, T0 : witness, T6 : combination of composted poultry manure + composted cow manure, T5 : combination of NPK + composted cow manure, (ITCM, 2022 Cited by Dada and Sayah, 2020) for organic doses and (Segnou et al., 2012) for mineral doses

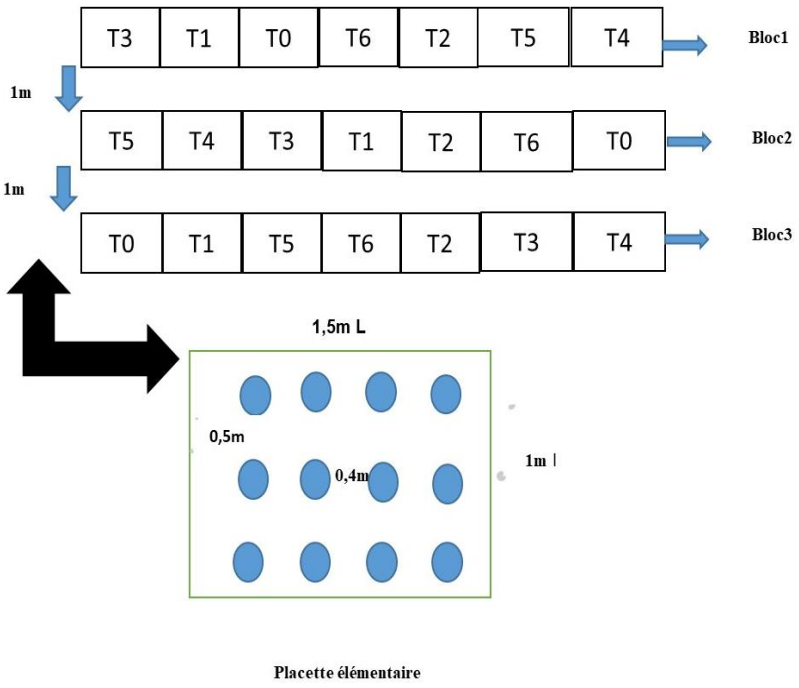


Fig. 3. Experimental design for mineral and organic fertilization

2.4 Conducting the Test

Sowing in the nursery will take place on April 8, 2023, at the UAS Experimental Farm. The seeds of the variety are selected following a flotation test and are sown covered with a thin layer of soil. The plants remained in the nursery for 30 to 60 days (IFATI). Daily watering (morning and evening) and manual weeding are also carried out. Two weeks before planting, the soil is tilled to loosen it and clear the site of brush and shrubs. Tilling is done using rudimentary tools such as the daba or hoe, shovel, rake, machete, hoes, etc. Transplanting took place two weeks after the application of basal fertilizer and was carried out in the evening. The seedlings in the pots were watered before being transplanted, as were the plots. Only vigorous seedlings were selected and pulled up with the clods of earth around their roots. The soil is firmly packed around the roots without damaging the seedling's root collar. Transplanting for the fertilization trial took place on June 20, 2023. Weeding is done manually so as not to interfere with the development or growth of the chili pepper crop. Weeding and hoeing involved turning over the surface of the soil to break up the crust to a depth of a few centimeters. It is used to aerate the soil and witness weeds. It is done with a hoe and/or a rake. This operation was carried out each time before adding nutrients. For organic fertilizer, 4 to 6 kg per m² is applied, and for mineral fertilizer, 40 to 60 g is also used. In addition, phytosanitary treatment was carried out on the thirty-seventh (37th) day after sowing with Sunhalontrin, which is an insecticide with rapid elimination and long residual action.

2.5 Observation of Characteristics

Twenty (20) characters defined according to the slightly modified 1995 IPGR chili pepper descriptors were evaluated. These consist of 19 quantitative characteristics described in Table 3 and one qualitative characteristic (Table 4). Measurements and observations of the various parameters were taken at the 50% phenological stage and on the date of the first appearance of secondary shoots, inflorescence, flowering, fruiting, and ripening for all treatments. From an agronomic perspective, observations focused on assessing plant development 60 days after transplanting in all twelve plots (Table 3). The characteristics of vegetative development are also observed after the first fruits set: at this stage, the vegetative organs are at their maximum development.

- **Plant height** : Plant height measurements were taken on days 30, 60, and 90 after transplanting. They were taken on all 12 plants in each plot using a tape measure or geometry ruler.
- **Number of days to 50% flowering (NJF)** : Through visual observation, we noted the date on which 50% of the plants produced flowers.
- **Number of days to 50% fruiting** : We noted the date on which 50% of the plants produced fruit.
- **Number of days to 50% maturity (NJM) :** Through visual observation, we noted the date on which 50% of the fruits on the plants reached maturity.
- **Average fruit weight (AFW) :** This was the average weight obtained from a sample of one fruit from each selected plant that was representative of all the fruits for each plant from all twelve pockets.
- **Average fruit length (AFL):** At harvest, we measured the length of the fruits from each randomly selected plant, which was also representative of all the fruits for each plant in all twelve pockets.
- **Leaf length and width** : On the 60th day, we sampled three leaves from each plant at random and calculated their averages.
- **Number of branches NbrB** : Only primary branches were considered for this study.

For qualitative characteristics (Table 7), observations were made when the vegetative organs were at their maximum development, in particular the color of the leaves, the vegetative habit of the plants, the type of growth of the plants, the shape, pubescence, and color of the leaves. The color of the flowers, corolla, and position of the inflorescence to the anther were evaluated at the flowering stage, while the other parameters were evaluated at the fruiting and ripening stages.

2.6 Data Analysis

Qualitative variables were analyzed using Excel version 2013. For each of the quantitative characteristics studied, we compared the means using analysis of variance (ANOVA) with Minitab 18 software. When a significant difference is observed between treatments for a given trait, the ANOVA is supplemented by grouping and

Table 3. Quantitative variables used to evaluate the effect of treatment on Mirriah chili peppers

N	Quantitative variables	Code	Description and data collection	Unit
1	Secondary shoot emergence	APS	Date 50% Emergence of first secondary growth	Number of Days
2	Flowering Time	TFl	Date 50% Flowering	Number of Days
3	Fruiting time	TeF	Date 50% Fruiting	Number of Days
4	Maturation Time	Tma	Date 50% Maturation	Number of Days
5	Leaf length	Lof	Measure the length of 3 healthy leaves per pocket and calculate their averages.	cm
6	Leaf width	Laf	Measure the widths of 3 healthy leaves per cluster and calculate their averages.	cm
7	Petiole length	Lop	Measure the lengths of 3 petioles and calculate the average.	cm
8	Shaft diameter	DiT	Measure using a caliper in cm.	cm
9	Plant height	HP	Measure using a ruler at 30, 60, and 90 days after transplanting.	cm
10	Number of branches	NbrB	The primary branches will be counted for each pocket.	Number
11	Stalk length	Lpd	Measure using a ruler	cm
12	Canopy width	LaC	Measure using a tape measure or ruler.	cm
13	Fruit diameter	**DiF**	Measure using a tape measure or ruler.	cm
14	Fruit length	Lfr	Measure using a ruler	cm
15	Poids du Fruit par plant	PFP	Fruit weight per plant	g
16	Nombre de graine par Fruit	NbrGrF	Number of seeds per fruit.	Number
17	Nombre des fleurs	Nbr Fle	Number of flowers.	Number
18	Nombre de fruit par plant	NbrFP	Number of fruits per plant.	Number
19	Weight of 1000 seeds	P1000gr	Weight of 1000g measured using precision scales	g

Table 4. Qualitative variable used to evaluate the effect of treatment on Mirriah chili peppers

N	Quantitative variables	Code	Description and data collection
1	Leaf color	CFe	1. light green, 2 green, 3 dark green

pairwise comparisons of treatment means using Tukey's method, which allowed us to identify treatments that differ significantly from others. In addition to Minitab 18, R software was also used to perform principal component analysis (PCA) and to illustrate, using figures, the differences and similarities between the treatments on the performance of the different genotypes of the Mirriah chili pepper variety evaluated.

3. Results and Discussion

3.1 Results

3.1.1 Effects of Fertilizers according to the Phenological Stage of Mirriah Chili Peppers

Table 5 presents the results of the analysis of variance of the phenological parameters of chili

peppers according to treatment. The analysis of variance showed a significant difference (P=0.000) between treatments for all parameters studied. It was found that treatments with fertilizers yielded convincing results compared to the witness. The results obtained showed that secondary growth occurred between 21 and 31 days after transplanting. Thus, treatments T3, T4, and T6 for this stage were the same, with an average of 21.5 Days After Transplanting (DAT). The intermediate averages were obtained with treatments T5, T1, and T2, with 23.5 and 25.5 DAT, respectively. The lowest average value was recorded for treatment T0, which corresponded to the witness, with a value of 31 days after transplanting.

As for the date of the onset of flower bud formation, it occurred between 25 and 39.5 DAT. According to the analysis of chili pepper performance based on a comparison of the average times of flower bud appearance according to treatment, the difference is highly significant (P=0.000) at the α =5% threshold between the different treatments. T6, T3, and T4 treatments were the earliest, with averages of 27.35, 28, and 28 DAT, respectively. T5, T1, and T2 treatments had an average duration of 30, 30, and 31 DAT respectively. Witness (T0) treatment was the latest, with an average of 39.5 DAT (Table 5).

For flowering, treatments T3 and T6 were the earliest, with an average of 33.5 DAT. On the other hand, the intermediate treatments T4, T5, T2, and T1 had averages of 34.33, 36.35, 37.5, and 39.5 DAT, respectively, and the latest was the witness with 52 DAT. Fruiting occurred between 43 and 62 days after treatment. The earliest fruits were observed in treatments T3, T4, and T6, with 43.5, 46, and 46.5 days after treatment, respectively. The witness recorded a high average value of DAT. Maturation for all these treatments was effective between 69.5 and 83.5 DAT. Treatment T3 was the earliest with exactly 69.5 DAT, followed by treatments T6, T4, T1, T2, T5, and finally T0 with averages of 72, 73, 74.5, 76.5, 79, and 83.5 DAT, respectively.

3.1.2 Effect of Fertilizers on the Growth Parameters of Mirriah Chili Peppers

Descriptive analysis of growth parameters such as leaflet length and width, petiole length, number of branches, stem diameter at the collar, number of flowers, and canopy width showed a significant difference (P=0.000) between treatments for HPPl30, HPPl60, and HPPl90. The average leaf lengths were statistically identical between treatments T3 and T6, with respective averages of 8.68 and 8.31, followed by treatments T5 and T4, which recorded averages of 7.61 and 7.47. For treatments T1 and T2, the mean values were 6.39 and 6.25, respectively, which were higher than that of treatment T0, which recorded a low mean of 5.24. The highest values for leaflet width were recorded in treatments T3, T6, T5, and T4, with 3.52, 3.44, 3.07, and 3.06 cm, respectively, while the lowest averages were recorded in T1, T2, and T0, with 2.63, 2.59, and 2.06 cm, respectively. The petiole length varies from 4.21 to 2.11 cm. The highest value was observed in treatment T6 and the lowest in T0. For the stem diameter at the collar, the highest average value was recorded in treatment T3 at 13.07 mm and the lowest in T0 at 6.5 mm. The highest number of branches was recorded in treatments T3, T4, and T6, with values of approximately 7.44, 7.22, and 7.17 branches, respectively, followed by treatments T5, T2, and T1, which were statistically similar with respective averages of 6.92, 6.28, and 6.08, and finally T0 with an average of 4.81. The highest number of flowers was observed in treatments T6, T3, T4, and T5, with 44.92, 37.75, 27.61, and 23.19 flowers, respectively, followed by treatments T1 and T2, which were statistically equivalent with averages of 13.17 and 12.75, and finally treatment T0, which recorded the lowest value of 7.47. The HPPl30, HPPl60, HPPl90, and laC showed a significant difference between treatments. The treatments with the highest levels at 30, 60, and 90 days were T3, T4, and T6, with averages of 31.92; 40.97, and 47.39 for T3; 29.83, 37.67, and 43.94 cm for T4; and 29.25, 36.44, and 41.86 cm for T6. Intermediate values were recorded at T5, T1, T2, and T0 with averages of 26.67; 32.42; 37.58 cm for T5; 24.89; 32.39; 37.19 cm for T1; 24.78; 32; 36.67 cm for T2 and 21.64; 27.94; 33.94 cm for T0. The width of the canopies in treatment T3 stood out from the others with an average of 35.11 cm, followed by the intermediate values T4 and T6, which were statistically identical at 32.75 and 32.39 cm, and finally the lowest average values for T1, T2, and T0, which were 27.22, 26.56 cm and 24.11 cm, respectively (Table 5).

Table 5. Performance of Mirriah chili pepper growth parameters according to treatments

Traits	APS mean	Bflo mean	Flor mean	Fruc mean	Mat mean	Lof mean	Laf mean	Lpet mean	DiaT mean	Nbr B mean	Nfle mean	HPPl30 mean	HPPl60 mean	HPPl90 mean	LaCa mean
T0	31a	39.5a	52a	62a	83.5a	5.24d	2.06d	2.11c	6.5e	4.81c	7.47e	21.64d	27.94d	33.94c	24.11d
T1	25.5b	30b	39.5b	50.5b	74.5d	6.39c	2.63c	3.24b	9.88bcd	6.08b	13.17de	24.89cd	32.39bcd	37.19bc	27.22cd
T2	25.5b	31b	37.5c	49.5bc	76.5c	6.25c	2.59c	2.56bc	9.05d	6.28ab	12.75de	24.78cd	32cd	36.67bc	26.56d
T3	21.5d	28c	33.5d	43.5e	69.5f	8.68a	3.52a	4.14a	13.07a	7.44a	37.75b	31.92a	40.97a	47.39a	35.11a
T4	21.5d	28c	34.33d	46d	73e	7.47b	3.06b	3.21b	11.19bc	7.22ab	27.61bc	29.83ab	37.67ab	43.94a	32.75ab
T5	23.5c	30b	36.5c	49c	79b	7.61b	3.07b	3.1b	9.52cd	6.92ab	23.19cd	26.67bc	32.42bcd	37.58bc	27.94cd
T6	21.5d	27.5c	33.5d	46.5d	72e	8.31a	3.44a	4.21a	11.59ab	7.17ab	44.92a	29.25ab	36.44abc	41.86 ab	32.39abc
F	**167,83**	**196,03**	**552,8**	**325**	**285**	**59,63**	**47,9**	**17,07**	**24,52**	**9,12**	**16,83**	**11,82**	**10,69**	**10,61**	**10,13**
P(Value)	**0,000****	**0,000*****	**0,000****	**0,000****	**0,000*****	**0,000***	**0,000****	**0,000*****	**0,000****	**0,000*****	**0,000****	**0,000*****	**0,000*****	**0,000*****	**0,000*****

*Note : For each character, values marked with the same letters are statistically equal using Turkey's method. *p ≤ 0.05, **p ≤ 0.01, and ***p ≤ 0.001. Different shades of gray differentiate between the treatment of growth parameters studies, APS: appearance of secondary shoots; Bflo: flower bud; Flor: flowering; Fruc: fruiting; Mat: Maturation. , Lfo: leaflet length, Laf: leaflet width; Lpet: petiole length; DiaT: stem diameter; NbrB: number of branches, NFle: number of flowers, Lac: canopy width, HPPl: plant height T0: witness, T1: NPK; T2: Urea, T3: Composted poultry manure, T4: Composted cow manure, T5: Combination of NPK and composted cow manure, and T6: Combination of composted cow manure and composted poultry manure*

Table 6. Performance of Mirriah pepper yield parameters according to treatment

Traits	Lped mean	DiaFr mean	Lofr mean	PFrP mean	NbgrF mean	P1000Gr mean	NFrP mean	PTFP mean	Rdt, Kg/ha mean
T0	1.78c	0.64d	4.96c	1.77c	42.08c	2.83^{e}	11.22d	20.58d	1646.09d
T1	1.89bc	0.69cd	5.1c	1.98bc	50.39c	3.15c	44.72c	89.79c	7183.4c
T2	2.1ab	0.78b	5.52bc	2.15b	46.75c	2.70f	42.39c	93.73c	7498.76c
T3	2.08ab	0.94a	6.44a	3.02a	79.33a	2.96d	87.97a	266.85a	21348.18a
T4	2.05abc	0.81b	6.39a	2.03bc	67.81b	2.87^{e}	64.42b	130b	10399.84bc
T5	1.86bc	0.75bc	5.35bc	1.91bc	53.42c	3.50a	48.5c	93.22c	7457.84c
T6	2.24a	0.81b	5.98ab	2.2b	49.81c	3.27b	64.75b	148.45b	11876.02b
F	**5,68**	**20,59**	**10,03**	**20,58**	**22,93**	**235,41**	**43,24**	**49,29**	**49,29**
P(Value)	**0,000****	**0,000*****	**0,000*****	**0,000*****	**0,000****	**0,000****	**0,000*****	**0,000*****	**0,000*****

*Note : *p ≤ 0.05, **p ≤ 0.01, and ***p ≤ 0.001. Different shades of gray differentiate between the yield parameters studies according treatment for Tukey test. Lped: peduncle length, DiaFr: fruit diameter, Lofr: fruit length; PFrP: Fruit weight per plant; NbgrF: Number of seeds per fruit, NbFP: Number of fruits per plant ; PTFP: Total fruit weight per plant, Yield in kg/ha: Yield per pocket in kg/ha, P100Gr: Weight of one thousand seeds T0: Witness, T1: NPK; T2: Urea, T3: Composted poultry manure, T4: Composted cow manure, T5: Combination of NPK and composted cow manure, and T6: Combination of composted cow manure and composted poultry manure*

3.1.3 Effect of Fertilizers on Yield Parameters of Mirriah Chili Peppers

The analyses of variance for quantitative fruit characteristics are summarized in Table 6. A significant difference (p=0.000) was observed for each trait. For peduncle length, treatments T6, T3, and T4 showed the highest values, with averages of 2.24, 2.08, and 2.05 cm, respectively, while the lowest average value was observed for T0, at 1.78 cm. Conversely, in terms of fruit diameter, T3 recorded the highest average value at 0.94 cm. Treatments T6 and T4 had intermediate values, each recording an average of 0.81 cm. However, the highest averages for fruit length were recorded in treatments T3 and T4, with approximate values of 6.44 and 6.39 cm, while the lowest average was recorded in treatment T0, with 4.96 cm. As for fruit weight per plant, the averages vary between 3.02 and 1.77 g. The highest value was observed in T3, which had an average of 3.02 g, followed by T6 and T2 with averages of 2.2 and 2.15 g, respectively. T4, T1, and T5 recorded averages of 2.03, 1.98, and 1.91 g, respectively, while T0 had the lowest value with an average of 1.77 g.

In terms of the number of seeds per fruit, treatment T3 recorded the highest value with an average of 79.33. This was followed by T4, T5, T1, T6, T2, and T0 with averages of 67.81, 53.42, 50.39, 49.81, 46.75, and 42.08, respectively. In terms of the weight of a thousand seeds, the best average was observed in T5 with 3.50 g, followed by T6 and T5 with 3.27 and 3.15 g respectively. The low average for P1000 seeds is observed at T2 with 2.7 g. Regarding the number of fruits per plant, T3, T6, and T4 stood out from the other treatments with averages of 87.97, 64.75, and 64.42, respectively. T5 recorded an intermediate average of 48.5, followed by T1 and T2, which had respective averages of 44.772 and 42.39. Finally, T0 recorded the lowest average value for this parameter, at 11.22. In terms of total fruit weight per plant, T3 recorded the highest PTFP, with an average of 266.85g. It is followed by T6 and T4, which had averages of 148.45g and 130g, respectively. Treatments T2, T5, and T1 had averages of 93.73g, 93.22g, and 89.79g, respectively, and T0 had an average of 20.58g. Nevertheless, for the estimated yields per plot in kg/ha, we see that T3 obtained the highest value with an average of 21,348.18 kg/ha, followed by T6, which had an average of 11,876.02 kg/ha. T4 recorded an average of 10,399.84 kg/ha, while T2, T5, and T1 recorded averages of 7,498.76 kg/ha, 7,457.84 kg/ha, and 7,183.4 kg/ha, respectively. The lowest value was observed in T0, with a low average of 1,646.09 kg/ha.

3.1.4 Effect of Fertilizers on Leaf Color

The qualitative variables were analyzed using Excel. The results are shown in Fig. 4. Plants treated with T3, T4, and T6 had 100% dark green leaves. Plants in treatments T1, T2, and T5 had 100% green leaves, while those in treatment T0 had 100% light green leaves (Fig. 4).

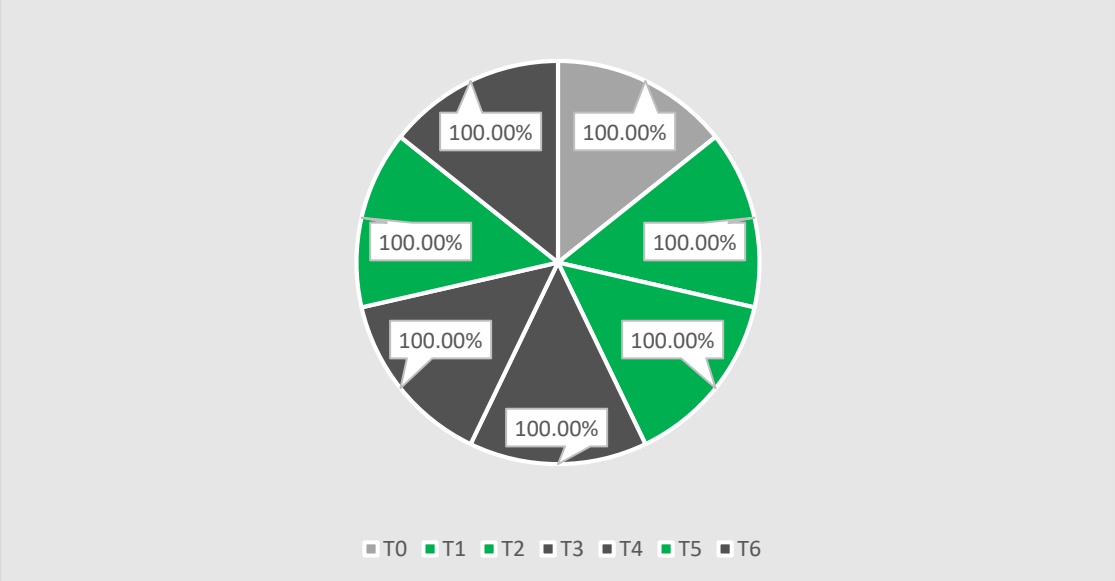
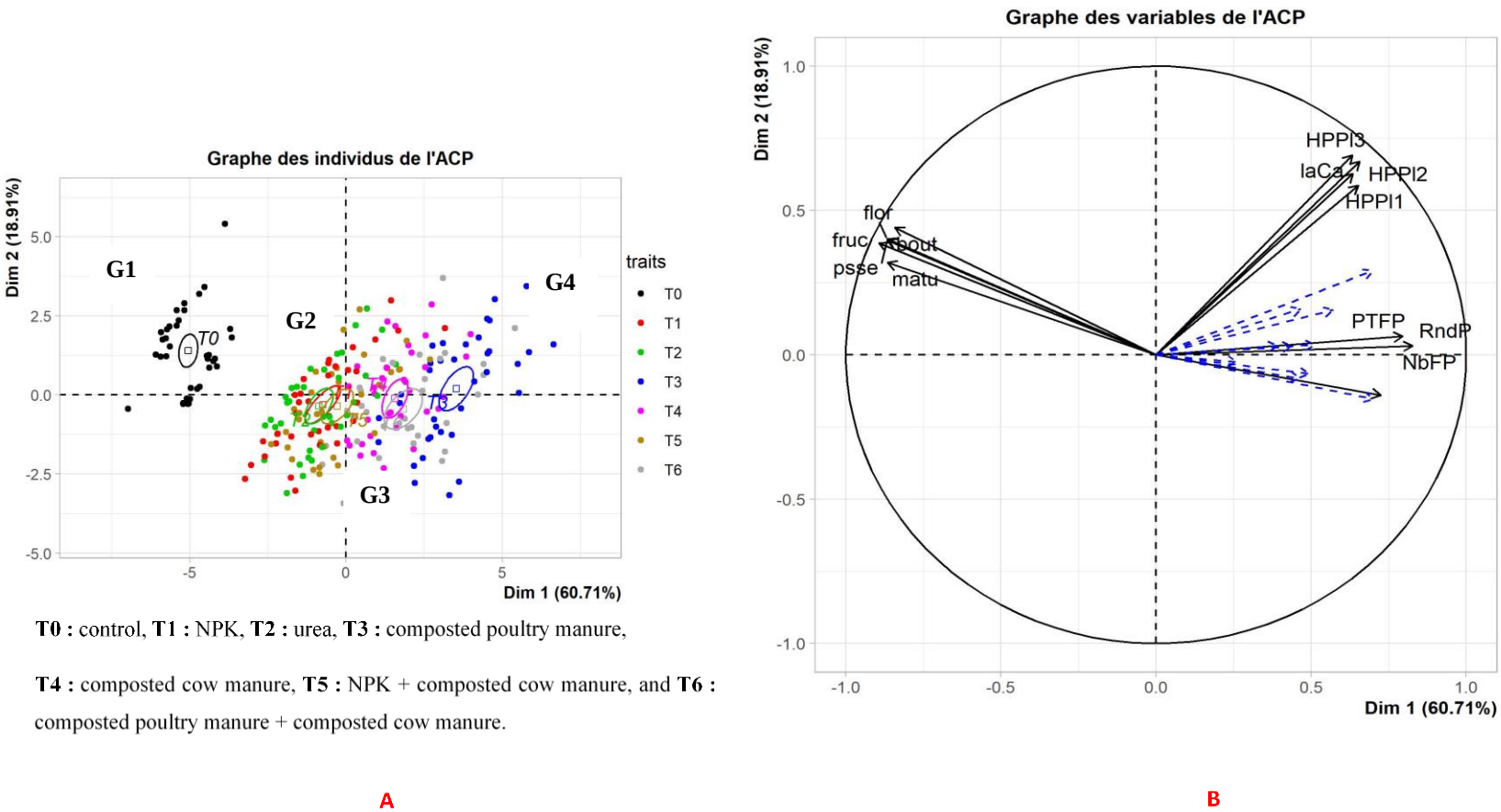


Fig. 4. Percentage of leaf colors according to treatment

T0 : witness, T1: NPK, T2: urea, T3: composted poultry manure, T4: composted cow manure, T5: NPK + composted cow manure, and T6: composted poultry manure + composted cow manure



T0 : control, **T1 :** NPK, **T2 :** urea, **T3 :** composted poultry manure,

T4 : composted cow manure, **T5 :** NPK + composted cow manure, and **T6 :** composted poultry manure + composted cow manure.

A B

Fig. 5. A : Distribution of individuals according to treatment on the plane formed by the first two PCA axes, and B : Circle of correlations between variables

Table 7. Correlation between variables and axes

	Axe 1	Axe 2
Total variance (%)	60.71	18.91
Total variance accumulation (%)	60.71	79.62
Contribution of variables		
Bflo	-0.84	0.44
Flor	-0.84	0.44
Fruc	-0.89	0.39
Mat	-0.87	0.32
NbFP	0.83	0.03
PTFP	0.80	0.06
RndP	0.80	0.06
HPPl1	0.65	0.59
HPPl2	0.66	0.67
HPPl3	0.63	0.69
LaC	0.63	0.63

3.1.5 Relationships between Treatments and the Different Variables Studied

The data on the different variables subjected to principal component analysis (PCA) enabled us to characterize, describe, and represent the similarities between treatments in relation to all the variables studied.

The first two components absorb 79.62% of the total variation in the information (Fig. 5). This analysis with axis 1 showed us that the variables Plant height at 30, 60, and 90 days after transplanting, canopy width, yield in kilograms per hectare, and total fruit weight per plant are positively correlated with axis 1, while phenological stages, particularly the appearance of secondary shoots, the onset of flower budding, flowering, fruiting, and ripening, are negatively correlated with axis 1 (Fig. 5, Table 7). With regard to axis 2, it was found that all variables were in perfect positive correlation with axis 2 (Table 7). The PCA analysis allowed us to divide the treatments into four (4) groups, as illustrated in the figure below (Fig. 5). Group 1 consisted of the witness (T0), group 2 consisted of T1, T2, and T5 (NPK, urea, and a combination of NPK and cow manure), group 3 consisted of T4 and T6 (composted cow manure and a combination of composted poultry manure + composted cow manure), and group 4 consisted of T3, which was composted poultry manure. T0 stood out from the other treatments because its phenological stages were all late, while T3 stood out from the others because it was early but also because it had higher values for almost all the parameters studied.

3.2 Discussion

Plants essentially need large amounts of nitrogen, phosphorus, and potassium to complete their growth cycle, which makes it essential to periodically replenish soil reserves of these elements in order to maintain good productivity (Mouria et al., 2007). The results of the effect of organic and mineral fertilizers on a variety of chili peppers in terms of quantitative characteristics showed significant differences. In fact, all treatments yielded results superior to the witness. This is probably due to the nutrient poverty of the witness plots. The stages of phenology (flowering to ripening) and growth, in particular heights at 30, 60, and 90 days after transplanting, stem diameter at the collar, leaf length and width, number of branches, and canopy width showed greater growth in the treatments based on poultry manure (T3), a combination of poultry manure and cow manure (T6), and cow manure (T4). This could be explained by the high nitrogen content of poultry manure according to (Aliyu, 2000), which is the main factor in the growth of green plants. In addition, organic matter improves growth by lowering the pH of the rhizosphere, which results in better solubilization of nutrients and high availability for plants (Sawadogo et al., 2021).

The length and width of the leaves, the length of the petiole, and the number of branches are also more developed in the fertilized plots compared to the witness. These results are consistent with those of Francou (2003); Assogba-Komlan et al., 2009 ; Ghemam et al., 2020) who reported that organic and mineral fertilizers accelerate the

increase in leaf area. It should be noted that the highest number of branches is observed in poultry droppings, with an average of 7. These results exceed those of GHEMAM et al. (2020). In addition, organic fertilizer promoted high fruit production compared to the witness. This difference in the average number of fruits per plant, peduncle length, fruit length and diameter, fruit weight per plant, total fruit weight per plant, and yield in kilograms per hectare illustrates the importance of using fertilizers and, above all, mixing them with poultry manure, which is known to be rich in phosphate, as phosphorus is a major element important for fruit production (FAO, 2000 ; Samia et al., 2010 ; Ehouman et al., 2023). Similar results were found by Useni et al. (2012), Useni et al. (2014) on Chinese cabbage crops after applying chicken manure compost. Akanza (2015) indicates that poultry manure has a positive influence on fruit weight and plant yields. According to (Aliyu, 2000 ; Aguessy et al., 2021), high-yielding fruits are recorded in plants treated with organic fertilizers, particularly cow manure and dung. The large volume of fruit can be explained by the amount received, which allowed the plants to accumulate a significant amount of photosynthate and water thanks to the potassium content in these two organic materials. Cow manure also recorded significant values for vegetative and productive organs. This is because it is rich in various organic elements. It is a high-quality fertilizer, particularly due to its high nitrogen content, which is essential for plant growth (FAO, 2015). After poultry manure; poultry manure combined with cow manure and cow manure, the combination of NPK mineral fertilizer and cow manure had positive effects on the growth and productivity of chili plants. Organic matter could provide an additional source of nutrients that would improve the effectiveness of mineral fertilizers. It would make nutrients more available to plants. These results are similar to those of Mouria et al. (2007) on the effect of various strains of Trichoderma on the growth of a tomato crop in a greenhouse. These authors showed that almost all Trichoderma strains were able to stimulate the growth parameters of tomato plants to varying degrees. For our study, the combination of NPK and cow manure was no more effective than treatments based on organic matter. These results do not confirm those of Théodore et al. (2021), who reported that combined organic fertilizer applications are more effective on the growth of solanaceous plants than organic fertilizers alone. For mineral fertilization, there was no difference in growth and productivity parameters for NPK and urea treatments, which remained lower than treatments with organic matter. This could be explained by the fact that organic matter is an effective and non polluting resource for maintaining fertility, providing the soil with a wide range of macro- and microelements (Pulgar et al., 2000 ; Segnou et al., 2012 ; R'him et al., 2013 ; Gomgnimbou et al., 2016 ; Moreno et al., 2011 ; ITCM, 2022 ; Shaaban et al., 2025).

4. Conclusion and Perpectives

The study assessed the effects of fertilization (mineral and organic) on the production of Mirriah chili peppers in Zinder. This study shows that the different treatments had very significant effects on all parameters of chili pepper growth and yield. Indeed, the best values for growth parameters and yield variables were obtained with Composted poultry manure (T3) because had recorded the most effective treatment averages for almost all of the parameters studied. T3 treatment improves yield more effectively than the witness in the study. In addition, treatment with T3 poultry manure yielded the best results across all growth and productivity parameters. It is followed by T6 (a combination of composted poultry manure + composted cow manure), then T4 (composted cow manure). Next we have T5, which was a combination of NPK and cow manure, followed by T1 (NPK) and T2 (urea). On the other hand, the PCA shows that treatments T3, T4, and T6 are characterized by good variable productivity yields (NbFP, PTFP, and RndP) and high values for growth parameters (laC, HPPl1, HPPl2, and HPPl3). On the other hand, treatments T0, T1, and T2 are those with higher values for phenological parameters, i.e., later than the genotypes of peppers from other treatments. Treatment with T3, T6, and T4 contributes more to improving crop yields, respectively, and can be offered to communities for agroecological management of soil fertility and healthier crops for consumption, with the aim of increasing production and improving producers' incomes.

Disclaimer (Artificial Intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

Competing Interests

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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