



Effect of Six Fertilization Treatments on the Agronomic Performance of Amaranth Under Morning and Evening Irrigation Conditions in Burkina Faso

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Authors' contributions

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

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Abstract

Background: Leafy vegetables, particularly amaranth, are important in Burkina Faso for food security, nutrition, income generation, and livelihoods. However, their production is limited by poor soil fertility and nutrient deficiencies, highlighting the need for improved soil management and fertilisation strategies.

Aims: The general objective of this study was to contribute to improving and maintaining amaranth productivity in Burkina Faso. Specifically, the aim was to assess the effects of fertiliser treatments on the growth and agromorphological development of amaranth, and to identify the effects of fertiliser treatments on amaranth productivity.

Methodology: Six treatments were evaluated: T0: no fertiliser; T1: organic fertiliser; T2: organic fertiliser + NPK; T3: NPK; T4: organic fertiliser + composite fertiliser; T5: composite fertiliser. The plant material consisted of the *Amaranthus hybridus* variety

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known as FOTETE. The composite fertiliser consisted of urea, triple superphosphate and calcined Burkina phosphate. The design was a Fisher block with three replicates. Growth, development and harvesting parameters were evaluated.

Results: Analysis of variance and comparison of means showed that the composite fertiliser performed best in terms of growth, development and productivity. In addition, the results showed that the composite fertiliser (Urea+TSP+CBKCa) produced a total leaf weight of 2347 g, compared with 1715 g under the T0 treatment.

Conclusion: The composite fertiliser (Urea+TSP+CBKCa) could therefore be promoted to improve soil fertility and amaranth productivity.

Keywords: *Amaranth; burkina phosphate; fertilization; agronomy.*

1. Introduction

In Burkina Faso, leafy vegetables are an essential part of households' diets and nutrition and contribute to food security. They are also a source of income and have been the subject of numerous studies, including those on the genetic diversity and agronomic performance of amaranth (*Amaranthus* L.) (Ouédraogo et al., 2021) and Cleome (*Cleome gynandra* L.), as well as agromorphological characterisation (Sakande et al., 2022).

Amaranth (*Amaranthus hybridus*) is a leafy vegetable that occupies a prominent place among market garden crops. Amaranths are short-cycle, fast-growing plants; in some areas, they are cultivated several times a year (Fondio, 2012; Jimoh et al., 2022). They are involved in several sectors, including food, health and the economy, and contribute to job creation. Amaranth is used to produce tender leaves and seeds for human consumption, animal fodder, ornamental plants, flour and pasta. Its seeds and leaves are rich in mineral salts (calcium, iron, magnesium, phosphorus, potassium and sodium) and vitamins B and C (Souleymane et al., 2018; Terzieva et al., 2026). They are also vegetable plants. However, despite its dietary, nutritional and socio-economic importance, the sector faces numerous problems that considerably limit production. Amaranth production is hampered by a combination of biotic and abiotic factors. Among the abiotic constraints, poor soil fertility in Burkina Faso is a major constraint. This poor soil fertility is associated with low organic matter content and deficiencies in phosphorus and nitrogen (Konfe et al., 2019; Phillips et al., 2021), which are essential nutrients for plant growth and development (Giroux, 2015). In this situation, the use of local inorganic fertilisers containing phosphorus, potassium and nitrogen is necessary to improve crop production and replace nutrients removed after harvest.

Although soil fertility constraints affecting amaranth production have been recognised, the comparative responses of the 'fotète' variety to the six fertiliser treatments assessed here have not been established for the study conditions. Evaluating their effects on growth, development and harvested leaf weight is therefore necessary to identify the most productive treatment under the irrigation routine used.

The general objective of this study is to contribute to improving and maintaining amaranth productivity in Burkina Faso. Specifically, the study aims to (i) assess the effects of fertiliser treatments on amaranth growth and agromorphological development and (ii) identify the effects of fertiliser treatments on amaranth productivity.

2. Materials and Methods

2.1 Plant material

The plant material used was the *Amaranthus hybridus* 'fotète' variety. This is a short-cycle variety with an 80-day growth period. It is the most widely used and cultivated variety compared with the others, which are largely wild.

Technical equipment: From site preparation to data collection and trial establishment, the following equipment was used:

- a balance for weighing the manure to be spread;
- an electronic scale for weighing NPK;
- dabas for ploughing and weeding operations;
- string, stakes and a tape measure for setting up the trial;
- calipers and a graduated ruler for measuring plant diameter and length;
- watering cans for plant irrigation.

2.2 Methods

2.2.1 Experimental Design

The experimental design used was a Fisher block design with three replicates and a single factor: fertiliser treatment. The distance between two successive replicates was 1 m. Each replicate comprised six elementary plots. Each elementary plot consisted of one row, 5 m long and 0.6 m wide, with 20 bunches per row. The distance between rows was 0.3 m, and the spacing between bunches was 0.2 m.

2.2.2 Application of Fertiliser Treatments

Six treatments were tested, combining NPK 14-23-14, composite fertiliser and organic fertiliser (Table 1). The composite fertiliser consisted of urea, triple superphosphate and CBKCa. Urea was the source of nitrogen (46% N), triple superphosphate was the source of phosphate (45% P) and CBKCa was also a source of potassium (14.90% K) and phosphate (18.50% P).

NPK (14-23-14) was applied at a rate of 300 kg/ha. The quantities of the elements making up the composite fertiliser (Table 2) were calculated using the per-hectare dose of NPK (14-23-14) as a reference.

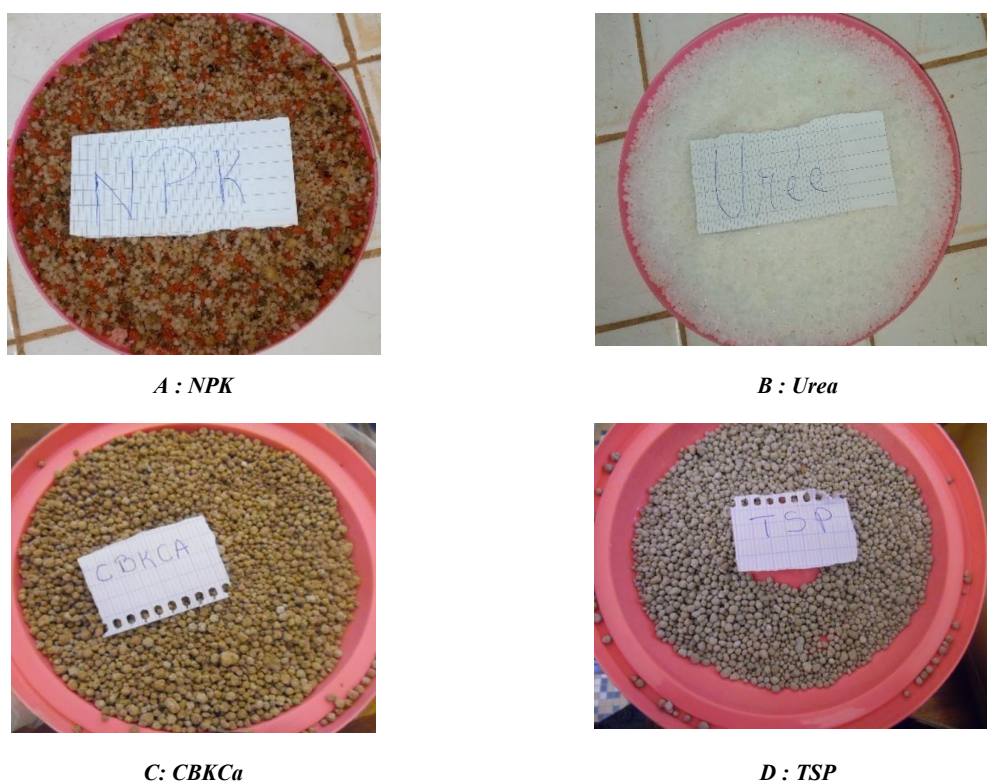


Fig. 1. Various fertilizers used

Table 1. Treatment composition and application periods

Treatment	Fertilizers	Application Period
T0	No fertilizer (SF)	
T1	Organic manure (FO)	Soil preparation
T2	Organic manure + NPK	-- Soil preparation (FO)
T3	NPK	- NPK at 14 days
T4	Organic manure + composite fertilizer	-- AT 14 DAYS
T5	Composite fertilizer	A 14 JAR

Composite fertilizer= Urea + Triple super phosphates (TSP)+ Burkina Faso phosphate rock calciné (CBKCa), DAR: Day After Transplanting

Table 2. Quantities of fertilizers used

Various fertilizers	FO	NPK	Urea	TSP	CBKCa
For 1ha (Kg)	10000	300	91,3	37,4	281,9
For 1 elementary plot (g)	3000	90	27,40	11,22	84,60

FO = Organic manure; NPK = Nitrogen + Phosphorus + Potassium; TSP = Triple super phosphate; CBKCa = Burkina Faso rock phosphate

2.2.3 Trial Conduct

Sowing was carried out in open ground on 28 February 2023. The plot was covered with mosquito netting until the plants emerged and was watered regularly. After emergence, the netting was removed, and the plants were observed until they had at least three to four leaves, at which point they were transplanted.

Soil preparation was carried out on 3 March, starting with deep ploughing using a tractor. After ploughing, the ground was levelled by crushing the large, very compact clods of earth. Next, 5 m long and 0.6 m wide plots were laid out using the Fisher block system. During land preparation, poultry droppings were applied to the plots assigned to receive them before irrigation began. Open-ground planting was carried out on 30 March at a density of 20 plants over a length of 5 m, with 0.2 m between bunches. Each plot consisted of one row, spaced 0.3 m apart. The surface area of each elementary plot was 3 m², and that of the trial was 61.2 m². Dead plants were subsequently replaced.

Maintenance consisted of fertiliser applications, phytosanitary treatments, weeding and irrigation. Manual weeding was carried out twice a week throughout the growing cycle. Plants were watered in the mornings and evenings using two watering cans per bed (12 l of water per can). Fertilisation was carried out as indicated in Table 1. Furrows were made at the base of the plants, and the required quantity of fertiliser was spread along each row. Ridges were then formed to prevent fertiliser from flowing from one plot to another. Phytosanitary treatments were carried out as needed during the trial, one month after transplanting. The treatment consisted of 50 ml of acarus per 16 l of water.

2.3 Data Collection

Data were collected from the growth phase to the harvest phase.

> Plant height

Plant height was measured in each elementary plot on ten plants per row, two weeks after transplanting, from the plant collar to the terminal bud using a graduated ruler, and was expressed in cm.

> Collar diameter

Collar diameter was measured every 14 days after transplanting until the tenth week on ten plants per row in each elementary plot. Measurements were taken from the same plants used for height measurements. Diameter was measured using callipers and reflected stem size.

> Harvesting frequency

Harvesting was carried out from the fourth week after transplanting to the tenth week after transplanting.

> Date of appearance of first flowers

The date of first flowering was recorded through daily observations after transplanting until buds appeared in each elementary plot.

> Date of appearance of 50% flowering

This date was determined through daily observations after transplanting until 50% of the plants had flowered.

> Number of plants harvested

This was the total number of plants from which leaves had been harvested.

> Total leaf weight

This was the sum of leaf weights from all harvests.

> Average leaf weight

This was determined by dividing the total harvested leaf weight by the number of plants harvested.

2.4 Statistical Analysis

Data were analysed using Mini table version 2018 software. Descriptive analysis and comparisons of means using the least significant difference (LSD) at the 5% significance level were performed.

3. Results

3.1 Assessment of Growth Parameters

3.1.1 Description of Growth Parameters

The descriptive analysis of growth parameters showed a maximum stem height of 124 cm and a minimum height of 19 cm at 10 weeks after transplanting (SAR). The mean height was 67.90 cm. The descriptive analysis also showed that diameter at 10 SAR ranged from 6.64 cm to 42.11 cm, with a mean of 24.26 cm.

Table 3. Descriptive analysis of growth parameters

Variables	Moy	ET	CV	Min	Max
H2SAR	11.88	4.26	35.88	3.00	25.00
H4SAR	36.01	12.54	34.83	10.00	70.00
H6SAR	51.97	17.10	32.90	15.00	97.00
H8SAR	61.04	19.89	32.58	17.00	110.00
H10SAR	67.90	22.40	32.99	19.00	24.00
D2SAR	4.42	2.08	47.07	0.37	13.49
D4SAR	15.72	6.06	38.57	4.28	30.75
D6SAR	19.01	6.70	35.25	5.60	40.18
D8SAR	21.83	7.17	32.85	6.50	41.40
D10SAR	24.26	8.02	33.0	7 6.64	42.11
No. of branches	12.24	5.01	40.92	1.0	23.00

H2SAR: height at two weeks after transplanting; H4SAR: height at four weeks after transplanting; H6SAR: height at six weeks after transplanting; H8SAR: height at eight weeks after transplanting; H10SAR: height at 10 weeks after transplanting; D2SAR: diameter at four weeks after transplanting; D4SAR : diameter at four weeks after transplanting ;D6SAR : diameter at six weeks after transplanting ; D8SAR : diameter at eight weeks after transplanting ; D10SAR : diameter at ten weeks after transplanting Avg : mean ; SD : standard deviation ; CV : coefficient of variance ; Min : minimum ; Max : maximum

3.1.2 Effect of Fertilisation Treatments on Height

Analysis of variance showed a significant difference between treatments for height at 2, 4 and 8 SAR. Comparison of treatment means showed that, at H2SAR, treatments T2 (13.56 cm) and T4 (13.27 cm) showed the best performance. By contrast, treatments T0 (11cm), T1 (10.63cm) and T3 (11.06cm) performed less well; the least significant difference at 2 SAR was 2.2 cm. Comparison of means showed that, at H4SAR, treatments T2 (38.90cm) and T5 (42.85cm) gave the best performance, while treatment T0 (27.25cm) showed the lowest performance; the least significant difference at 4 SAR was 7.76cm. Comparison of treatment means showed that, for height at 8 SAR, treatment T2 (66.5cm) recorded the highest value, compared with T0, which recorded the lowest; the least significant difference at 8 SAR was 13.04cm.

Table 4. Analysis of variance and comparison of height averages

Treatment	H2SAR	H4SAR	H6SAR	H8SAR	H10SAR
T0	11 ^b	27,25 ^c	48,7 ^a	53,46 ^b	61,31 ^a
T1	10,63 ^b	31,14 ^{bc}	49,07 ^a	58,86 ^{ab}	66,10 ^a
T2	13,56 ^a	38,90 ^a	56,07 ^a	66,5 ^a	72,13 ^a
T3	11,06 ^b	36,97 ^{ab}	52,17 ^a	63,43 ^{ab}	68,6 ^a
T4	13,27 ^a	37,03 ^{ab}	53,21 ^a	60,52 ^{ab}	68,21 ^a
T5	11,76 ^{ab}	42,85 ^a	52,61 ^a	63 ^{ab}	70,96 ^a
LSD	2,2	7,76	-	13,04	-
P	s	s	ns	s	ns

H6SAR: height at six weeks after transplanting, H8SAR: height at eight weeks after transplanting, H10SAR: height at 10 weeks after transplanting; LSD: smallest significant difference, S: significant; ns: not significant; T0: no fertilizer; T1: organic fertilizer; T2: organic fertilizer + NPK; T3: NPK; T4: organic fertilizer + composite fertilizer; T5: composite fertilizer

Table 5. Analysis of variance and comparison of collar diameter

Treatment	D2SAR	D4SAR	D6SAR	D8SAR	D10SAR
T0	4,49 ^a	14,35 ^{bc}	17,65 ^a	19,54 ^a	21,82 ^a
T1	4,19 ^a	12,70 ^c	17,92 ^a	22,41 ^a	24,75 ^a
T2	4,22 ^a	16,73 ^{ab}	20,11 ^a	22,52 ^a	25,87 ^a
T3	4,39 ^a	16,02 ^{ab}	18,86 ^a	21,35 ^a	24,25 ^a
T4	4,90 ^a	16,24 ^{ab}	18,64 ^a	22,10 ^a	23,84 ^a
T5	4,36 ^a	18,17 ^a	20,96 ^a	23,10 ^a	25,04 ^a
LSD	-	3,33	-	-	-
P	ns	s	ns	ns	ns

D2SAR: diameter four weeks after transplantation; D4SAR: diameter four weeks after transplantation; D6SAR: diameter six weeks after transplantation; D8SAR: diameter eight weeks after transplantation; D10SAR: diameter 10 weeks after transplantation; LSD: least significant difference; S: significant; ns: not significant; T0: no fertilizer; T1: organic fertilizer; T2: organic fertilizer + NPK; T3: NPK; T4: organic fertilizer + compound fertilizer; T5: compound fertilizer

3.2 Evaluation of Growth Parameters

3.2.1 Description of Growth Parameters

The descriptive analysis of development parameters showed that the time to first flowering ranged from 3 to 10 JAR, with a mean of 5.83 JAR. For 50% flowering, the maximum interval was 16 JAR and the minimum was 7 JAR, with a mean of 11.16 JAR. The number of branches ranged from 1 to 23, with a mean of 12.24.

Table 6. Descriptive analysis of development parameters

Variable	Moy	ET	CV	Min	Max
DPF	5,83	2,00	34,41	3,00	10,00
D50%	11,16	2,30	20,66	7,00	16,00
NB	12,24	5,01	40,92	1,00	23,00

Avg: mean; SD: standard deviation; CV: coefficient of variance; Min: minimum; Max: maximum; DPF: date of first flowering; D50%: date of fifty percent flowering, NR: number of branches

3.2.2 Effect of Fertilisation Treatments on Development

Analysis of variance of development parameters showed a significant difference between treatments only for the date of 50% flowering. Comparison of means showed that, for 50% flowering, treatments T0 and T2 recorded the longest intervals, at 13.33 and 12.66 days, respectively, whereas treatment T1 recorded the shortest interval, at 9 days. The least significant difference recorded for D50% flowering was 3.67 cm.

Table 7. Analysis of variance and comparison of development parameters

Traitement	DPF	D50%	NR
T0	6,67 ^a	13,33 ^a	11,86 ^a
T1	5,33 ^a	9 ^b	11,61 ^a
T2	5 ^a	12,66 ^a	13,3 ^a
T3	5,33 ^a	11,33 ^{ab}	11,36 ^a
T4	5,67 ^a	10 ^{ab}	11,72 ^a
T5	7 ^a	10,67 ^{ab}	13,56 ^a

3.2.3 Description of Harvesting Parameters

The descriptive analysis of harvesting parameters showed a maximum leaf weight of 334 g and a minimum weight of 25 g at 10 SAR, with a mean of 152.6 g.

For total leaf weight, the descriptive analysis showed a maximum of 2,637 g and a minimum of 421 g with a mean of 1,545 g.

Table 8. Descriptive analyses of growth parameters

Variable	Avg	SD	CV	Min	Max
P4SAR	539,8	277,7	51,43	109,0	971,0
P6SAR	528,2	291,8	55,24	110,0	1024,0
P8SAR	324,2	171,3	52,85	88,0	638,0
P10SAR	152,6	92,0	60,30	25,0	334,0
PT	1545	617	39,93	421	2637

Avg: mean; SD: standard deviation; CV: coefficient of variance; Min: minimum; Max: maximum; P4SAR: weight at four weeks after transplanting; P6SAR: weight at six weeks + after transplanting; P8SAR: weight at eight weeks after transplanting; P10SAR: weight at 10 weeks after transplanting; TP: total weight

Table 9. Analysis of variance and comparison of harvest parameters

Traitement	P4SAR	P6SAR	P8SAR	P10SAR	PT
T0	722 ^{ab}	544 ^{abc}	324 ^a	124,7 ^b	1715 ^{ab}
T1	366 ^{bc}	643 ^{ab}	307 ^a	105 ^b	1421 ^{bc}
T2	415 ^{bc}	529,3 ^{abc}	285,7 ^a	143 ^{ab}	1373 ^{bc}
T3	630 ^{abc}	332,7 ^{bc}	332 ^a	282,3 ^a	1577 ^{abc}
T4	273,3 ^c	231,7 ^c	206 ^a	125 ^b	836 ^c
T5	832,67 ^a	888,7 ^a	490 ^a	135,3 ^b	2347 ^a
LSD	418	556	-	147	879
P	s	s	ns	s	s

P4SAR: weight at four weeks after transplanting; P6SAR: weight at six weeks after transplanting; P8SAR: weight at eight weeks after transplanting; P10SAR: weight at 10 weeks after transplanting; PT: total weight T0: no fertilizer; T1: organic fertilizer; T2: organic fertilizer + NPK; T3: NPK; T4: organic fertilizer + composite fertilizer; T5: composite fertilizer; LSD: smallest significant difference, S: significant; ns: not significant

3.2.4 Effect of Fertilisation Treatments on Harvest

Analysis of variance showed that, with the exception of weight at 8 SAR, significant differences between treatments were observed for weight at 4 SAR, 6 SAR and 10 SAR. There was also a significant difference in total weight. Comparison of treatment means showed that, for weight at 4 SAR, treatment T5 (832.67 g) recorded the highest value. By contrast, treatment T4 (273.3 g) recorded the lowest value. Comparison of means showed that, for weight at 6 SAR, treatment T5 (888.7 g) recorded the highest value. By contrast, T4 (231.7 g) recorded the lowest value. Comparison of means showed that, for leaf weight at 10 SAR, treatment T3 (282.3 g) recorded the highest value. By contrast, treatments T0 (124.5 g) and T1 (105 g) recorded lower values. Analysis of variance also showed a significant difference between treatments in total weight. Comparison of treatment means showed that, for total leaf weight, treatment T5 (2347 g) recorded the highest value, whereas treatment T4 (836 g) recorded the lowest value.

4. Discussion

Declining soil fertility in sub-Saharan Africa is one of the main constraints to the intensification of agricultural production. Soils are characterised by low organic matter, phosphorus and nitrogen deficiencies, a poor absorptive complex and low water-retention capacity (Konfe et al., 2019). This comparative study describes amaranth growth following the application of composite fertiliser (urea + triple superphosphate + calcined Burkina phosphate rock), NPK and organic manure. Significant effects on plant growth and development were observed at different assessment times following the application of different fertiliser types and doses. For plant height, treatments T2 (NPK + FO) and T4 (composite fertiliser + FO) performed well from the second week onwards.

Treatment T5, containing the composite fertiliser, showed similar growth at the eighth week after transplanting. By contrast, treatment T3 (NPK), treatment T1 (FO) and the control T0 (SF) performed less well. The better performance obtained with

treatments (T2), (T4) and (T5) could be explained by their nitrogen, phosphorus, potassium and calcium content. For plant diameter, analysis of variance showed no significant differences between treatments at 2, 6, 8 or 10 SAR; a significant difference was observed only at 4 SAR. At 4 SAR, treatment T5 (composite fertiliser) recorded the highest value, whereas treatment T1 (FO) recorded the lowest. These results indicate that applying composite fertiliser (urea + TSP + CBKca) promotes plant growth. These findings indicate increased amaranth growth in the presence of a nitrogen source. Nitrogen is therefore an important fertilising element for amaranth growth (Koussihouédé et al., 2016).

Plant development is defined as the appearance of new organs on the plant. Plants fertilised with organic fertiliser flowered more rapidly than those fertilised with composite fertiliser (T5). Earlier flowering may limit plant growth and leaf production through the mobilisation of photosynthates to maintain floral organs. By contrast, later flowering promotes growth and leaf production. The later flowering observed under T5 may be associated with its positive effect on leaf production. As with plant height, stem diameter and development, differences in leaf weight between treatments may be associated with differences in nutrient content.

The ANOVA results showed that, except for weight at 8 SAR, significant differences between treatments were observed for weight at 4 SAR, 6 SAR and 10 SAR. There was also a significant difference in total weight. Leaf weight was significantly higher under treatment T5 (composite fertiliser) than under T4 (composite fertiliser + organic fertiliser) and T0 (no fertiliser), which recorded lower yields. The differences observed among fertiliser types may be related to the forms and quantities of nitrogen they contain (the nitrogen content of the composite fertiliser is 46%, whereas that of NPK is 14%, differing from the content of the organic fertiliser). Thus, nitrogen-rich substrates may increase leaf number and plant height in amaranth.

Meyer et al. (2008) state that nitrogen is a component of essential plant molecules, such as amino acids and nucleic acids. Treatment T4, combining organic fertiliser and composite fertiliser, was least favourable for leaf production in the field-grown amaranth plants in this study. The low yields observed under T4 and some other treatments may reflect limited plant uptake of the nutrients supplied by those treatments.

5. Conclusion

The study compared six fertilisation treatments for the 'fotètè' variety of *Amaranthus hybridus*, using growth, development and harvested leaf weight as measures of agronomic performance. Treatment responses differed across the observation periods and evaluated characteristics. Fertiliser combinations containing organic manure and mineral nutrients performed favourably for some height measurements, whereas the composite fertiliser alone (T5) produced the highest observed total leaf weight. The recorded total leaf weight was 2,347 g under T5, compared with 1,715 g without fertiliser (T0) and 836 g under the combination of organic manure and composite fertiliser (T4). The composite fertiliser also performed well for leaf weight at four and six weeks after transplanting, while NPK alone (T3) gave the highest recorded leaf weight at ten weeks. These findings indicate that treatment performance depended on the agronomic characteristic and assessment time. Within the conditions of this experiment, T5 was the most favourable treatment for total harvested leaf weight. This conclusion relates to the irrigation schedule applied to the experimental plants and does not establish a difference between morning and evening irrigation.

6. Limitations

The conclusions are specific to the 'fotètè' amaranth variety, the six fertilisation treatments and the growing conditions evaluated in this experiment. The findings are based on the recorded growth, flowering and leaf-weight characteristics and do not independently demonstrate changes in soil fertility. Morning and evening watering formed part of the reported management routine; their individual effects were not compared. Interpretation should therefore remain focused on the relative fertiliser responses observed under that routine.

Declaration of AI Use

This manuscript was prepared through the intellectual contributions of the author(s) to the study design, data analysis, interpretation of results, and scholarly content. Grammarly and ChatGPT were used solely to assist with grammatical refinement and reference formatting during manuscript revision. The author(s) accept full responsibility for the accuracy, integrity, and final content of the manuscript.

Competing Interests

Authors have declared that no competing interests exist.

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