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ASSESSMENT OF THE ECONOMIC BENEFIT OF CABBAGE PRODUCTION UNDER DIFFERENT IRRIGATION LEVELS AND SOIL AMENDMENTS IN A SEMI-ARID ENVIRONMENT

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Irrigation

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Cabbage production

ABSTRACT

Crop production in small-scale farming communities in semi-arid Central Namibia faces significant challenges due to the high costs associated with irrigation and fertilizers. This study evaluated the impact of different irrigation levels (full and reduced) and six types of soil amendments—biochar, compost, zeolite, NPK, Be-Grow Boost (L) hydrogel, hoof and horn combined with a bone meal (HHB meal), and control on the economic benefits of cabbage production and assessed their feasibility. In the first experiment, irrigation was implemented at 79.6 m³ (100% of the water requirement) for four days a week, classified as full irrigation, and at 39.6 m³ (50% of the water requirement) for two days a week, termed reduced irrigation. Among the fully irrigated treatments, Be-Grow Boost (L) hydrogel, zeolite, and NPK demonstrated the highest Benefit-Cost Ratios (BCRs) at 3.81, 3.67, and 3.65, respectively. In the second experiment, irrigation schedules were adjusted to five and four days per week, using a total of 136.0 m³ (170% of the water requirement) and 124.8 m³ (150% of the water requirement) of water. The compost, HHB meal, and NPK application rates were also modified. The fully irrigated Be-Grow Boost (L) hydrogel, NPK, and reduced irrigation with HHB meal achieved the highest and comparable yields of marketable cabbage heads per hectare, with BCRs of 3.43, 3.24, and 3.29, respectively. In conclusion, utilizing fully irrigated Be-Grow Boost (L) hydrogel, NPK, and reduced irrigation with HHB meal could be effective practices for sustainable crop production in the semi-arid, sandy soil conditions typical of Central Namibia. Moreover, local biochar production could enhance sustainability by reducing overall production costs.

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1 Introduction

With alarming global population growth, meeting the increasing food demand is becoming a significant challenge, mainly due to the impacts of climate change and inflated input prices affecting crop production. In sub-Saharan Africa (SSA), and specifically in the semi-arid region of Central Namibia, the challenges in crop production primarily stem from low fertilizer usage, the result of unfavourable input prices (Araya et al. 2024), poor sandy soils, and lack of irrigation (Chivenge et al. 2022), all of which lead to low yields. Furthermore, many farmers in this area are small-scale farmers most affected by these challenges due to their limited financial resources (Chivenge et al. 2022; Wanga et al. 2022).

The increasing rural-to-urban migration also hinders food security in Central Namibia, where Windhoek, the capital city, is a preferred destination for many migrants. Many Windhoek inhabitants are food-insecure women living in informal settlements (Kazembe et al. 2024). Additionally, according to the Namibia Statistics Agency (NSA) national census report (2013), the population of the Khomas region is projected to rise to 827,619 by 2041, up from 342,141 in 2010, constituting approximately 24% of the Namibian population. Alongside urban migration and population growth, Namibia's agricultural sector contributes a mere 5% to the GDP (Sichoongwe 2024), in contrast to 23% for SSA (Nyambo et al. 2022). The Namibian crop industry accounts for only 2% of the local sector, compared to 3% of the livestock industry. Furthermore, Namibia imports around 60% of its crop and vegetable needs (Neema and Kalitanyi 2023), primarily from neighbouring South Africa (World Integrated Trade Solution "WITS" 2021). Therefore, increasing crop production, particularly in Central Namibia, is crucial to ensure the region's food security amidst the rapidly growing population.

The abundant natural resources available, such as soil amendments and fertilizers, can be leveraged to address these challenges and enhance crop production. These resources hold the potential to bridge the gap between current crop production levels and the potential yields required to meet increasing food demand (Van Ittersum et al. 2016). However, these inputs must remain affordable to keep production costs low while achieving high yields, ensuring sustainable crop production.

Globally, researchers have studied the use of soil amendments to improve crop yields and economic benefits. Naik et al. (2020) evaluated the effects of hydrogel polymer on castor crops. They found that applying 5 kg ha^{-1} of hydrogel polymer combined with synthetic NPK significantly improved overall seed yield by 43%, yielding a higher benefit-cost ratio than the control (no hydrogel polymer). In a separate study, Roy et al. (2022) examined the effects of combining organic and inorganic fertilizers on rice. Their findings indicated that combining 75% synthetic nitrogen with 25% organic nitrogen (from either farmyard manure or Brassicaceous seed meal) improved rice yield and benefit-cost ratio compared to 100% synthetic nitrogen. Additionally, Roy et al. (2022) investigated the impact of irrigation levels and fertilization practices on tomato yield and economic benefits, finding that combining soluble chicken manure with soluble chemical fertilizer provided high net profit and significantly higher yield than the control.

Another advocated concept, particularly in areas with scarce water resources, is deficit or reduced irrigation. Reduced irrigation has been shown to improve water use efficiency in various crops, including cabbage (Sabah et al. 2023), cucumber (Piri et al. 2022), and tomato (Muroyiwa et al. 2023), although this often comes at the expense of overall yield compared to full irrigation. Sabah et al. (2023) reported that providing 50% of cabbage's water requirements resulted in higher water use efficiency than providing 75% or 100% of the required water, although yields were reduced at the 50% and 75% water levels. Similarly, Lubajo and Karuku (2022) found that irrigating at 25% of field capacity improved maize water use efficiency compared to 50%, 75%, and 100% of field capacity irrigation, though the yield decreased at lower field capacity levels. Nonetheless, the reduced yields from lower irrigation levels may be acceptable, considering the cost savings from water conservation in water-scarce areas (Lubajo and Karuku 2022).

Although studies assessing the economic benefits of various irrigation levels and soil amendment applications have been conducted in other regions, similar research is lacking in Namibia. Our previous study provided agronomic results on the effects of different irrigation levels and soil amendments on cabbage productivity in semi-arid Central Namibia (Enguwa et al. 2023). Against this backdrop, the current study aims to assess the economic benefits (total production cost, net returns, and benefit-cost ratio) of different amended soils under full and reduced irrigation levels to determine their feasibility.

2 Materials and Methods

2.1 Experimental site

Two field experiments were conducted in 2021 and 2022 at the Tsumis Arid Zone Agricultural Centre (TAZAC) in the Rehoboth Rural Constituency of the Hardap region in Central Namibia. The geographical coordinates are approximately 23.7308° S latitude and 17.1987° E longitude (Figure 1). This area is classified as semi-arid, with average annual rainfall ranging from 250 to 300 mm and average temperatures ranging from a minimum of 13.5 °C to a maximum of 28.1 °C (Grab and Zumthurm 2020; Shikangalah et al. 2022). The first experiment occurred from October 2021 to February 2022, while the second was conducted from June to November 2022. The topography of Tsumis is primarily flat, with some mountainous regions.

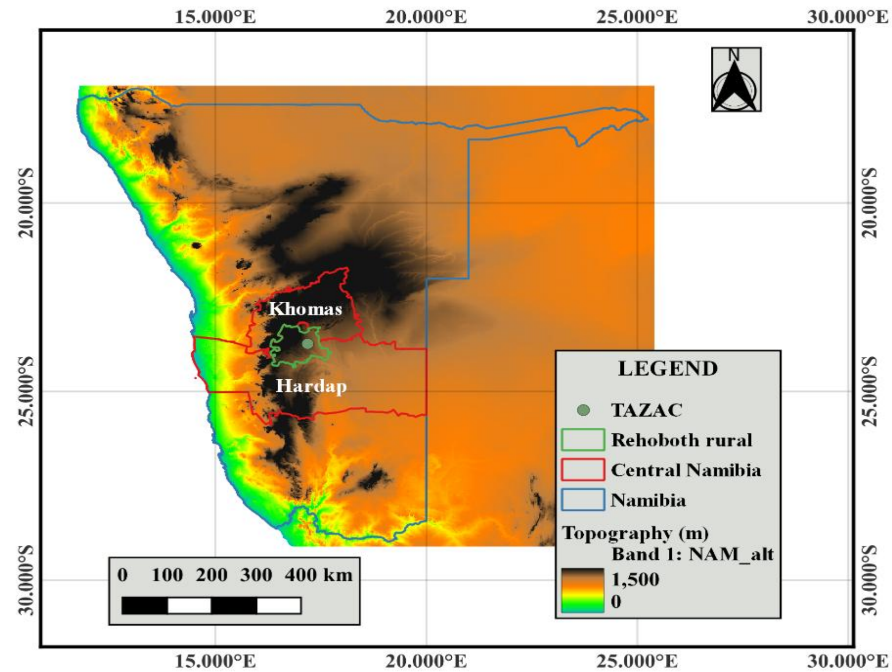

Figure 1 Map indicating Central Namibia and the Tsumis Arid Zone Agricultural Centre (TAZAC)

2.2 Treatments and plant materials

A split-plot design was utilized in both experiments, featuring two irrigation levels, full and reduced irrigation, as the main plots. In addition, six soil amendments were tested in the subplots: biochar, compost, zeolite, NPK, Be-Grow Boost (L) hydrogel, hoof, and horn + bone meal (HHB), and a control group with no soil amendment. Each treatment was replicated three times. The total experimental area measured 39.9 m × 22.5 m, with each subplot covering 4.8 m × 3 m. Each subplot consisted of 64 plants, spaced 0.75 m apart in the inter-rows and 0.30 m apart in the intra-rows. The cabbage hybrid variety Star 3301 F1 was grown in the first experiment. However, in the second experiment, a different variety, Menzania, was used due to the unavailability of the Star 3301 F1 hybrid in the market. Both varieties are hybrids known for their large head sizes, ranging from 4 to 6 kg, and they perform well in both cool and warm seasons (Seminis 2014; Starke Ayres 2020). Cabbage was chosen as the test crop because of its high nutritional requirements, responsiveness to various soil treatments, and strong local demand (Carla et al. 2016).

2.3 Irrigation management

The surface drip irrigation method was used in this study, utilizing flowmeters (Sensus Z15NRV02 XNP plastic meter from Xylem Inc., South Africa). During the three weeks following transplanting, all plots received equal water based on the crops' requirements. After this period, irrigation was automated using a controller (Hunter Node-400, Hunter Industries, South Africa). The drip pipes had a discharge rate of 1 liter per hour per dripper, with a dripper spacing of 30 cm. Each schedule was set for one hour for both irrigation levels, supplying approximately 1 liter of water per plant daily, based on the cabbage's water requirement of 4 mm/day (Beshir 2017). The difference in irrigation was created by varying the irrigation frequency for full and reduced irrigation levels.

In sandy soils, it is recommended that cabbage be irrigated frequently, at least three times a week (Beshir 2017; Bute et al. 2021; Nyatuame et al. 2013; Rasanjalia et al. 2020). Therefore, in the first experiment, irrigation was scheduled for three days a week for the full irrigation level and two days a week for the reduced irrigation level. The two days of irrigation for the reduced treatment were intended to create a water-stressed condition for the plants. Consequently, 79.6 m^3 (100% water requirement) and 39.6 m^3 (50% water requirement) were applied for the full and reduced irrigation levels during the crop growing period.

In the second experiment, the irrigation frequency was increased in response to the slightly poor quality of the cabbage heads observed in the first experiment, which was believed to be due to insufficient watering. In this experiment, water was applied five times a week for the full irrigation treatment and four times a week for the reduced irrigation treatment, resulting in a total application of 136.0 m^3 (170% water requirement) and 124.8 m^3 (150% water requirement) under the full and reduced irrigation levels during the crop production period. The treatment details for the study are presented in Table 1.

Table 1 Treatments for experiments 1 and 2 comprising different soil amendments and irrigation regimes.

First experiment		Second experiment		
Irrigation (Factor 1)	Soil amendment (Factor 2)	Irrigation	Soil amendment	Treatments
Full-3 irrigation days week^{-1} (100% water requirement)	Ctr	Full-5 irrigation days week^{-1} (170% water requirement)	Ctr	Full-Ctr
	NPK (21:31:21 + 6 (S) kg ha^{-1} + Procote Zn)		NPK (88.:40:27 + 8 (S) kg ha^{-1} + Procote Zn)	Full-NPK
	Co (97 t ha^{-1})		Co (24 t ha^{-1})	Full-Co
	Bio (20 t ha^{-1}) + NPK		Bio+ NPK	Full-Bio
	HHB (2 t ha^{-1})		HHB (2.8 t ha^{-1})	Full-HHB
	Ze (14 t ha^{-1}) + NPK		Ze+ NPK	Full-Ze
	Be (44 kg ha^{-1}) + NPK		Be (88 kg ha^{-1}) + NPK	Full-Be
Reduced-2 irrigation days week^{-1} (50% water requirement)	Ctr	Reduced-4 irrigation days week^{-1} (150% water requirement)	Ctr	Reduced-Ctr
	NPK (21:31:21 + 6 (S) kg ha^{-1} + Procote Zn)		NPK (88:40:27 + 8 (S) kg ha^{-1} + Procote Zn)	Reduced-NPK
	Co (122 kg ha^{-1})		Co (24 t ha^{-1})	Reduced-Co
	Bio (20 t ha^{-1}) + NPK		Bio+ NPK	Reduced-Bio
	HHB (2 t ha^{-1})		HHB (2.8 t ha^{-1})	Reduced-HHB
	Ze (14 t ha^{-1}) + NPK		Ze + NPK	Reduced-Ze
	Be (44 kg ha^{-1}) + NPK		Be (88 kg ha^{-1}) + NPK	Reduced-Be

2.4 Soil amendment management

In the first experiment, all plots were tilled with a broad fork and leveled with a rake before applying the amendments. Biochar and compost were broadcast and incorporated into the soil, while zeolite and Hoof and Horn + Bone (HHB) meal were spread along the rows and worked into the soil. The Be-Grow Boost (L) hydrogel and synthetic NPK fertilizer [2:3:2 (35) + 2.9% S + Procote Zn] were applied to the transplanting holes. A mixture of Hoof and Horn (HH) meal and Bone (B) meal was applied in a 1:1 proportion to create the HHB treatment. HH meal has a higher nitrogen (N) concentration (12%) but a lower phosphorus (P) concentration (2%), while B meal is a rich source of P (15%) but has only about 3% N (Möller and Schultheiß 2015; NJoshi 2015; Oluwafisayo and Olusegun 2023). Consequently, in this experiment, the HH meal served as the nitrogen source and the B meal as the phosphorus source in the HHB treatment.

Additionally, the application rates for biochar, zeolite, HHB meal, and compost were 20 t ha^{-1} (Hossain et al. 2020; Toková et al. 2020), 14 t ha^{-1} (Chen et al. 2017; Zheng et al. 2018), 2 t ha^{-1} (Wang et al. 2017), and 97 t ha^{-1} (Carla et al. 2016; Papafilippaki et al. 2015), respectively. The Be-Grow Boost (L) hydrogel was applied at 44 kg ha^{-1} (1 g per planting hole) (Yang et al. 2019) at a depth of 20 cm during transplanting. Due to the limited nutrient content in biochar, zeolite, and Be-Grow Boost (L) hydrogel, they were complemented with synthetic fertilizers at the following application rates: 21 kg ha^{-1} N, 31 kg ha^{-1} P, 21 kg ha^{-1} K, and 6 kg ha^{-1} S. Of the total synthetic fertilizer application, 50% was applied at the transplanting stage, and the remaining half was applied as top dressing six weeks later. The same application rates were used for the NPK treatment plots based on laboratory soil analysis results. No synthetic or organic fertilizers (compost and HHB meal) were applied to the control plots. The chemical compositions of the soil amendments are presented in Enguwa et al. (2023).

In the second experiment, the experimental area was not tilled. The application rates of HHB meal and Be-Grow Boost (L) hydrogel were increased to 2.8 t ha^{-1} and 88 kg ha^{-1} (2 g per transplanting hole), respectively. Additionally, the synthetic NPKS fertilizer application rates were increased to a total of 88 kg ha^{-1} N, 40 kg ha^{-1} P, 27 kg ha^{-1} K, and 8 kg ha^{-1} S. For nitrogen, 15% was applied at transplanting, 70% as a top dressing six weeks later, and the remaining 15% eight weeks following transplanting. For phosphorus and potassium, 50% of each was applied at transplanting, with the remaining half applied as top dressing eight weeks later. The compost application rate was reduced to 24 t ha^{-1} in the second experiment (down from 97 t ha^{-1} in the first experiment) due to poor plant performance under the higher application rate in the first experiment. The application methods for the amendments were the same as in the first experiment. Biochar and zeolite were not reapplied in this experiment since these materials are reported to remain stable in the soil for many years (Maroušek et al. 2017; Soudejani et al. 2019). The treatment details for the study are shown in Table 1.

2.5 Quantitative agronomic data analysis

The data on the number of marketable heads were tested for normality to determine if it followed a normal distribution. An Analysis of Variance (ANOVA) was conducted to evaluate significant differences among the treatment means. This analysis was performed using General Statistics Software [GenStat 64-bit Release 20.1 (PC/Windows 8-10)]. The treatment means were found to be statistically different at a significance level of 5% using the Least Significant Difference (LSD) method.

2.6 Economic analysis

Tables 2 and 3 present the costs incurred during the study. Budgets were created for all soil amendment systems to determine their Total Production Cost (TPC), estimate their Net

Table 2 Costs estimation of the initial investment for cabbage cultivation in the first experiment

	COST (N\$ ha^{-1})						
Incurred Cost	CTR	NPK	Co	Bio	HHB	Ze	Be
Full irrigation (79.6180 m^3)							
Permanent labour	15720.00	15720.00	15720.00	15720.00	15720.00	15720.00	15720.00
Casual labour	5000.00	5000.00	5000.00	5000.00	5000.00	5000.00	5000.00
Land preparation	3750.00	3750.00	3750.00	3750.00	3750.00	3750.00	3750.00
Seeds	11100.00	11100.00	11100.00	11100.00	11100.00	11100.00	11100.00
Seedling trays	15885.00	15885.00	15885.00	15885.00	15885.00	15885.00	15885.00
Nutrigrow substrate	1068.00	1068.00	1068.00	1068.00	1068.00	1068.00	1068.00
NPK	0.00	3250.00	0.00	3250.00	0.00	3250.00	3250.00
Amendment	0.00	0.00	451360.00	32240.00	15640.00	4260.56	6800.00
Urea	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Irrigation	3538.60	3538.60	3538.60	3538.60	3538.60	3538.60	3538.60
Neem	30240.00	30240.00	30240.00	30240.00	30240.00	30240.00	30240.00
Cypermethrin	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Metacystox	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total cost	86301.60	89551.60	537661.60	121791.60	101941.60	93812.16	96351.60
Reduced irrigation (39.6200 m^3)							
Permanent labour	15720.00	15720.00	15720.00	15720.00	15720.00	15720.00	15720.00
Casual labour	5000.00	5000.00	5000.00	5000.00	5000.00	5000.00	5000.00
Land preparation	3750.00	3750.00	3750.00	3750.00	3750.00	3750.00	3750.00
Seeds	11100.00	11100.00	11100.00	11100.00	11100.00	11100.00	11100.00
Seedling trays	15885.00	15885.00	15885.00	15885.00	15885.00	15885.00	15885.00
Nutrigrow substrate	1068.00	1068.00	1068.00	1068.00	1068.00	1068.00	1068.00
NPK	0.00	3250.00	0.00	3250.00	0.00	3250.00	3250.00
Amendment	0.00	0.00	451360.00	32240.00	15640.00	4260.56	6800.00
Urea	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Irrigation	1760.80	1760.80	1760.80	1760.80	1760.80	1760.80	1760.80
Neem	30240.00	30240.00	30240.00	30240.00	30240.00	30240.00	30240.00
Cypermethrin	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Metacystox	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total cost	84523.80	87773.80	535883.80	120013.80	100163.80	92034.36	94573.80

Values were extrapolated to 1 ha; Ctr, Control; Co, Compost; Bio, Biochar; HHB meal, Hoof and Horn + Bone meal; Ze, Zeolite; and Be, Be-Grow boost (L) hydrogel

Table 3 Costs estimation of the initial investment for cabbage cultivation in the second experiment

	COST (N$ ha^{-1})						
Incurred Costs	Ctr	NPK	Co	Bio	HHB	Ze	Be
Full irrigation (136.0092 m^3)							
Permanent labour	18864.00	18864.00	18864.00	18864.00	18864.00	18864.00	18864.00
Casual labour	5000.00	5000.00	2500.00	5000.00	5000.00	5000.00	5000.00
Land preparation	3750.00	3750.00	3750.00	3750.00	3750.00	3750.00	3750.00
Seeds	11100.00	11100.00	11100.00	11100.00	11100.00	11100.00	11100.00
Seedling trays	15885.00	15885.00	15885.00	15885.00	15885.00	15885.00	15885.00
Nutrigrow substrate	1068.00	1068.00	1068.00	1068.00	1068.00	1068.00	1068.00
NPK	0.00	3250.00	0.00	3250.00	0.00	3250.00	3250.00
Amendment	0.00	0.00	90350.00	32240.00	15640.00	4260.56	6800.00
Urea	0.00	1950.00	0.00	390.00	0.00	1950.00	1950.00
Irrigation	6044.80	6044.80	6044.80	6044.80	6044.80	6044.80	6044.80
Neem	30240.00	30240.00	30240.00	30240.00	30240.00	30240.00	30240.00
Cypermethrin	900.00	900.00	900.00	900.00	900.00	900.00	900.00
Metacystox	900.00	900.00	900.00	900.00	900.00	900.00	900.00
Total cost	93751.80	98951.80	181601.80	129631.80	109391.80	103212.36	105751.80
Reduced irrigation (124.8040 m^3)							
Permanent labour	18864.00	18864.00	18864.00	18864.00	18864.00	18864.00	18864.00
Casual labour	5000.00	5000.00	5000.00	5000.00	5000.00	5000.00	5000.00
Land preparation	3750.00	3750.00	3750.00	3750.00	3750.00	3750.00	3750.00
Seeds	11100.00	11100.00	11100.00	11100.00	11100.00	11100.00	11100.00
Seedling trays	15885.00	15885.00	15885.00	15885.00	15885.00	15885.00	15885.00
Nutrigrow substrate	1068.00	1068.00	1068.00	1068.00	1068.00	1068.00	1068.00
NPK	0.00	3250.00	0.00	3250.00	0.00	3250.00	3250.00
Amendment	0.00	0.00	90350.00	32240.00	15640.00	4260.56	6800.00
Urea	0.00	1950.00	0.00	390.00	0.00	1950.00	1950.00
Irrigation	5546.80	5546.80	5546.80	5546.80	5546.80	5546.80	5546.80
Neem	30240.00	30240.00	30240.00	30240.00	30240.00	30240.00	30240.00
Cypermethrin	900.00	900.00	900.00	900.00	900.00	900.00	900.00
Metacystox	900.00	900.00	900.00	900.00	900.00	900.00	900.00
Total cost	93253.80	98453.80	183603.80	129133.80	108893.80	102714.36	105253.80

Values were extrapolated to 1ha; Ctr, Control; Co, Compost; Bio, Biochar; HHB meal, Hoof and Horn + Bone meal; Ze, Zeolite; and Be, Be-Grow boost (L) hydrogel

Economic Return (NER), and compute their Benefit-Cost Ratios (BCR). Data from both experiments and market prices were utilized for budgeting. The parameters used in constructing the budgets included the inputs and their prices (including soil amendments), the farm gate cabbage price, agronomic practices, and labor used (Kanton et al. 2017). The total cost of cabbage production under each soil amendment system, from sowing to harvesting, was calculated for each irrigation level. Additionally, the TPC of each system was interpolated to a single cabbage head by dividing the TPC of each production system by the total marketable cabbage heads (TMH) produced by each system (EQN 1).

Borehole water was used in the study; therefore, the cost of irrigation was considered as the cost incurred for pumping the necessary water under each irrigation level, based on the pump specifications and the unit cost of electricity (10 m³/hr, 10 kW/hr, and N$2.00/kW). The fixed labor cost was based on the minimum wage for entry-level agricultural employees in Namibia, which is N$5.40/hr (Ministry of Labour, Industrial Relations and Employment Creation 2021), and casual labor at N$100.00/day. Each system's Gross Return (GR) per hectare was calculated by multiplying the farm gate price of cabbage, N$13.80/head (Namibian Agronomic Board 2023), by the TMH per hectare for each system. The TPC was then subtracted from the GR to obtain the NER, which was also interpolated to a single cabbage head (EQN 2). Furthermore, the BCR was calculated by dividing the GR by the TPC (EQN 3).

$$\text{Total Production Cost (head)} = \frac{\text{Total Production Cost (hectare)}}{\text{Total Marketable Heads}} \quad \text{(EQN 1)}$$

$$\text{Net Economic Returns (head)} = \frac{\text{Net Economic Returns (hectare)}}{\text{Total Marketable Heads}} \quad \text{(EQN 2)}$$

$$\text{Benefit} - \text{Cost Ratio} = \frac{\text{Gross Return}}{\text{Total Production Cost}} \quad \text{(EQN 3)}$$

3 Results

3.1 Effect of irrigation levels on Cabbage Number of marketable heads and economic benefits

The effects of irrigation levels on the number of marketable cabbage heads and their associated economic benefits are summarized in Table 4. In the first experiment, the irrigation levels did not significantly impact the number of marketable cabbage heads. However, the fully irrigated treatment yielded slightly more marketable heads, with a count of 21561, compared to 19345 under reduced irrigation. Additionally, full irrigation resulted in a lower total production cost (TPC) of N$7.98, compared to N$8.55 for reduced irrigation. Full irrigation also demonstrated a higher net economic return (NER) of N$5.82, compared to N$5.25 with reduced irrigation. Furthermore, full irrigation produced a higher benefit-cost ratio (BCR) of 2.70, compared to 2.36 under reduced irrigation.

In the second experiment, full irrigation again yielded slightly more marketable heads, producing 23,909 compared to 21,958 under reduced irrigation. The full irrigation level also had a lower TPC of N$5.67, along with a higher NER per head at N$ 8.13 and a BCR of 2.81, compared to N$ 5.82, N$ 7.98, and 2.66, respectively, under reduced irrigation. Moreover, full irrigation achieved a significantly higher NER per hectare of N$ 201974.58, compared to N$ 177927.98 under reduced irrigation.

3.2 Effect of soil amendments on cabbage marketable heads and economic benefits

The results presented in Table 5 highlight the effects of soil amendments on the number of marketable cabbage heads and their economic implications. In the first experiment, the application of biochar, Be-Grow boost (L) hydrogel, zeolite, and NPK resulted in a significantly higher number of marketable heads, yielding 24884, 23958, 22801, and 22454 heads per hectare, respectively. In contrast, the control group had the lowest number of marketable heads, with only 13079 heads per hectare recorded. Additionally, the NPK, Be-Grow boost (L) hydrogel, zeolite, and biochar

Table 4 Effect of irrigation levels on cabbage number of marketable heads and economic benefits in the first and second experiments

Irrigation levels	No. of Marketable heads	Total production cost/head (N$)	Net economic return/head (N$)	Net economic return/ha (N$)	Benefit-cost ratio
First Experiment					
Full	21561	7.98	5.82	136482.98	2.70
Reduced	19345	8.55	5.25	99468.98	2.36
SEM±	2116	0.84	0.55	11389.62	0.25
LSD	NS	NS	NS	NS	NS
Second Experiment					
Full	23909	5.67	8.13	201974.58 [a]	2.81
Reduced	21958	5.82	7.98	177927.98 [b]	2.66
SEM±	2496	0.59	0.83	19347.97	0.28
LSD	NS	NS	NS	55452.75*	NS

1 U$= 18.51; N$ - Values with the same letters within a column are not statistically significant by Fisher's protected LSD at a 5% probability level; SEM - standard error mean; LSD - least significant difference; NS - not significant. *,** and *** denote significance at P≤ 0.05, P≤ 0.01 and P≤ 0.001, respectively

Table 5 Effect of soil amendments on cabbage number of marketable heads and economic benefits, experiments 1 and 2.

Soil amendments	No. of Marketable heads	Total production cost/head (N$)	Net economic return/head (N$)	Net economic return/ha (N$)	Benefit-cost ratio
First Experiment					
Ctr	13079[c]	6.53[bc]	7.27[b]	95070.60[b]	2.11[b]
NPK	22454[a]	3.96[d]	9.84[a]	221202.50[a]	3.49[a]
Co	19792[ab]	27.12[a]	-13.32[c]	-263643.10[c]	0.51[c]
Bio	24884[a]	4.90[cd]	8.90[ab]	222496.50[a]	2.84[ab]
HHB	16204[ab]	7.20[b]	6.60[ab]	93810.20[b]	1.93[bc]
Ze	22801[a]	4.15[d]	9.65[ab]	221730.54[a]	3.38[a]
Be	23958[a]	4.00[d]	9.80[a]	235164.60[a]	3.46[a]
SEM±	2296	0.73	1.00	21845.67	0.30
LSD (0.05)	6366.93[***]	2.09[***]	2.49[***]	56523.60[***]	1.07[***]
Second Experiment					
Ctr	14873[c]	7.65[ab]	6.15[b]	99761.60[c]	2.07[c]
NPK	23553[ab]	4.42[bc]	9.38[a]	222338.10[ab]	3.25[a]
Co	18461[bc]	10.09 [a]	3.71[c]	74551.00[d]	1.41[d]
Bio	27199[a]	5.01[bc]	8.79[a]	228396.00[ab]	2.76[bc]
HHB	25752[ab]	4.26[c]	9.54[a]	248633.70[a]	3.28[a]
Ze	23206[ab]	4.74[bc]	9.06[a]	198913.94[b]	2.93[ab]
Be	27489[a]	4.06[c]	9.74[a]	257066.90[a]	3.44 [a]
SEM±	2442	0.74	0.88	19678.02	0.30
LSD (0.05)	6609.84 [***]	3.25[**]	2.24[***]	57449.11[***]	0.80[***]

1 U$ - 18.51 N$; Values with the same letters within a column are not statistically significant by Fisher's protected LSD at a 5% probability level; Ctr - Control; Co - Compost; Bio - Biochar; HHB meal, Hoof and Horn + Bone meal; Ze - Zeolite; and Be, Be- Grow boost (L) hydrogel; SEM - standard error mean; LSD - least significant difference; NS - not significant. *, ** and *** denote significance at P≤ 0.05, P≤ 0.01 and P≤ 0.001, respectively

treatments exhibited the lowest total production costs (TPC) per head, which were N$ 3.96, N$ 4.00, N$ 4.15, and N$ 4.90, respectively. Compost, however, had the highest TPC at N$ 27.12. The same treatments also provided the highest net economic return (NER) per head, with values of N$ 9.84, N$ 9.80, N$ 9.65, and N$ 8.90, while compost produced the lowest, resulting in a negative NER of N$ 13.32. Furthermore, NPK, Be-Grow boost (L) hydrogel, zeolite, and biochar systems achieved the highest benefit-cost ratios (BCRs) of 3.49, 3.46, 3.38, and 2.84, respectively, whereas compost showed an unprofitable BCR of 0.51.

In the second experiment, the Be-Grow boost (L) hydrogel and biochar treatments resulted in significantly higher marketable heads, yielding 27,489 and 27,199 heads per hectare, respectively. The control group again had the lowest, with only 14,873 heads per hectare. The Be-Grow boost (L) hydrogel, HHB meal, and NPK treatments also recorded the lowest total production costs per head, at N$ 4.06, N$ 4.26, and N$ 4.42, respectively, compared to N$ 7.65 for the control group and the highest TPC of N$ 10.09 for compost. Moreover, these treatments provided the highest NER per head, yielding N$ 9.74, N$ 9.54, and N$ 9.38, respectively, while compost recorded a NER of only N$ 3.71. Finally, Be-Grow boost (L) hydrogel, HHB meal, and NPK achieved the highest BCRs of 3.44, 3.28, and 3.25, while compost had the lowest BCR of 1.41.

3.3 Interactive effect of irrigation level with soil amendments on marketable heads of cabbage and economic benefits

Table 6 presents the interactive effects of irrigation levels and soil amendments on the number of marketable cabbage heads and the economic parameters associated with cabbage production. In the first experiment, no significant interaction was observed between irrigation and soil amendments concerning the number of marketable heads. However, full irrigation combined with biochar,

Table 6 Interactive effect of irrigation levels and soil amendments on cabbage number of marketable heads, total production costs, and economic benefits for experiments 1 and 2

Irrigation levels × Soil amendments		No. of Marketable heads	Total Production Cost (N$)	Net Economic Return/head (N$)	Net Economic Return/ha (N$)	Benefit-Cost Ratio (N$)
First Experiment						
Full	Ctr	13194	6.54	7.26	95775.60	2.11[bc]
	NPK	23843	3.76	10.04	239481.80	3.67[a]
	Co	19908	27.01	-13.21	-262931.20	0.51[d]
	Bio	27315	4.46	9.34	255155.40	3.10[ab]
	HHB	15278	6.67	7.13	108894.80	2.07[bc]
	Ze	25926	3.62	10.18	263966.64	3.81[a]
	Be	25463	3.78	10.02	255037.80	3.65[a]
Reduced	Ctr	12963	6.52	7.28	94365.60	2.12[bc]
	NPK	21065	4.17	9.63	202923.20	3.31[a]
	Co	19676	27.24	-13.44	-264355.00	0.51[c]
	Bio	22453	5.35	8.45	189837.60	2.58[bc]
	HHB	12963	7.73	6.07	78725.60	1.79[bc]
	Ze	19676	4.68	9.12	179494.44	2.95[ab]
	Be	22454	4.21	9.59	215291.40	3.28[a]
SEM±		2858.262	0.96	1.27	26656.54	0.37
LSD (0.05)		NS	NS	NS	NS	1.07*
Second Experiment						
Full	Ctr	9028[d]	10.38	3.42[b]	30830.00[d]	1.33[c]
	NPK	28009[a]	3.53	10.27[a]	287577.00[a]	3.91[a]
	Co	21759[abc]	8.35	5.45[a]	118677.00[c]	1.65[c]
	Bio	27546[a]	4.71	9.09[a]	250507.60[ab]	2.93[ab]
	HHB	23148[ab]	4.73	9.07[a]	210050.60[b]	2.93[ab]
	Zeo	23611[ab]	4.37	9.43[a]	222624.04[b]	3.16[ab]
	Be	28935[a]	3.65	10.15[a]	293555.80[a]	3.78[a]
Reduced	Ctr	18982[bc]	4.91	8.89 [a]	168693.20[bc]	2.81[b]
	NPK	18518[bc]	5.32	8.48[a]	157099.20[c]	2.60[b]
	Co	15509[cd]	11.84	1.96[b]	30425.00[d]	1.17[c]
	Bio	24306[ab]	5.31	8.49[a]	206284.40[bc]	2.60[b]
	HHB	28703[a]	3.79	10.01[a]	287212.20[a]	3.64[a]
	Zeo	20139[bc]	5.10	8.70[a]	175203.84[bc]	2.71 [b]
	Be	23611[ab]	4.46	9.34[a]	220578.00[b]	3.10[ab]
SEM±		3009.499	1.08	1.03	22742.47	0.36
LSD (0.05)		9775.99**	NS	2.43***	59549.11 ***	0.86**

1 U$= 18.51 N$; Values with the same letters within a column are not statistically significant by Fisher's protected LSD at a 5% probability level; Ctr - Control; Co - Compost; Bio - Biochar; HHB - Hoof and Horn + Bone meal; Ze - Zeolite; Be - Be-Grow boost (L) hydrogel; SEM - standard error mean; LSD - least significant difference; NS - not significant. *,** and *** denotes significance at P≤ 0.05, P≤ 0.01 and P≤ 0.001, respectively

zeolite, Be-Grow Boost (L) hydrogel, and NPK resulted in the highest number of marketable heads, specifically 27315, 25926, 25463, and 23843 heads per hectare, respectively. In contrast, reduced irrigation using the control and HHB meal produced the fewest marketable heads, with each yielding 12963 heads per hectare. Furthermore, total production cost (TPC) ranged from N$ 3.62 to N$27.24 in the first experiment. Under full irrigation, zeolite, NPK, and Be-Grow Boost (L) hydrogel had the lowest TPCs per head at N$ 3.62, N$ 3.76, and N$ 3.78, respectively, while compost used under reduced irrigation had the highest TPC at N$27.24. This means that for each cabbage head produced with zeolite, NPK, and Be-Grow Boost (L) hydrogel under full irrigation, a farmer spent N$3.62, N$3.76, and N$3.78, respectively, compared to N$27.24 for compost under reduced irrigation. Notably, zeolite, NPK, Be-Grow Boost (L) hydrogel, and biochar exhibited lower TPCs than the control in both irrigation levels. Additionally, except for the control, full irrigation and soil amendments combined resulted in relatively lower TPCs than reduced irrigation.

Under full irrigation, zeolite, NPK, and Be-Grow Boost (L) hydrogel yielded the highest net economic returns (NERs) per head at N$10.18, N$10.04, and N$10.02, respectively. Conversely, compost under reduced irrigation led to a negative NER of N$-13.44. Moreover, all soil amendments, except compost under both irrigation levels, demonstrated higher NERs compared to the control (Table 5). Similarly, under full irrigation, zeolite, NPK, and Be-Grow Boost (L) hydrogel exhibited the highest benefit-cost ratios (BCRs) of 3.81, 3.67, and 3.65, respectively. Importantly, all soil amendments, except for compost across all irrigation levels, had higher BCRs than the control, while compost consistently showed an unprofitable BCR of 0.51 across all irrigation regimes (Table 6).

In the second experiment, combining full irrigation with Be-Grow Boost (L) hydrogel, NPK, and biochar resulted in significantly more marketable heads, producing 28935, 28009, and 27546 heads per hectare. Reduced irrigation with HHB meal yielded a comparable number of marketable heads at 28703 per hectare. The economic analysis indicated that NPK and Be-Grow Boost (L) hydrogel under full irrigation, along with HHB meal under reduced irrigation, had the lowest TPCs of N$3.53, N$3.65, and N$3.79, respectively, compared to N$10.38 for the full irrigation control and a maximum TPC of N$11.84 under reduced irrigation with compost. Additionally, NPK, Be-Grow Boost (L) hydrogel under full irrigation, and HHB meal under reduced irrigation generated relatively higher NERs per head, at N$ 10.27, N$ 10.15, and N$ 10.01, compared to N$ 3.42 for the control and the lowest NER of N$ 1.96 for compost under reduced irrigation. Thus, for every cabbage head produced under full irrigation using NPK, a farmer could expect a net profit of N$ 10.27, compared to N$ 3.42 from the control under the same irrigation regime, suggesting a potential 66% improvement in NER (Table 6).

4 Discussion

The primary goal of commercial crop production is to maximize marketable yields while minimizing production inputs, such as irrigation water and fertilizers. With water scarcity affecting many regions worldwide, including Central Namibia, and the high cost of fertilizers, it is crucial to identify methods and systems that require fewer resources while maximizing output for more significant economic benefits. This study aimed to evaluate the economic advantages (including total production cost, net returns, and benefit-cost ratio) of various amended soils—such as biochar, compost, zeolite, hoof and horn with bone meal, Be-Grow Boost (L) hydrogel, and NPK under both full and reduced irrigation levels to assess their feasibility.

The first experiment indicated that full irrigation led to more marketable heads than reduced irrigation. This increase in marketable heads under full irrigation was associated with lower Total Production Costs (TPC) and higher Net Economic Returns (NER), resulting in a better Benefit-Cost Ratio (BCR) than what was observed under reduced irrigation (Table 4). Moreover, different soil amendments significantly enhanced the number of marketable heads and the associated economic benefits (Table 5). Specifically, amendments like Biochar, Be-Grow Boost (L) hydrogel, zeolite, and NPK resulted in a notably higher number of marketable heads. This improvement can be attributed to these amendments' positive effects on nutrient availability and water dynamics within the soil (Baiamonte et al. 2020; Dorraji et al. 2010; Mondal et al. 2021). Theoretically, if we assume that the TPCs of the various amendments were equal, the amendments producing the most marketable heads would demonstrate better economic viability through lower TPC and increased NER and BCR. However, in reality, the interaction of both factors affects the viability of the amendments. For example, while biochar produced the highest number of marketable heads, its BCR was lower than that of NPK, Be-Grow Boost (L) hydrogel, and zeolite, which had lower TPCs and higher NERs than biochar due to the high cost associated with biochar (Table 5).

The control group, which did not use any soil amendments, did not yield the lowest total production costs (TPC) or the highest net economic return (NER) despite not incurring any amendment costs. This was mainly due to the few marketable heads produced (Table 5). Considering the potential for on-farm production of biochar, which could be more cost-effective than purchasing amendments, using biochar presents a viable economic alternative. The bush encroachment problem in Namibia, particularly in central regions (Shikangalah and Mapani 2020), offers farmers a chance to harvest biomass from encroaching bushes for biochar production. This practice could contribute to sustainable crop production in these areas. The economic unviability of compost stemmed from its low number of marketable heads, resulting in a much higher

TPC and a lower NER. In contrast, amendments applied under full irrigation resulted in slightly more marketable heads, leading to relatively lower TPC and higher NER and benefit-cost ratios (BCR) (Table 6).

The economic benefits of crop production are closely tied to marketable yield and selling price while inversely related to production costs (Lim et al. 2015). Therefore, since market conditions typically determine selling prices and production costs, farmers should maximize their yields and efficiently utilize inputs to achieve the greatest economic benefits. In the second experiment, different irrigation levels resulted in a similar number of marketable heads, with full irrigation leading to a slightly higher count of marketable heads and a greater Benefit-Cost Ratio (BCR) (Table 4). The Be-Grow Boost (L) hydrogel, followed by HHB meal and NPK, demonstrated the highest economic benefits due to their relatively high number of marketable heads, low Total Production Costs (TPC), and high Net Economic Return (NER) compared to other amendments. Additionally, compost proved economically viable when its application rate decreased from 192 kg to 35 kg, reducing TPC (Table 5). Combining full irrigation with various soil amendments led to significantly higher economic benefits than reduced irrigation due to increased marketable heads (Table 6). Therefore, full irrigation (4 mm/day, five days a week) of amended soils may be the most economically viable option in semi-arid Central Namibia.

Other than compost, all systems in the first experiment showed slightly better economic benefits than those in the second experiment (Tables 4, 5, and 6). This difference was primarily due to fewer applications of fertilizers and pesticides in the first experiment, resulting in lower overall costs. In the second experiment, two additional pesticides (cypermethrin and metasystox) were used (Tables 2 and 3), and the rates and frequencies of fertilizer applications were increased (Table 1). However, the cabbage heads produced in the second experiment were larger than those in the first, making them more likely to be preferred by consumers in the market (Enguwa et al. 2023). The positive economic benefits of full irrigation in crop production, as found in this study, align with findings from other researchers (Bairwa et al. 2023; Onkoba et al. 2021; Xiang et al. 2019). Bairwa et al. (2023) reported that irrigating Blond psyllium at 0.5 and 0.4 cumulative pan evapotranspiration (CPE) resulted in higher yields, net returns, and a better benefit-cost ratio compared to irrigation at 0.2 and 0.3 CPE. Similarly, Jat et al. (2018) found that growing Indian mustard at 0.8 CPE irrigation levels produced higher seed yields and benefit-cost ratios compared to the control (no irrigation) and other irrigation levels (0.4, 0.6, and 0.7 CPE). Soil moisture is crucial in crop production, significantly affecting economic yield and benefits (Xiang et al. 2019).

The positive economic benefits associated with hydrogel polymers have been consistently highlighted in the current study and acknowledged by numerous authors (Bairwa et al. 2023; Cornejo et al. 2022; Patra et al. 2022; Ram et al. 2018; Rathore et al. 2019). For instance, Ram et al. (2018) reported that applying hydrogel polymer to lentils resulted in higher net returns per kilogram of lentil grains and a better benefit-cost ratio compared to the control group. Similarly, Cornejo et al. (2022) found that using hydrogel polymer significantly improved the net economic return per tomato plant and benefit-cost ratio over the control. Additionally, Rathore et al. (2019) showed that hydrogel polymer treatments under various irrigation regimes in a semi-arid region yielded greater net returns per kilogram of mustard seeds than those without hydrogel. Their study also indicated that applying the hydrogel polymer with full irrigation (0.8 CPE) led to higher mustard yields and a better benefit-cost ratio than rain-fed treatments and other irrigation levels (0.4 and 0.6 CPE), consistent with the current study's findings. The high benefit-cost ratio of the HHB meal in the second experiment can be attributed to the long-term positive effects of the amendment on the number of marketable cabbage heads. This reduced total production costs (TPC) and increased net economic returns (NER). HHB meal acts as a slow-release fertilizer, meaning its effects may take longer to manifest than other amendments (Jain 2019; NJoshi 2015; Peter et al. 2019).

Conclusion

This study evaluated the economic feasibility of applying different irrigation levels and soil amendments to improve cabbage production in semi-arid Central Namibia. The results indicated that Be-Grow Boost (L) hydrogel, NPK fertilizer, and biochar consistently produced the highest number of marketable cabbage heads. Furthermore, apart from biochar, these same amendments also demonstrated the most significant economic benefits in both experiments. In the second experiment, HHB meal showed a relatively high number of marketable heads and economic benefits, surpassing NPK's, suggesting a long-term positive effect of this amendment. Full irrigation complemented by Be-Grow Boost (L) hydrogel, NPK, and reduced irrigation with HHB meal resulted in the highest number of marketable cabbage heads and benefit-cost ratios (BCRs). Therefore, the application of Be-Grow Boost (L) hydrogel (88 kg/ha) and NPK (88:40:27 + 8 [S] kg/ha + Procote Zn) with full irrigation (4 mm of daily irrigation for five days a week) can be a viable strategy for increasing marketable cabbage production and achieving higher BCRs in semi-arid regions like Central Namibia. Similarly, the consecutive seasonal application of HHB meal at 2.8 t/ha can also enhance the number of marketable heads and BCR. Finally, local production of biochar has the potential to reduce total production costs (TPC) while increasing BCR in its application.

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Conflict of interest

The authors declare no conflicts of interest.

Ethical Clearance

No animal model was utilized in this study; therefore, ethical clearance is not required.

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