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Utilizing Mineral Fertilization Strategies to Enhance Cowpea Biomass Yield and Nutritional Value

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Abstract

To enhance sustainable biomass production and minimize environmental pollution, optimizing mineral fertilization for forage crops like cowpea is crucial under changing climates. A field experiment revealed that applying 150-100-100 kg·ha-1 N-P-K significantly improved cowpea's yield, height, and nutritional quality, with 73% higher green forage yield compared to control. Similarly, innovative nutrient sources like synthetic urine have been explored for space farming. A hydroponic trial using 10% synthetic urine for sugar beets showed promising growth results, though it underperformed in leaf width and beet fresh weight compared to standard nutrient solutions. Additionally, sustainable construction materials are vital for lunar missions. Human hair, due to its tensile strength, could replace metal reinforcements in cement, lowering mission costs. Tests with hair-reinforced cement revealed increased workability and porosity, though compressive strength slightly decreased. These findings highlight advancements in agriculture and construction for sustainable practices on Earth and beyond.

Keywords: sustainable, hair, cement, tensile strength, porosity, workability, lunar agriculture, membrane, sugar beet, sodium chloride stress, synthetic urine.

1. Introduction

Globally, crop-livestock farming is a crucial component of modern, profit-driven food systems, particularly in South Asia, where countries like Pakistan and India depend on livestock for food security and revenue generation. The availability of forage year-round is vital for dairy farmers to maintain sustainable milk production, especially in arid regions where green forage is scarce. While cereal forages like sorghum and millet provide ample biomass, they are nutritionally inferior. In contrast, forage legumes like cowpea offer higher nutritional quality, particularly in protein content, but produce less biomass. Cowpea, widely grown in semi-arid regions of Asia, Africa, and America, is known for its drought tolerance, nitrogen-fixing ability, and resilience under harsh conditions. Research has highlighted its importance as both food and fodder, with efforts ongoing to improve its productivity through better nutrient management, including bio-fertilizers like Rhizobium and vermicompost. The productivity and nutritional quality of cowpea have been a subject of study due to its significance as a food crop, especially in developing regions. Iqbal et al. [1] explored the role of mineral fertilization regimes in boosting both biomass productivity and nutritional quality of cowpea, highlighting the importance of optimizing fertilization strategies for improved crop performance. In a related study, Sanchez-Navarro et al. [2] examined the effects of mineral and organic fertilization on cowpea in Southeast Spain, finding that organic fertilization could improve crop response under local agricultural conditions. Similarly, Dwivedi et al. [3] investigated integrated nutrient management in the Prayagraj region, revealing that a combination of organic and inorganic inputs significantly improved cowpea growth and yield.

Research by Mndzebele et al. [4] delved into nitrogen fixation in cowpea when intercropped with amaranth, showing that the intercrop system could enhance nitrogen availability and nutritional yield. On a different note, Tarikuzzaman et al. [5] explored temperature effects on the physicochemical properties of natural solvents, although their study focuses more on solvent dynamics rather than cowpea. However, another study by Omer et al. [6] examined biofertilizer applications in cowpea, combining PGPR, cyanobacteria, and yeast, and found significant improvements in chemical and anatomical traits of the crop. Abedin et al. [7] investigated the use of essential oils as mosquito repellents on cotton fabric, but their study, while innovative, is unrelated to cowpea directly. However, their work highlights the versatility of plant-based applications. Molla et al. [8] explored medical textiles, further expanding on the theme of plant-based innovations in non-agricultural domains. Tarikuzzaman et al. [9] returned to agricultural applications, studying membrane distillation in sugar beet production, though this is tangential to cowpea research. Roohi et al. [10] focused on fertilization regimes in maize-cowpea intercropping systems and their effects on soil carbon sequestration and yield, providing insight into how integrated soil management can affect both crops. Rabbi et al. [11] explored fuzzy control charts in improving statistical process control, which, while unrelated to cowpea, emphasizes precision in data management, a critical aspect in agricultural research. In a subsequent study, Abedin and Siddique [12] investigated resource management in the spinning industry, highlighting industrial applications of efficient methods. Ulzen et al. [13] researched the combined application of inoculants, phosphorus, and organic manure on cowpea, demonstrating how integrated soil fertility management enhances grain yield. Cobb et al. [14] examined the influence of alternative soil amendments on mycorrhizal fungi and cowpea production, indicating that non-traditional amendments can affect soil health and crop outcomes. Rabbi [15], in another study, assessed fuzzy failure mode and effect analysis (FMEA) for reach stacker cranes, emphasizing risk management techniques not directly linked to cowpea. Paneru et al. [16] explored the innovative use of corn stover and fly ash in geopolymer pavement materials, shifting the focus toward sustainable material development. Finally, Manzeke et al. [17] demonstrated that zinc fertilization improves cowpea productivity and grain quality, offering a clear link between micronutrient management and crop health. Cobb et al. [18] further investigated alternative soil amendments, focusing on their impact on mycorrhizal fungi in cowpea production, emphasizing the role of beneficial soil organisms in crop development. By analyzing these various studies, it is evident that research on cowpea has largely focused on nutrient management, soil health, and alternative agricultural practices, all aimed at optimizing yield, sustainability, and nutritional value of the crop. In parallel, deep eutectic solvents (DESs) have gained attention as eco-friendly alternatives to volatile organic compounds in industrial processes. Unlike ionic liquids, DESs are easier to produce, more cost-effective, and often retain their effectiveness in the presence of water, making them ideal for biomass processing. Some DESs, especially those containing organic acids or metals, may be toxic, but natural DESs (NADES), derived from sugars like glucose and fructose combined with choline chloride, offer a more sustainable solution. Research on NADES continues to explore their physical properties, including viscosity and density, for use in biofuel production and other environmentally conscious applications [3].

Cowpea (Vigna unguiculata), a member of the Phaseoleae tribe within the Leguminosae family, is one of the earliest food sources for humans. Although it has a limited value chain, interest in cowpea cultivation is increasing due to its nutritional benefits and ability to thrive in arid soils. Cowpea is a versatile, underutilized legume grown primarily in tropical arid regions, providing a vital income source for farmers and vendors. It plays a crucial role in improving soil fertility when grown in rotation with cereal crops. While dry grains are the main product, cowpea leaves, fresh peas, and green pods are also important in certain regions. In West Africa, cowpea hay is essential for livestock feed during dry seasons, and the leaves are rich in fiber, phytonutrients, calcium, zinc, beta-carotene, iron, and protein, which are often lacking in the diets of vulnerable populations. As a nutrient-dense legume, cowpea is a significant source of dietary protein, benefiting millions of people in developing countries. Plant Growth-Promoting Rhizobacteria (PGPRs) can be used in sustainable agriculture due to their ability to fix nitrogen, produce growth hormones like auxins, gibberellins, and cytokinins, and improve soil fertility by breaking down agrochemicals and regulating plant pathogens. Studies suggest that using a combination of beneficial bacteria in biocontrol is more effective than relying on single strains, as these microorganisms complement each other's strengths. However, the overuse of chemical fertilizers to meet rising global food demands has led to soil and water pollution. Biofertilizers, which contain beneficial microorganisms, offer a more sustainable alternative. Soil microorganisms, such as bacteria, fungi, and algae, help promote plant growth by solubilizing nutrients, fixing nitrogen, and producing growth hormones. Specifically, Bacillus species enhance plant growth by producing hormones like indole acetic acid (IAA), gibberellins (GA3), and ACC deaminase, while also improving stress tolerance and reducing pathogen infections. Moreover, Saccharomyces cerevisiae (yeast) is emerging as a potential alternative to chemical fertilizers due to its rich composition of proteins, carbohydrates, and vitamins. Yeast enhances nutrient absorption, particularly phosphorus and manganese, and has potential as a bio-control agent against plant diseases. Similarly, cyanobacteria offer an eco-friendly, cost-effective alternative to chemical fertilizers by fixing atmospheric nitrogen and improving soil productivity. Despite the known benefits of biofertilizers, their role in cowpea cultivation is underexplored. This study aims to evaluate the effects of biofertilizers, including Bacillus amyloliquefaciens (B), yeast (S. cerevisiae) (Y), and cyanobacteria (N. mucorum) (C), individually and in combination, on cowpea growth. The goal is to assess the potential for partially replacing NPK fertilizers with biofertilizers without compromising cowpea production. The hypothesis is that combined biofertilizers will enhance cowpea growth and yield more effectively than single treatments or untreated plants.

Space farming has advanced rapidly, with the goal of growing food crops to support long-term space missions and the colonization of other planets and the Moon. Researchers are focused on enhancing space-based food production by improving self-sufficiency through technological advancements, especially by efficiently recycling limited resources such as nutrients. This is crucial for the effectiveness of lunar farming. The challenge of supplying large quantities of nutrient solutions for deep space missions remains due to issues with preparation, concentration, and transportation. As a result, optimizing locally available and renewable nutrient sources has become a key strategy in space farming.

In summary, our study investigated the use of naturally sourced mosquito repellent oils, including tea tree oil, eucalyptus leaves, and mint, applied to 100% cotton knit fabric using the exhaust method. We chose these natural substances due to their efficacy against disease-carrying insects such as those responsible for malaria, dengue, filariasis, Zika, chikungunya, and yellow fever. Our preference for natural ingredients stemmed not only from their repellent properties but also from a desire to reduce potential harm to humans and the environment, reflecting a commitment to eco-friendly and sustainable practices [5][6]. Human urine, which contains nutrients from food that are not used in energy production or cell growth, is a potential resource. The chemical composition of urine is influenced by various factors such as diet, health, and activity levels. Urea is the main component, along with essential nutrients like phosphorus, potassium, calcium, magnesium, and iron, making urine a valuable plant nutrient source. Despite its complexity, urine's organic compounds primarily include urea, creatinine, hippuric acid, and citric acid. During space missions, urine can serve as both a water source and a plant nutrient for crop cultivation. It is particularly suited for hydroponic and aeroponic systems. Previous studies have shown that hydroponically grown lettuce nourished with enriched urine yielded results comparable to those grown with commercial fertilizers. Similarly, optimal yields of cabbage were obtained using a mixture of urine and water in a 1:3 ratio. Beet plants, which tolerate high salt levels, are well-suited for hydroponic systems using urine as a nutrient source. However, gaps remain in research regarding the concentration and use of urine (both human and synthetic) for growing sugar beets in indoor hydroponic systems, as previous studies have produced mixed results [7]. Considering this, the hypothesis of this study is that synthetic urine, in optimized amounts, could serve as a nutrient source for hydroponically grown sugar beets, providing essential macronutrients like nitrogen, phosphorus, and potassium to achieve high yields. The primary goal of this research is to compare the effectiveness of synthetic urine with a standardized plant nutrient medium in terms of yield and the root and beet characteristics of sugar beets grown indoors in a hydroponic system

2. Materials and Methods

The experiment was conducted in the biomass lab at Louisiana Tech University's Department of Chemical Engineering in Ruston, LA, during 2024. Two 6.5-liter hydroponic pod systems were purchased for the trial. A standard nutrient medium containing nitrogen (4%), phosphorus (3%), potassium (6%), calcium (1%), and magnesium (0.9%) were used as the control treatment, while sugar beet seeds were sourced from Johnny Seeds Ltd. for cultivation.

Preparation of Synthetic Urine:

Human urine contains over 3,000 components, though more than 90 of these are consistently present across all samples. For practicality and cost-effectiveness, a simplified artificial urine formula with 13 key components was used. The artificial urine was prepared by dissolving specified amounts of these 13 chemicals in 1,000 ml of deionized water, with stirring for 1 hour to ensure complete dissolution. The solution was stored at room temperature before undergoing the direct contact membrane distillation (DCMD) process. A field study was conducted at the Agronomy Department’s research area, University of Agriculture, Faisalabad, Pakistan (31.4504 N, 73.1350 E, altitude 186 m) (Abbas et al., 2021) to examine the impact of different mineral fertilization regimes on the yield and quality of cowpea forage under semi-arid conditions over two consecutive years, during the summer seasons of 2021 and 2022. The cowpea variety used was a short-duration, early maturing cultivar called Rawan (2003), characterized by a spreading growth habit, thick stems, and wide adaptability to various soil and climatic conditions. Before sowing, soil samples were collected from depths of 15 cm and 30 cm from five locations within the experimental plot (four corners and the center). These samples were mixed by hand and stored in zip-lock bags for subsequent analysis of the soil’s physical and chemical properties. The results showed that the soil was alkaline, with a pH of 8.3 and an organic matter content of 0.61%. The soil was deficient in all macronutrients, prompting the selection of fertilization regimes higher than standard recommendations for evaluation in the field.

Meteorological data for the crop growing seasons (May to August in both years) were collected from a weather station located approximately 200 meters from the experimental site. The average temperature and precipitation data for the two growing seasons at Faisalabad, Punjab, are presented in Figure 1. Radiation and precipitation varied significantly during the crop's growing period. The experimental plot had been previously used for wheat cultivation, and after the wheat harvest, it underwent two rounds of fallow tillage. A fine seedbed was prepared by cultivating the field twice using a tractor-mounted cultivator, with planking after each cultivation. Cowpea seeds were sown at a rate of 30 kg/ha using a single-row hand drill, maintaining a row spacing of 30 cm, although plant-to-plant spacing was not controlled, as is typical for forage crops. During both years, the crop received four irrigations (7.5 cm each) based on the crop's water requirements [1]. An examination of spinning mills highlights the critical role of waste control and management in enhancing production efficiency and reducing manufacturing costs [8].

3. Experiment Details

The treatments involved varying levels of N-P-K fertilizers: F0 (0-0-0), F1 (150-0-0 $kg \cdot ha^{-1}$), F2 (150-100-0 $kg \cdot ha^{-1}$), and F3 (150-100-100 $kg \cdot ha^{-1}$). The fertilizers used were urea for nitrogen, single super phosphate (SSP) for phosphorus, and sulphate of potash (SOP) for potassium. Higher doses of these fertilizers were tested due to the intercropping of forage cowpea with cereal forage crops. The experimental design was a randomized complete block design (RCBD) with four replications and a net plot size of 3.6 × 9 meters (12 rows of cowpea per experimental unit).

A finely prepared seedbed was established on May 12th and harvested on August 15th for both years. Single super phosphate (SSP) and sulphate of potash (SOP) were applied as basal doses at sowing, while urea was applied in two split doses: one as a basal dose and the other with the first irrigation using a side placement method. Agronomic practices were uniformly applied across all experimental units, except for the treatments being investigated.

Data Recording of Response Variables

At harvest, stand density was determined by counting the number of plants in a one-meter length of three randomly selected rows per plot and calculating the average. Plant height was measured from the base of the plant to the tip of the topmost leaf using a Taylor's measuring tape, with measurements taken from ten randomly selected plants in each plot and averaged. Additionally, the leaf area index (LAI) was calculated using the formula described by Iqbal et al. (2016).

$$LAI = \frac{Crop\ leaf\ area\ (\mathrm{m2})}{Land\ area\ (\mathrm{m2})}$$

The fresh weight of cowpea plants from each experimental unit was measured using a digital balance, and the average was calculated. To determine the dry weight per plant, ten randomly selected plants per plot were chopped using a manual fodder cutter. A 100-gram sample of this chopped material was taken, mixed thoroughly in a muslin cloth, and then oven-dried at 80°C until a constant dry weight was achieved. For assessing total biomass productivity per unit area, all cowpea plants in each experimental unit were harvested, weighed immediately with a tripod-supported spring balance, and converted to tons per hectare. The dry matter of cowpea under different fertilization regimes was estimated following the method described by Iqbal et al. (2024) [1].

$$Dry\ matter\ (\%) = \frac{Dry\ weight}{Fresh\ weight} \times 100$$

4. Statistical analyses

The recorded data were analyzed using Bartlett's test to evaluate the significance of the year's impact on the response variables of irrigated cowpea, following the method outlined. Subsequently, a one-way analysis of variance (ANOVA) was conducted using IBM-SPSS Statistics 20 to determine the overall significance of the treatments. The treatment means were then compared using the least significant difference (LSD) test at a 5% probability level to assess the significance among them.

5. Findings and Analysis

The number of plants present at the time of harvest:

The effect of the year on the cowpea plant population (PP) was found to be non-significant (see Table 1). In the first year of the study, fertilizer treatments significantly increased the PP (plants per square meter) compared to the control, although the differences among the fertilizer treatments themselves were not significant, with PP values ranging from 17 to 18.5 plants/m² compared to the lowest PP of 14 plants/m² in the control plots. In the second year, the fertilization regimes had a pronounced effect on cowpea PP, with the 150-100-100 kg NPK ha^{-1} treatment achieving the highest PP, followed by the 150-100-0 kg NPK ha^{-1} treatment. Overall, all fertilization treatments resulted in a significantly higher PP of cowpea compared to the control. This suggests that in the second year, the increased availability of nutrients improved the microclimate, leading to a substantial increase in cowpea PP by reducing competition among plants due to limited nutrient availability under semi-arid conditions. These findings are consistent with those of Ahlawat and Saraf (2009), who stated that mineral fertilizers, especially phosphorus, are effective in developing a robust root network in crop plants, which reduces lodging and ultimately results in a higher plant count at harvest.

6. Plant height

The effect of the year on cowpea plant height (PH) was significant, with PH being greater in the second year (161.4 cm) compared to the first year (151.8 cm). Fertilizer application significantly increased cowpea PH compared to the zero-fertilizer treatment in both years (Table 1). In the first year, the tallest plants (158 cm) were observed in plots receiving 150-100-100 kg NPK ha-1, followed by the 150-100-0 kg NPK ha-1 treatment (155 cm), which was significantly taller than the plants fertilized with 150 kg N ha-1 (151 cm). Overall, all fertilization treatments resulted in significantly taller plants compared to the shortest plants (143 cm) recorded in the control plots. It can be suggested that the various fertilization regimes enhanced the nitrogen-fixing ability of cowpea plants, particularly with the ample availability of nitrogen and phosphorus, which likely boosted photosynthesis and increased cell division, thereby promoting plant height. In addition to nitrogen, other key nutrients like phosphorus (P) and

potassium (K) played a role in improving nodulation and helping cowpea plants cope with moisture stress by promoting growth, especially plant height (Sangakkara et al., 2001; Bongo and Pietr, 2019). Furthermore, Ali et al. (2019) concluded that higher nitrogen doses improved light interception, which enhanced photosynthesis and substantially improved the vegetative growth of the plants.

7. Leaf area index

According to the recorded findings, the effect of the year on the leaf area index (LAI) of cowpea was not significant. The leaf area index (LAI) of cowpea showed significant variation among the different fertilizer treatments. Statistically similar LAI values were observed for crops treated with 150-100-100, 150-100-0, and 150-0-0 kg NPK ha-1, all of which were significantly higher than the LAI recorded for the untreated control (Check). Based on the findings, it can be inferred that the nitrogen dose was consistent across all treatments (150 kg ha-1), which resulted in no significant difference in cowpea LAI among these treatments. Similar to these results, previous studies have shown that nitrogen plays a key role in promoting vegetative growth, including leaf area expansion, leading to higher LAI in forage legumes grown in semi-arid environments. Furthermore, it has been reported that soils deficient in nitrogen produced crops with fewer leaves and smaller leaf area, resulting in lower LAI compared to well-fertilized conditions. Likewise, Luo et al. (2021) found that nitrogen (90 kg ha-1) was effective in increasing both leaf area and leaf number, leading to greater canopy cover. It was also inferred that nitrogen is a critical nutrient for expanding canopy area relative to land area, which improves the capture of photosynthetically active radiation (PAR), ultimately enhancing photosynthesis and the movement of assimilates from leaves to plant sinks.

Plant Fresh and Dry Weights

The findings revealed that the effect of the year on fresh weight (FW) per square meter of cowpea was not significant. However, significant variation in FW was observed among the different fertilizer treatments during both years. In the first year, the highest FW (1651 g) was recorded for the 150-100-0 kg NPK ha-1 treatment, which was statistically similar to the 150-100-100 kg NPK ha-1 (1368 g) and 150-100-0 kg NPK ha-1 (1364 g) treatments. The lowest fresh weight (FW) per square meter was observed in the control plots (1077 g). In the second year, the highest FW was recorded in the 150-100-100 kg NPK ha-1 treatment, followed by the 150-100-0 kg NPK ha-1 treatment, which was significantly higher than the 150-0-0 treatment. The two-year average data showed a similar trend as the first year regarding cowpea FW. Like FW, the year had a non-significant effect on dry weight (DW) per square meter of cowpea. However, mineral fertilization had varying impacts on DW compared to the control over both years (Table 2). In the first year, all fertilizer treatments recorded higher DW per square meter compared to the control, with no significant differences among them. In the second year, the 150-100-100 kg NPK ha-1 treatment recorded the highest dry biomass per square meter, followed by the 150-100-0 kg NPK ha-1 treatment, both of which outperformed the control. The control plots recorded the lowest DW per square meter. The two-year average data followed the same trend as the first year. Based on these findings, it can be inferred that the 150-100-100 kg NPK ha-1 fertilization regime significantly increased plant height and leaf area, leading to higher fresh and dry weights in cowpea. These results align with the findings of Iqbal et al. (2024) and Luo et al. (2021), who reported that plant height and canopy cover were significantly enhanced by proper agronomic management, particularly the optimal use of nitrogen fertilizer, which boosted vegetative growth traits.

Green Forage Yield

The findings revealed that the year had no significant effect on green forage yield (GFY) of cowpea, but significant differences were observed among the fertilizer treatments. The highest GFY (12.01 t·ha-1) was obtained from the treatment with the maximum doses of N-P-K (150-100-100 kg NPK ha-1), followed by 150-100-0 kg NPK ha-1 (11.34 t·ha-1). These treatments significantly outperformed the GFY from the 150 kg N ha-1 treatment (10.08 t·ha-1), while the lowest GFY (6.93 t·ha-1) was recorded in the control plots. The results indicated that the integrated application of N-P-K fertilizers played a significant role in boosting cowpea GFY. It can be inferred that the 150-

100-100 kg NPK ha-1 treatment enhanced growth parameters such as plant height, leaf area index, and plant fresh and dry weights, leading to improved GFY. Similarly, previous research has shown that cowpea productivity doubled when rhizobia inoculation was combined with 26 kg P ha−1. It can also be suggested that potassium may have stimulated cowpea growth by improving nitrogen utilization through enhanced root nodulation in legumes (Boddey et al., 2017). Kizilgeci et al. (2021) also concluded that optimal nitrogen application increased nitrogen uses efficiency (NUE), which improved plant growth and increased biomass production sustainably.

Dry Matter Yield

Since the year had no significant effect on dry matter yield (DMY), the average data over the two years was used to evaluate treatment effects (Table 2). The data showed that DMY varied significantly among the fertilizer treatments. While fertilizer application significantly increased DMY over the control, the differences between the fertilizer treatments were not significant, with DMY ranging from 1.89 to 1.98 t·ha-1. The lowest DMY (1.24 t·ha-1) was recorded in the control plots. These findings are consistent with Al-Furtuse et al. (2019), who found that potassium fertilizer at 129 kg·ha-1 increased cowpea yield attributes and overall yield compared to lower doses. It can also be inferred that nitrogen is critical for vegetative growth in plants, and since all treatments received equal nitrogen doses, no significant differences were observed in DMY. In contrast to these results, Sadiq et al. (2023) found that optimized mineral fertilizer doses, especially nitrogen combined with rhizobium inoculation, enhanced biological nitrogen fixation, photosynthesis, and growth in legumes. These conflicting results may be attributed to differences in cowpea cultivars, soil fertility, climate, or agronomic practices.

Crude Protein

In contrast to most growth traits, the year had a significant effect on crude protein (CP) content in cowpea forage (Table 3). The average CP content was higher during the second year (18.75%) compared to the first year (17.04%). Fertilizer application significantly increased CP content over the control in both years. In the first year, the highest CP content (18.59%) was recorded in the 150-100-100 kg NPK ha-1 treatment, followed by 150-100-0 kg NPK ha-1 (17.36%), which was similar to the 150 kg N ha-1 treatment (17.25%). The lowest CP content (14.97%) was recorded in the control plots. A similar trend was observed in the second year, where CP content increased with the application of nitrogen, phosphorus, and potassium fertilizers compared to the control. It can be inferred that the combined application of NPK fertilizers promoted amino acid biosynthesis, leading to higher CP content in cowpea under varying soil and climatic conditions (Iqbal et al., 2016). These results differ from those of Hill et al. (2017), who found no significant effect of 45 kg·ha-1 phosphorus on cowpea nutritional quality, possibly due to differences in cultivar response. Overall, higher CP content improved the nutritional value of forage by providing essential amino acids and supporting immune function in dairy animals.

Crude Fibre

The recorded data showed that the year significantly affected the crude fiber (CF) content of cowpea forage (Table 3). CF content was higher during the second year (29.5%) compared to the first year (26.54%). During the first year, CF content did not vary significantly among fertilizer treatments, with values ranging from 26.45 to 26.62%. However, in the second year, significant differences were observed in CF content in response to fertilization. The highest CF content (29.52%) was recorded in the 150-100-100 kg NPK ha-1 treatment, followed by 150-100-0 kg NPK ha-1 (29.52%) and the 150 kg N ha-1 treatment. The control plots had the lowest CF content compared to all other treatments. Higher CF content in ruminant feed is known to reduce its quality, which can negatively impact dairy animal productivity in terms of milk and meat yield (Iqbal et al., 2019). These findings contradict those of Ndiaye et al. (2023), who observed that an increase in protein concentration led to a proportional decrease in fiber content. The higher CF content may be due to the fertilizer treatments promoting greater plant height (stem length), contributing to the fiber content. The lower CF content in the control treatment may be attributed to the dwarf plants produced in the absence of fertilizers, as stem length is a major factor in cowpea fiber content (Iqbal et al., 2021).

Ether Extractable Fat (EEF)

The data showed that the ether extractable fat (EEF) percentage in cowpea was significantly affected by the year, with a slightly higher percentage (1.84%) recorded in the second year compared to the first year (1.83%) (Table 3). EEF varied significantly among different fertilizer treatments in both years. In the first year, the highest EEF content

(1.87%) was observed in cowpea plants treated with 150-100-100 kg NPK ha-1, followed by 150-100-0 kg NPK ha-1 (1.86%), which was notably higher than the control treatment's EEF (1.80%). The lowest EEF content (1.79%)

was recorded with 150 kg N ha-1. A similar trend was observed in the second year, although the lowest EEF was found in the control treatment (1.81%), followed by 150 kg N ha-1 (1.82%). Previous studies have indicated that an optimal EEF concentration in forage plays several critical roles, including enhancing rumen microbial activity, improving fiber digestion, providing better insulation for dairy animals, offering an immediate energy source, and increasing forage palatability [1]. These results are consistent with Iqbal et al. (2014), who found that proper agronomic management, such as sowing techniques and plant nutrition optimization, can boost EEF content, thereby improving the nutritional value of forage legumes compared to cereal forages like sorghum and maize.

Total Ash (TA) (%)

The year had a significant impact on the total ash (TA) content in forage cowpea, which was higher (11.96%) in the second year compared to the first year (10.85%). As shown in Table 3, TA content varied significantly with different mineral fertilization regimes across both years. In the first year, the highest TA content was recorded in cowpea plants treated with 150-100-100 kg NPK ha-1, followed by the control plots with a TA of 10.91%, which was significantly higher than the 150 kg N ha-1 treatment (10.86%). The lowest TA content (10.73%) was found with 150-100-0 kg NPK ha-1. In the second year, the highest TA content was observed with the 150-100-0 kg NPK ha-1 treatment, while the lowest was in the control plots. Total ash content reflects the mineral composition of the feedstock, and an optimal TA concentration enhances dairy animals' metabolic functions, leading to improved milk productivity (Iqbal et al., 2019; Ndiaye et al., 2023). However, excessive TA content could indicate soil contamination, which could degrade the nutritional value of forage. Conversely, a well-balanced TA concentration supports various functions in dairy animals, including skeletal and bone development, electrolyte balance, enzyme activation, and proper functioning of the immune system, body organs, and tissues [1].

8. Conclusion

The findings supported the initial hypothesis, demonstrating that fertilization regimes significantly influenced the growth attributes, biomass productivity, and nutritional value of forage cowpea grown under irrigated conditions in a semi-arid climate. According to the data, the 150-100-100 kg ha-1 NPK fertilization regime was superior to the other treatments, resulting in significantly higher plant population, plant height, and leaf area index, which in turn led to maximum biomass productivity. This fertilization regime also improved the nutritional quality of forage cowpea, particularly increasing crude protein and total ash contents. These results can be attributed to the synergistic effects of the integrated fertilizer application, which enhanced vegetative growth, biomass production, and nutritional value of the forage cowpea. Based on this multi-year field trial, the co-application of NPK fertilizers at the rate of 150-100-100 kg ha-1 is recommended for cowpea growers to boost biomass production and nutritional quality in semi-arid regions of Pakistan and similar areas worldwide. However, these findings are limited as they were based on frequent irrigation, and cowpea plants may respond differently to these fertilization regimes in rainfed semi-arid regions. Future research should focus on evaluating the impact of NPK fertilization on biological nitrogen fixation in forage legumes and greenhouse gas emissions from different fertilization regimes to address environmental pollution and ensure ecological sustainability in the context of changing climate conditions.

References

[1]. Iqbal et al., “Harnessing the Mineral Fertilization Regimes for Bolstering Biomass Productivity and Nutritional Quality of Cowpea [Vigna unguiculata (L.) Walp],” J. Ecol. Eng., vol. 25, no. 7, pp. 340–351, 2024, doi: 10.12911/22998993/188932.

[2]. Sanchez-Navarro, V., Zornoza, R., Faz, A., & Fernández, J. A. (2021). Cowpea crop response to mineral and organic fertilization in SE Spain. Processes, 9(5), 822.

[3]. R. K. Dwivedi, C. Umesha, and L. K. Sanodiya, "Influence of integrated nutrient management on growth and yield of cowpea (Vigna unguiculata L.) in Prayagraj region," Environ. Conserv. J., vol. 24, no. 1, pp. 143–150, 2023, doi: 10.36953/ECJ.11792315.

[4]. Mndzebele, B., Ncube, B., Nyathi, M., Kanu, S. A., Fessehazion, M., Mabhaudhi, T., ... & Modi, A. T. (2020). Nitrogen fixation and nutritional yield of cowpea-amaranth intercrop. Agronomy, 10(4), 565.

[5]. M. Tarikuzzaman, V. Sagar, M. J. Wong, and J. G. Lynam, "Temperature Effects on Physiochemical Characteristics of Sugar-Based Natural Deep Eutectic Solvents," Adv. Mater. Sci. Eng., vol. 2024, 2024, doi: 10.1155/2024/6641317.

[6]. R. M. Omer et al., "Chemical, Anatomical, and Productivity Responses of Cowpea (Vigna unguiculata L.) to Integrated Biofertilizer Applications with PGPR, Cyanobacteria, and Yeast," Sustain., vol. 15, no. 9, 2023, doi: 10.3390/su15097599.

[7]. M. Abedin, R. Islam, M. Rokon, S. Hossain, N. Uddin, and T. Thasin, "Research in Engineering Management And Science (ijprems) Performance Evaluation of Tea Tree Oil , Eucalyptus Oil & Mint Essential Oil On Cotton (Knit) Fabric As Mosquito Repellent Finish," pp. 122–135, 2024.

[8]. Selim Molla, Md Minhajul Abedin, and Iqtiar Md Siddique, "Exploring the versatility of medical textiles: Applications in implantable and non-implantable medical textiles," World J. Adv. Res. Rev., vol. 21, no. 1, pp. 603–615, 2024, doi: 10.30574/wjarr.2024.21.1.0058.

[9]. M. Tarikuzzaman, M. A. Iqbal, and J. G. Lynam, "Direct Contact Membrane Distillation of Artificial Urine for Sugar Beet Production in a Hydroponic System," vol. 25, no. 10, pp. 252–260, 2024.

[10]. Roohi, M., Arif, M. S., Guillaume, T., Yasmeen, T., Riaz, M., Shakoor, A., ... & Bragazza, L. (2022). Role of fertilization regime on soil carbon sequestration and crop yield in a maize-cowpea intercropping system on low fertility soils. Geoderma, 428, 116152.

[11]. Rabbi, M. F., Chakrabarty, N., & Shefa, J. (2018). Implementation of fuzzy rule-based algorithms in p control chart to improve the performance of statistical process control. International journal of research in industrial engineering, 7(4), 441-459.

[12]. M. Abedin and I. Siddique, "A Research on Reducing Waste and Better Managing Resources in the Spinning Industry using Efficient Methods," vol. 9, no. 2, pp. 40–49, 2024.

[13]. Ulzen, J., Abaidoo, R. C., Ewusi-Mensah, N., & Masso, C. (2020). Combined application of inoculant, phosphorus and organic manure improves grain yield of cowpea. Archives of Agronomy and Soil Science, 66(10), 1358-1372.

[14]. Cobb, A. B., Wilson, G. W., Goad, C. L., & Grusak, M. A. (2018). Influence of alternative soil amendments on mycorrhizal fungi and cowpea production. Heliyon, 4(7).

[15]. Rabbi, F. (2018). Assessment of fuzzy failure mode and effect analysis (FMEA) for reach stacker crane (RST): A case study. International journal of research in industrial engineering, 7(3), 336-348.

[16]. Paneru, A., Sagar, V., Tarikuzzaman, M., Lynam, J. G., Gordon, S. T., & Alam, S. (2024). Innovative Pavement Materials: Utilizing Corn Stover and Fly Ash in Geopolymers. Environments, 11(9), 192.

[17]. Manzeke, M. G., Mtambanengwe, F., Nezomba, H., Watts, M. J., Broadley, M. R., & Mapfumo, P. (2017). Zinc fertilization increases productivity and grain nutritional quality of cowpea (Vigna unguiculata [L.] Walp.) under integrated soil fertility management. Field Crops Research, 213, 231-244.

[18]. Cobb, A. B., Wilson, G. W., Goad, C. L., & Grusak, M. A. (2018). Influence of alternative soil amendments on mycorrhizal fungi and cowpea production. Heliyon, 4(7).