

Harnessing the Mineral Fertilization Regimes for Bolstering Biomass Productivity and Nutritional Quality of Cowpea [*Vigna unguiculata* (L.) Walp]

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ABSTRACT

To prevent environmental pollution, promote ecological restoration and impart production sustainability in biomass crops, optimization of mineral fertilization regimes is strategically required under changing climatic scenarios. There exist research gaps regarding optimal use of nitrogen (N), phosphorous (P) and potassium (K) fertilizers for the fertilizer-responsive cultivars of forage legumes like cowpea under decreasing soil fertility in semi-arid regions. Therefore, a multi-year field experiment was executed to study yield attributes, green and dry matter yields along with nutritional quality attributes of forage cowpea. The treatments were comprised of different N-P-K levels viz. $F_0 = (0-0-0)$, $F_1 = (150-0-0 \text{ kg}\cdot\text{ha}^{-1})$, $F_2 = (150-100-0 \text{ kg}\cdot\text{ha}^{-1})$ and $F_3 = (150-100-100 \text{ kg}\cdot\text{ha}^{-1})$. The findings revealed that F_3 fertilization regime surpassed rest of treatments by recording the maximum plant population, plant height, leaf area index, plants fresh and dry weights, which led to the highest green forage yield (73% and 5.8% higher than control and following treatment of F_2 , respectively). For dry matter yield, all fertilization regimes performed better than control, however those were statistically at par to each other. Moreover, F_3 treatment exhibited 4.4% and 1.6% higher crude protein and ether extractable fat respectively, compared to the following treatment of F_2 treatment that remained at par with F_3 for total ash content. Contrastingly, the control treatment remained superior by giving the minimum crude fiber content which could be attributed to dwarf plants produced in the absence of fertilizers because stem length tends to contribute the major portion of fiber content in cowpea. Thus, $150-100-100 \text{ kg}\cdot\text{ha}^{-1}$ N-P-K might be recommended to cowpea growers for boosting biomass productivity and nutritional quality, however further field investigations need to assess the impact of these fertilization regimes on biological N fixation process and solar radiation capture by cowpea plants under irrigated and dry semi-arid conditions.

Keywords: urea, forage legumes, crop-livestock farming, biological nitrogen fixation, ecological restoration.

INTRODUCTION

Globally, crop-livestock mixed farming has become an integral, indispensable and vital component of modern profit-oriented and

economic-centered food production systems (Ben Abdallah et al., 2024). The economies of developing countries in south Asia particularly Pakistan and India rely heavily on livestock sector in order to ensure the food security of rapidly

increasing population through sustainable generation of revenues (Iqbal et al., 2019). In the modern era, the economic competitiveness of dairy farmers depends in part on forage availability throughout the year in order to achieve sustainable milk productivity targets (Aguerre et al., 2023). The productivity and profitability of dairy animals are directly influenced by the type and nutritional value of feed especially during the summer months when the green forages become scarce (Akdeniz et al., 2019). Especially in the scarce-arid regions of South Asia, the demand for high quality forages is persistently increasing in order to sustain livestock enterprises (Lauriault et al., 2023; Hosafioğlu et al., 2024). Additionally, the most of the cereal forages (sorghum, millets etc.) produce sufficient quantities of forage, however these are regarded poor in terms of nutritional value owing to the presence of higher fiber content (Iqbal et al., 2019). To cope with this situation, forage legumes hold bright perspectives due to having higher nutritional quality especially protein content compared to cereal crops (Sabagh et al., 2022; Islam et al., 2023). However, forage legumes tend to produce significantly lesser biomass compared to forage cereals (Iqbal et al., 2018; Kumar et al., 2022), which necessitates conducting fresh studies for boosting the biomass productivity of forage legumes like cowpea [*Vigna unguiculata* (L.) Walp].

Cowpea commonly known as lobia, chunra, rawan, black-eye beans and southern pea, is a short day summer season crop and requires relatively higher temperature to produce higher biomass (Iqbal et al., 2021; Lazaridi et al., 2023). Primarily, it is grown in the semi arid regions of Indo-Pak subcontinent, Bangladesh and south-east Asia along with sub humid tropics of west Africa, Australia, Brazil and southern USA (Samireddypalle et al., 2017). It is believed to have originated in the African continent and immensely contributes to ensuring food security in dry regions of Africa because cowpea's entire aerial sections (grain, green pods, and leaves) are edible (Maman et al., 2017; Islam et al., 2018). Globally, the current estimated land area under cowpea cultivation was around 14.5 million hectares, whereas over 80% of this acreage (11.4 mha) was in African continent. Cowpea offer numerous advantages over other forage legumes especially unprecedented drought tolerance, greater nitrogen (N) fixing capability (up to 200 kg N ha⁻¹), adaptability to thrive well under varying pedo-climatic conditions and higher

nutritional quality (especially crude protein content). By virtue of its unmatched hardiness, cowpea plants tend to thrive well on marginal lands under unfavorable weather conditions, making it one of the most climate-resilient crops for dry regions (Toyinbo et al., 2021; Togola et al., 2023). Additionally, higher biomass production potential of cowpea can generate greater economic revenues and thus, it becomes forage crop of immense importance for dairy farmers having limited land resources (particularly land) to grow feed for livestock (Watanabe et al., 2019; Horn and Shimelis, 2020). Moreover, it might be grown as a dual-purpose crop both for human consumption and green succulent feed for dairy animals (Iqbal et al., 2018). In African semi-arid regions, cowpea has been grown as an integral component of conventional farming systems, whereby grains find their use as food while haulms are fed to livestock (Kulkarni et al., 2018). Its fodder is quite succulent, palatable and highly relished by the buffaloes and cattle. Iqbal et al. (2018) reported that cowpea tend to develop more extensive root system that made it more competitive biomass crop than cluster bean or guar (*Cyamopsis tetragonoloba* (L.) Taub.) and soybean (*Glycine max*). However, limited research has been conducted on quantifying the nutritional quality of cowpea forage owing to expensive and intricate wet chemistry analytical techniques (Ndiaye et al., 2023).

Despite genetic improvement of many field crops (wheat, rice, sugarcane, sorghum etc.) using modern genetic engineering approaches like clustered regularly interspaced short palindromic repeats (CRISPR) (Hussin et al., 2022; Li and Iqbal, 2024), biomass productivity and nutritive quality of leguminous crops particularly cowpea have remained lower than genetic potential of presently grown cultivars. A wide range of factors including sub-optimal plant nutrition management (Iqbal, 2019), weeds invasion (Li et al., 2024) and abiotic stresses drastically reduce the productivity of field crops (Iqbal et al., 2023). Cowpea biomass productivity and nutritional value might be enhanced by the balanced and optimized use of mineral fertilizers (Xu et al., 2022). Although, mineral fertilization plays strategic role in improving soil fertility and crop yields, however, their inappropriate use is linked to green-house gaseous emissions along with soil and water pollution owing to rapid mineralization (Sánchez-Navarro et al., 2021). The integrated use of NPK fertilizers in optimized doses have

become critical for restoration of ecological functioning and prevention of environmental degradation (Galindo et al., 2022; Mogale et al., 2023; Dimande et al., 2024). Among macronutrients, N and phosphorous (P) are essential nutrients for legumes growth due to their vital roles in triggering vegetative growth (through improved nutrients uptake and photosynthesis rate) and roots development (due to enzymes activation and translocation of assimilates from leaves towards roots), respectively (Yildirim et al., 2022). Additionally, N becomes even more important for biomass crops like cowpea because it is required for the physiological processes of protein synthesis and energy transfer in plants. However, N and P are the most limiting nutrients on small farms in Indo-Pak subcontinent owing to limited availability and high prices of fertilizers. Sánchez-Navarro et al. (2021) opined that N and P application as fertilization remained effective in bolstering biomass yield and nutritive quality of cowpea, however organic manures performed better than mineral fertilizers. Onduru et al. (2008) also reported similar positive interaction between inoculant and P for cowpea grain yield which led to 54% increase in grain yield compared with the yield for the control. Likewise, Musa et al. (2011), Dekhane et al. (2011), Singh et al. (2011), Nyoki and Ndakidemi (2014) and Kyei-Boahen et al. (2017) reported significant influence (77–21% increase) of P fertilizer with and without rhizobium inoculation on nutritional quality of cowpea. As per findings of another study, 30 kg P_2O_5 ha^{-1} and 20 kg K_2O ha^{-1} significantly improved yield attributes and yield of cowpea (Emmanuel et al., 2021). Likewise, Sabetha et al. (2015) reported pronounced increment in crude protein content of cowpea with increasing doses of N fertilizers. Likewise, potassium (K) stimulated several enzymes, boosted photosynthesis process and played strategic roles in the biosynthesis of protein and improved plants tolerance against diseases (Sangakkara et al., 2001; Iqbal et al., 2021). Moreover, Shokoohfar (2015) inferred that 140 kg ha^{-1} K produced 19% higher yield of cowpea than control treatment (no P fertilizer). However, being confined to one or two primary nutrients, these findings are limited in scope which necessitate conducting fresh studies involving N, P and K mineral fertilizers applied in conjunction with each other for irrigated cowpea sown under semi-arid conditions.

Therefore, in order to bridge the research and knowledge gaps pertaining to the optimized fertilization regimes for irrigated cowpea sown under semi-arid conditions of south Asia, it was hypothesized that cowpea might produce varying levels of biomass and nutritional quality in response to atypical fertilization regimes owing to the combined effects of varying doses of primary nutrients (nitrogen, phosphorous and potassium), site-specific soil conditions and agro-climatic variability. Thus, the prime aim of the study was to sort out the most performing fertilization regime for bolstering irrigated cowpea biomass productivity and nutritional quality under semi-arid conditions.

MATERIALS AND METHODS

A field study was conducted at the research area of Agronomy Department, University of Agriculture, Faisalabad, Punjab, Pakistan (31.4504 N, 73.1350 E, having an altitude of 186 m) (Abbas et al., 2021) to determine the effect of mineral fertilization regimes on forage yield and quality of cowpea forage under semi-arid conditions for two consecutive years (during the summer seasons of 2021 and 2022). The planting material was a short duration and early maturing cowpea cultivar (Rawan, 2003) that is of spreading type, having thick stem and wide adaptability to soil and climatic conditions. The pre-sowing soil sampling was performed by collecting samples from the depth of 15 and 30 cm by selecting collection spots from four corners as well as middle of the experimental field. Those samples were subsequently homogenized by hand mixing and stored in zip-lockable bags for analyzing different physico-chemical properties of the experimental soil. The result revealed that soil was alkaline in nature having pH of 8.3 and organic matter percentage of 0.61. The soil was found to be deficient in all macro nutrients and therefore, higher than recommended fertilization regimes were selected for field assessment.

For recording the meteorological features of the experimental area during the crop growth seasons (May to August during both years), data were collected from the meteorological observatory situated in the close vicinity of the experimental site (around 200 m from the experimental area). The mean values of meteorological features (temperature and precipitation) of the experimental site (Faisalabad, Punjab province of Pakistan)

during two consecutive crop growth seasons have been presented in Figure 1.

Radiation and precipitation receipts changed considerably during the crop growing seasons. The experimental block was previously under wheat crop and after wheat harvest, it was subjected to two fallow cultivations. Thereafter, a fine seedbed was prepared by cultivating field twice using a tractor-mounted cultivator, each followed by planking. Thereafter, cowpea sowing (seed rate of $30 \text{ kg}\cdot\text{ha}^{-1}$) was done using a single row hand drill. The row-row distance was maintained at 30 cm, whereas plant-plant distance was not maintained as a general practice for forage crops. During both years, four irrigations (7.5 cm each) was given to the crop as per need of the crop.

Experiment's details

The treatments were comprised of different N-P-K levels viz. F_0 (0-0-0), F_1 ($150\text{-}0\text{-}0 \text{ kg}\cdot\text{ha}^{-1}$), F_2 ($150\text{-}100\text{-}0 \text{ kg}\cdot\text{ha}^{-1}$) and F_3 ($150\text{-}100\text{-}100 \text{ kg}\cdot\text{ha}^{-1}$). The N-P-K fertilizers were supplied as urea, single super phosphate (SSP) and sulphate of potash (SOP), respectively. Overall, comparatively higher doses of mineral fertilizers were tested for forage cowpea owing to its intercropping with cereal forage crop. The experimental design was randomized complete block design (RCBD) with regular arrangement having four replications and net plot size was $3.6 \times 9 \text{ m}$ (12 rows of cowpea per experimental unit). The experiment was conducted on

a finely prepared seedbed on 12th of May and harvested on 15th of August during both years. Both SSP and SOP were supplied as basal doses at the time of sowing, whereas urea was split into two doses that were applied as basal dose and with first irrigation through side placement method. For all experimental units, the agronomic practices were implemented uniformly except those under investigation.

Data recordings of response variables

The stand density at harvest was calculated by counting total number of plants in one-meter length of three randomly selected rows in each plot and then their average was calculated. In addition, plant height was measured from the base of plants to the tip of the top most leaf using tailor's measuring tape by randomly selecting ten plants from each experimental plot and then those values were averaged. Moreover, leaf area index (LAI) was calculated by following Eq. (1) as described by Iqbal et al. (2016).

$$LAI = \frac{\text{Crop leaf area (m}^2\text{)}}{\text{Land area (m}^2\text{)}} \quad (1)$$

The fresh weight of cowpea plants from each experimental unit was recorded by using a digital balance and thereafter their average was computed. In order to determine the dry weight per plant, ten randomly selected plants were per plot were chopped with the help of a manual fodder cutter. Thereafter, a representative sample (100 g) was taken in a muslin cloth from the chopped plant material and was mixed thoroughly. Then, these

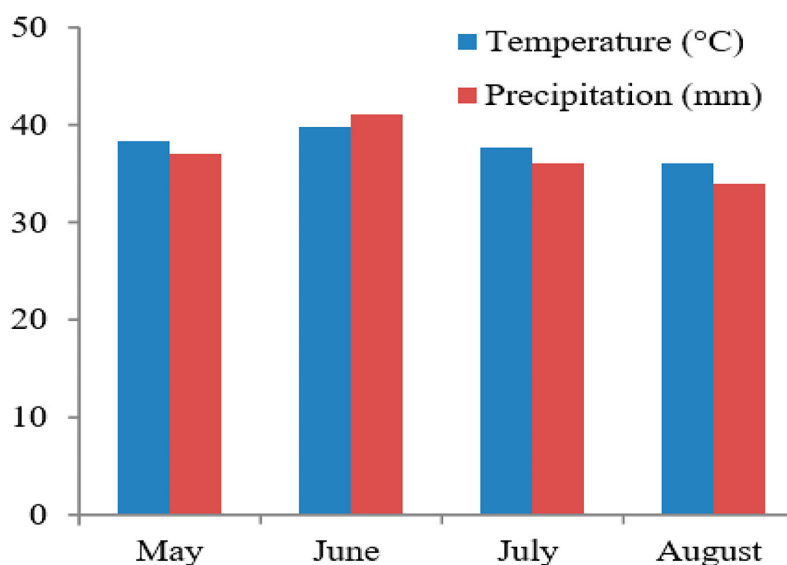


Figure 1. The meteorological characteristics (temperature and precipitation) of experimental site (Faisalabad, Punjab, Pakistan) during two consecutive crop growing seasons, (2 years mean data).

samples were oven dried (80 °C) until a constant dry weight was achieved. For estimating total biomass productivity per unit land area, cowpea plants in each experimental unit were harvested and weighed immediately using a tripod supported spring balance and thereafter it was converted into tons per hectare. The dry matter of cowpea under varying fertilization regimes was estimated by following the Eq. (2) as reported by Iqbal et al. (2016).

$$\text{Dry matter (\%)} = \frac{\text{Dry weight}}{\text{Fresh weight}} \times 100 \quad (2)$$

The *dry matter* percentage was thereafter used for converting the fresh biomass yield into dry matter yield per plot ($\text{t} \cdot \text{ha}^{-1}$). Moreover, nutritional quality attributes of forage cowpea including crude protein, crude fibre, ether extractable fat and total ash were determined by following the standard procedures described by AOAC (1990).

Statistical analyses

The recorded data were subjected to Barlett's test for determining the significance of year's impact on response variables of irrigated cowpea under investigation as suggested by Iqbal et al. (2021). Thereafter, Fisher's analysis of variance (ANOVA) technique of one-way type was employed to sort-out the overall significance of treatments using statistical package of IBM-SPSS (Statistical Package for the Social Sciences) Statistics 20, which were then subjected to the least significant difference (LSD) test at the probability level of 5% for assessing the significance among treatment means.

RESULTS AND DISCUSSION

Plant population at harvest

The year effect on plant population (PP) of cowpea was non-significant (Table 1). The results revealed that during first year of the trial, although the fertilizer treatments increased the PP (m^{-2}) significantly over check but the differences among them were non-significant showing the PP range of 17–18.5 m^{-2} against the lowest PP (14) in check plots. During the subsequent year of the trial, pronounced impact of fertilization regimes was evident on PP of cowpea as 150-100-100 kg NPK ha^{-1} surpassed rest of treatments by recording the maximum PP while it was followed by 150-100-0 kg NPK ha^{-1} . Overall, all fertilization regimes recorded significantly higher

PP of cowpea than control treatment. It might be inferred that during the second year of the trial, higher nutrients availability improved the microclimate which pronouncedly increased the PP of cowpea by restricting plants from going out of competition owing to limited nutrients availability under semi-arid conditions. These findings are in line with those of Ahlawat and Saraf (2009), who opined that mineral fertilizers especially phosphorous remained effective in developing robust roots network of crop plants which led to significantly lesser lodging and ultimately higher plant count was recorded at the time of harvesting.

Plant height

The year effect on plant height (PH) of cowpea was significant and the PH was greater (161.4 cm) during the second year than the preceding year (151.8 cm). Fertilizer application increased cowpea PH significantly over zero fertilizer treatment during both years of the trial (Table 1). During the first year, the maximum PH (158 cm) was recorded for experimental units receiving 150-100-100 kg NPK ha^{-1} and it was followed by 150-100-0 kg NPK ha^{-1} (155 cm) which was significantly greater than PH recorded by 150 kg N ha^{-1} (151 cm). Overall, all fertilization regimes recorded significantly taller plants of cowpea compared to the minimum PH (143 cm) of cowpea recorded in check plots. It might be inferred that different fertilization regimes influenced N-fixing capacity of cowpea plants especially nitrogen and phosphorus availability in abundance could have boosted the photosynthesis process and higher partition of assimilated could have triggered the cell division and ultimately plant height was increased significantly. Besides N, other primary nutrients (P and K) also hold potential to trigger nodulation and also assisted cowpea plants in overcoming the moisture deficit conditions by improving plant growth especially plant height (Sangakkara et al., 2001; Bongo and Pietr, 2019). Moreover, Ali et al. (2019) inferred that higher N doses resulted in greater light interception which triggered the photosynthesis process and ultimately plant vegetative growth was substantially improved.

Leaf area index

As per recorded findings, the year impact on the leaf area index (LAI) of cowpea was non-significant (Table 1).

Table 1. Effect of different fertilization regimes on plant population, plant height and leaf area index of cowpea grown under semi-arid conditions

NPK application rates (kg ha ⁻¹)	Plant population (m ⁻²)			Plant height (cm)			Leaf area index		
	Year 1	Year 2	Mean	Year 1	Year 2	Mean	Year 1	Year 2	Mean
F ₀ =0-0-0	16	12 d	14.0 B	143 d	151 c	149.5 D	1.52 b	1.18 d	1.35 B
F ₁ =150-0-0	21	16 c	18.5 A	151 c	162 b	156.5 C	2.12 a	1.77 c	1.95 A
F ₂ =150-100-0	17	17 b	17.0 A	155 b	166 a	160.5 B	1.69 ab	2.02 b	1.86 A
F ₃ =150-100-100	17	18 a	17.5 A	158 a	166 a	161.5 A	1.70 ab	2.16 a	1.93 A
LSD means(0.05)	NS	0.30	2.1	0.69	0.471	0.390	0.46	0.07	0.26
Year mean	17.7	15.5	–	151.8	161.4	–	1.76	1.78	–

Note: Values having atypical letters (small letters indicate significance among year-wise data, whereas capital letters depict significance among mean data) within same column differ significantly at 5% probability level. NS indicates non-significant difference among values within same column at 5% probability level.

The LAI of cowpea varied significantly among the fertilizer treatments. Statistically similar LAI was recorded for the crop fertilized with 150-100-100, 150-100-0 and 150-0-0 kg NPK ha⁻¹ which was significantly higher than that recorded at zero fertilizer (Check). Based on recorded findings, it might be inferred that N dose was equal in all fertilization regimes (150 kg ha⁻¹) and thus non-significant impact of treatments was observed on LAI of cowpea. Similar to our findings, previously it has been reported that N played a pivotal role in boosting the vegetative growth of crop plants including leaf area growth and resultantly higher N doses triggered the LAI in forage legumes grown under semi-arid conditions. Moreover, it was also reported that soils deficient in N content produced forage crops with lesser leaf number and leaf area which ultimately led to fewer LAI compared to well-watered conditions. Similar to these results, Luo et al. (2021) noted that among mineral fertilizers, N (90 kg·ha⁻¹) remained effective in boosting the leaf area and number of leaves

per plant which ultimately led to higher canopy cover. Moreover, it was also inferred that N was the most instrumental plant nutrient required by crop plants to increase the canopy area with relation to land area which assisted in improving the capture of photosynthetically active radiation (PAR) and the net result was significant increase in photosynthesis rate and partitioning of assimilates from leaves towards plants sinks.

Plant fresh and dry weights

The recorded findings revealed that the year effect on fresh weight (FW) per m² of cowpea was non significant. There was a significant variation in FW of cowpea among different fertilizer treatments during both years (Table 2).

During the first year of trial, significantly higher FW (1651 g) was recorded by 150-100-0 kg NPK ha⁻¹ which was at par with fertilization regimes of 150-100-100 kg NPK ha⁻¹ (1368 g) and 150-100-0 kg NPK ha⁻¹ (1364 g). Contrarily,

Table 2. Effect of different fertilization regimes on fresh and dry weights, green forage yield and dry matter yield of cowpea grown under semi-arid conditions

NPK application rates (kg·ha ⁻¹)	Fresh weight per m ² (g)			Dry weight per m ² (g)			Green forage yield (t·ha ⁻¹)			Dry matter yield (t·ha ⁻¹)		
	Year 1	Year 2	Mean	Year 1	Year 2	Mean	Year 1	Year-2	Mean	Year 1	Year 2	Mean
F ₀ =0-0-0	1077 b	848 d	962 B	138.9 b	109.6 d	124.3 B	6.86 d	7.01 c	6.93 D	1.38 b	1.09 d	1.24 B
F ₁ =150-0-0	1651 a	1291 c	1471 A	196.6 a	170.1 c	183.1 A	9.48 c	10.69 b	10.08 C	2.16 a	1.70 c	1.93 A
F ₂ =150-100-0	1364 ab	1491 b	1428 A	177.5 ab	200.8 b	189.1 A	11.30 b	11.38 ab	11.34 B	1.77 ab	2.00 b	1.89 A
F ₃ =150-100-100	1368 ab	1580 a	1474 A	184.9 ab	212.5 a	198.7 A	12.08 a	11.94 a	12.01 A	1.84 ab	2.12 a	1.98 A
LSD values (0.05)	361.7	28.2	174.0	47.6	3.78	23.0	0.071	0.975	0.454	0.477	0.050	0.222
Year mean	1365	1252	–	179.5	173.2	–	9.93	10.25	–	NS	1.73	–

Note: Values having atypical letters (small letters indicate significance among year-wise data, whereas capital letters depict significance among mean data) within same column differ significantly at 5% probability level. NS indicates non-significant difference among values within the same column at 5% probability level.

the minimum FW per m² was recorded in check plots (1077 g). However, in the following year, the maximum FW was recorded by 150-100-100 kg NPK ha⁻¹ and it was followed by 150-100-0 treated plot which was significantly higher than 150-0-0 treatment. Two years' average data also showed similar trend as that of first year pertaining to FW of cowpea plants. Similar to FW of cowpea grown under different fertilization regimes, there was a non-significant effect of year on dry weight (DW) per m² of cowpea. However, the mineral fertilization regimes had varying impact on the DW per m² of cowpea over check during both years (Table 2). During the first year, the maximum DW per m² was recorded by all fertilizer treatments compared to check plots and these were statistically similar to each other. Contrastingly, application of 150-100-100 kg NPK ha⁻¹ remained unmatched by recording the maximum dry biomass (m²) in the following year of study, followed by 150-100-0 kg NPK ha⁻¹ treated plots, which in turn remained higher than control treatment. The minimum DW (m²) was recorded in check plots. Two years mean data showed similar trend as that of first year. Based on recorded findings, it might be inferred that fertilization regime of 150-100-100 kg·ha⁻¹ of NPK was instrumental in boosting plant height and leaf area which led to higher fresh and dry weights of cowpea plants. These findings are in agreement with the results reported by Iqbal et al. (2016) and Luo et al. (2021), who noted that plant height and canopy cover were significantly improved by appropriate agronomic management particularly optimal use of N fertilizer was effective in increasing the plants vegetative growth traits.

Green forage yield

As revealed by recorded findings, the year effect on green forage yield (GFY) of cowpea was non-significant, however, significant differences among the fertilizer treatments were recorded (Table 2). Cowpea crop supplied with the maximum doses of N-P-K (150-100-100 kg NPK ha⁻¹) fertilizers produced the maximum GFY (12.01 t·ha⁻¹) and it was followed by the fertilization regime of 150-100-0 kg NPK ha⁻¹ (11.34 t·ha⁻¹), however, these treatments performed significantly higher than GFY recorded by 150 kg N ha⁻¹ (10.08 t·ha⁻¹) treatment. Contrastingly, the minimum GFY (6.93 t·ha⁻¹) was recorded in control experimental units. The results further indicated

that integrated application of N-P-K played a pronounced role in increasing the GFY of cowpea. It might be inferred that 150-100-100 kg·ha⁻¹ NPK triggered the growth attributes (plant height, leaf area index, plants fresh and dry weight), which led to improved GFY. Similarly, it has been reported that cowpea productivity was doubled when rhizobia inoculation was coupled with 26 kg P ha⁻¹. It might be inferred that K could have triggered the growth of cowpea plants by enhancing N utilization through robust nodulation in the roots of legume plants (Boddey et al., 2017). Moreover, Kizilgeci et al. (2021) opined that optimized application of N fertilizer improved N utilization and NUE (nutrient use efficiency) remained instrumental in enhancing the plant growth parameters which led to increased biomass production on sustainable basis.

Dry matter yield

As the year effect on dry matter yield (DMY) of cowpea remained non-significant, hence the 2-years average data was taken into account to interpret the impact of employed treatments on DMY (Table 2). The recorded data revealed that DMY varied significantly in response to mineral fertilization regimes under investigation. Although application of fertilizer increased the DMY significantly over check but the difference among employed treatments was non-significant. The DMY varied from 1.89 to 1.98 t·ha⁻¹ among the fertilizer treatments against significantly the lowest (1.24 t·ha⁻¹) DMY recorded for control treatment. Similar to these findings, Al-Furtuse et al. (2019) opined that potassium fertilizer up to 129 kg·ha⁻¹ surpassed rest of doses (43 and 86 kg·ha⁻¹) by triggering the yield attributes and yield of cowpea. Moreover, it might be inferred that N has been reported as the most crucial nutrient involved in vegetative growth of crop plants whereas all the fertilization regimes under investigation contained equal N doses and thus DMY of cowpea was not significantly influenced by fertilization regimes. In contrast to our findings, Sadiq et al. (2023) opined that optimized doses of mineral fertilizers especially N applied in conjunction with rhizobium inoculation remained effective in boosting biological N fixation which increased photosynthesis rate and ultimately higher partition of assimilates increased the growth attributes and productivity of legumes. Thus, these contradictory findings

might be attributed to atypical legume cultivars, soil fertility status, agro-climatic conditions, agronomic management etc.

Crude protein

In contrast to most of vegetative growth traits, the year effect on crude protein (CP) content of cowpea forage was significant (Table 3). However, CP content (18.75%) on an average was higher during the second year than the first year (17.04%) of trial. The CP content of forage cowpea was increased to a significant level with the application of fertilizers over check during both years of field investigation.

During the first year, the highest CP content (18.59%) was recorded for the crop supplied with 150-100-100 kg NPK ha⁻¹ and it was followed by fertilization regime of 150-100-0 kg NPK ha⁻¹ by recording the CP of 17.36% which was at par with 150 kg N ha⁻¹ (17.25%). Contrarily, the minimum CP content (14.97%) was recorded in check plots. Similar trend was noted during the second year of study showing a progressive increase in CP content with the application of N, NP and NPK against the check. It might be inferred that co-application of NPK fertilization remained effective in boosting biosynthesis of amino acids which led to increased content of CP in cowpea grown under varying pedo-climatic conditions (Iqbal et al., 2016). These results are in contradiction with Hill et al. (2017), who recorded no significant impact of P fertilizer (45 kg·ha⁻¹ P) on nutritional quality of cowpea and it might be inferred that this contradictory results could be owing to non-responsive cultivar of cowpea. Overall, CP of forage improved the nutritional value owing to its role in providing essential amino acids and improving the immune functions of dairy animals.

Crude fibre

According to recorded data, the year effect on crude fibre (CF) percentage of forage cowpea was significant (Table 3). The CF percentage of forage cowpea was higher (29.5%) during the second year of trial than the CF (26.54%) recorded during the previous year. The CF percentage did not vary significantly among the fertilizer treatments including check during the first year (which on average varied from 26.45 to 26.62% Table 3). Contrastingly, during the second year, there were significant differences in CF content demonstrated by forage cowpea in response to fertilization regimes. The highest CF (26.60%) was recorded for the crop supplied with 150-100-100 kg NPK ha⁻¹ and it was followed by fertilization regime of 150-100-0 kg NPK ha⁻¹ (29.52%) which was at par with 150 kg N ha⁻¹. However, the control treatment remained superior by recording the lowest CF content in comparison to all fertilizers treatments under investigation. It has been reported that higher CF content in ruminants feed deteriorated its quality which compromised the dairy animal's productivity in terms of milk and meat production over time (Iqbal et al. 2019). However, our findings are in contradiction with those of Ndiaye et al. (2023), who opined that increase in protein concentration led to a proportionate decrease in fiber content. Thus, it might be interpreted that optimized doses of NPK fertilizers triggered the growth of cowpea plants especially plant height (stem length) which resulted in higher concentration of fiber content. Moreover, the minimum CF content recorded in control treatment could be attributed to dwarf plants produced in the absence of fertilizers because stem length contributed the major portion of fiber content in cowpea (Iqbal et al., 2021).

Table 3. Effect of different fertilization regimes on qualitative parameters of cowpea grown under semi-arid conditions

NPK application rates (kg·ha ⁻¹)	Crude protein (%)			Crude fibre (%)			Ether extractable fat (%)			Total ash (%)		
	Year 1	Year 2	Mean	Year 1	Year 2	Mean	Year 1	Year 2	Mean	Year 1	Year 2	Mean
F ₀ =0-0-0	14.97 c	16.21 d	15.59 D	26.45	29.36 c	27.90	1.80 c	1.81 d	1.80 C	10.91 b	11.87 d	11.39 C
F ₁ =150-0-0	17.25 b	19.10 c	18.18 C	26.59	29.51 b	28.05	1.79 d	1.82 c	1.80 C	10.86 c	11.96 b	11.40 B
F ₂ =150-100-0	17.36 b	19.63 b	18.50 B	26.62	29.52 b	28.07	1.86 b	1.85 b	1.85 B	10.73 d	12.10 a	11.41 AB
F ₃ =150-100-100	18.59 a	20.04 a	19.32 A	26.50	29.60 a	28.05	1.87 a	1.88 a	1.87 A	10.93 a	11.90 c	11.42 A
LSD means (0.05)	0.242	0.385	0.212	NS	0.071	NS	0.005	0.009	0.005	0.009	0.009	0.006
Year mean	17.04	18.75	–	26.54	29.50	–	1.83	1.84	–	10.85	11.96	–

Note: Values having atypical letters (small letters indicate significance among year-wise data, whereas capital letters depict significance among mean data) within same column differ significantly at 5% probability level. NS indicates non-significant difference among values within the same column at 5% probability level.

Ether extractable fat

The recorded findings revealed that ether extractable (EEF) percentage of cowpea was significantly influenced by the year effect and it remained relatively higher (1.84%) during the second year of field trial than the preceding year (1.83%) (Table 3). During both years of field investigation, the EEF varied significantly among different fertilizer treatments. During the first year, the crop supplied with 150-100-100 kg NPK ha⁻¹ exhibited significantly higher EEF content (1.87%) than rest of the treatments and it was followed by the fertilization regime of 150-100-0 kg·ha⁻¹ NPK (1.86%), which was significantly higher than EEF (1.80%) exhibited by the control treatment. Contrastingly, the minimum EEF content (1.79%) was recorded by 150 kg N ha⁻¹. Interestingly, similar trend was noted during the second year but the minimum EEF percentage was recorded by cowpea plants in control treatment (1.81%) preceded by the fertilization regime of 150 kg N ha⁻¹ (1.82%). Previously, it has been inferred that optimal concentration of EEF in forage played several vital roles in animal's body such as improved rumen microbial activity, facilitated fiber digestion, provided better body insulation to dairy animals along with providing an instant source of energy and improved the palatability of the forage (Iqbal et al., 2021). These findings are in agreement with those of Iqbal et al. (2019), who reported that agronomic management (sowing technique and plant nutrition optimization) hold potential to increase the EEF content which improved the nutritional value of forage legumes in comparison to cereal forage crops (sorghum and maize).

Total ash (%)

As per recorded findings, the impact of year remained significant for total ash (TA) content of forage cowpea that was higher (11.96%) during the second year than the first year (10.85%) of field trials. It became evident from the data presented in Table 3 that TA contents of forage cowpea varied significantly in response to mineral fertilization regimes during both years of study. During the first year, the maximum TA content was recorded by cowpea plants receiving 150-100-100 kg ha⁻¹ NPK and it was followed by TA (10.91%) noted for control plots which was significantly higher than the experimental plots supplied with 150 kg N ha⁻¹ (10.86%). In contrast,

the minimum TA content (10.73%) was noted for cowpea plants that were given the dose of 150-100-0 kg·ha⁻¹ NPK. However, during the second year of study, the maximum TA content was exhibited by the fertilization regime of 150-100-0 kg ha⁻¹ NPK and the minimum corresponding value was recorded in control plots. Previously it has been reported that total ash content represented the mineral constituents of the feedstock and optimum concentration of TA boosted the metabolic functions of dairy animals leading to enhanced milk productivity (Iqbal et al., 2019; Ndiaye et al., 2023). However, it was also inferred that excessive TA content might indicate soil contamination which deteriorated the nutritional value of forage, whereas appropriately balanced concentration of TA in forage performed numerous functions in dairy animal's body particularly formation and strengthening of skeletal and bones, electrolyte balance, activation of key enzymes, proper functioning of immune system along with body organs and tissues (Iqbal et al., 2021).

CONCLUSIONS

The recorded findings corroborated with the postulated hypothesis as fertilization regimes had significant influence on growth attributes, biomass productivity and nutritional value of forage cowpea sown under irrigated conditions of semi-arid climate. As per recorded data, the fertilization regime of 150-100-100 kg·ha⁻¹ NPK remained superior to rest of treatments by recording significantly higher plant population, plant height and leaf area index which led to maximum biomass productivity. The same fertilization regimes also remained instrumental in enhancing the nutritional quality of forage cowpea especially crude protein and total ash contents. The underlying reasons could be attributed to synergistic impacts imparted by integrated use of fertilizers which led to improved vegetative growth, biomass productivity and nutritive value of forage cowpea. Thus, based on results of this multi-year field trial, co-application of NPK fertilizers using the dose of 150-100-100 kg ha⁻¹ might be recommended to cowpea growers for boosting the biomass production and nutritional quality in semi-arid regions of Pakistan and other areas of the world having similar agro-climatic and soil conditions. However, these findings are limited in scope because these trials were conducted with application of frequent

irrigations, whereas cowpea plants might respond differently in terms of biomass productivity and nutritional quality to these fertilization regimes in the rainfed regions of semi-arid climate. Moreover, future research must focus on assessing the impact of NPK fertilization regimes on biological N fixation capacity of forage legumes along with amount of green-house gaseous emissions from varying fertilization regimes in order to put a curb on fertilizers related environmental pollution and to ensure the ecological sustainability under changing climate scenarios.

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