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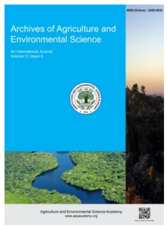

ORIGINAL RESEARCH ARTICLE

# Nutrient management with cow dung and chemical fertilizers enhances leaf yield and gel constituents in *Aloe vera*

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**ABSTRACT**

Since ancient times, *Aloe vera* has been used extensively, including in the cosmetics and food businesses. Commercial cultivation of *A. vera* is scarce due to lack of information. Therefore, a field experiment was conducted to examine the integrated effect of inorganic fertilizer (IF) and cow dung (CD) on the growth, yield, and nutritional composition of *A. vera*. A randomized complete block design (RCBD) with four replications was used for the experiment having total nine treatment combinations of IF and CD viz., IF 0% + CD 0%, IF 100% + CD 0%, IF 75% + CD 25%, IF 50% + CD 50%, IF 40% + CD 60%, IF 30% + CD 70%, IF 20% + CD 80%, IF 10% + CD 90%, and IF 0% + CD 100%. Varying combinations of IF and CD significantly influenced the studied parameters. On average, applications of 30% IF and 70% CD enhanced the leaf yield by 37%, gel yield by 31% and nutritional quality by 28% compared to control. The post-harvest soil characteristics, including the percentage of nitrogen and organic matter, soil pH, exchangeable potassium, available phosphorus, and available sulfur, were found to increase with the higher application of cow dung. Applying both 30% IF and 70% CD showed a substantial increase in growth, yield, gel nutritional quality, and post-harvest soil characteristics compared to other treatments including control. Therefore, application of 30% IF with 70% CD could be a best strategy for obtaining improved growth, yield, and nutritional quality of *A. vera*.



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## INTRODUCTION

In Bangladesh, soil fertility has declined significantly due to the increased application of inorganic fertilizers and higher cropping intensities in response to rising food demands, resulting in the vigorous depletion of soil nutrients (Uddin *et al.*, 2022). Nitrogen, phosphorus (P), and potassium (K) deficiencies affect almost the total arable land of Bangladesh (Huq & Shoaib, 2013). Soil organic matter content is also low in most soils, which is below the threshold. The areas with high and very high organic matter content were 5.28% and 1.21%, respectively, in 2010, which changed to 4.58% and 1.40% in 2020 (Hasan *et al.*, 2020). In addition, tillage operations and other favorable environmental factors are forcefully disturbing soils, which in turn increases microbial activity, speeds up the nutrient release by breakdown of organic matter (Aćin *et al.*, 2023). Organic agriculture is, in fact, a low-input, sustainable agricultural production system that fosters the environmentally, socially, and economically sound production of food, fiber, timber, and other agricultural products (Reganold & Wachter, 2016). Organic manure like cow dung, poultry manure, farmyard manure, bio-slurry, sewage sludge, vermicompost, and green manure etc. can improve the physical, chemical, and biological properties of soil, thus improving soil fertility and increasing the availability of deficient nutrients (Liu *et al.*, 2024; Yu *et al.*, 2025). On the other hand, inorganic fertilizers containing a high concentration of nutrients like nitrogen (N), P, K, and sulfur (S) play vital roles that are required for quick plant growth when they can be applied in a balanced way. Owing to their advantages, inorganic fertilizers are responsible for soil degradation, nutrient losses, and several environmental issues (Pahalvi *et al.*, 2021; Barłóg, 2023). So, maintaining soil health and crop growth and yield requires an improved and balanced nutrient supply through the integrated management of nutrients to minimize fertilizer loss and optimize fertilizer use efficiency (Barłóg, 2023).

In recent years, *Aloe vera* has gained significant popularity in Bangladesh due to its numerous beneficial, medicinal and cosmetic applications. This plant belongs to the Liliaceae family, the genus *Aloe*, and is a large plant class of xerophytes. It is grown in a variety of nations across the world (Sultana *et al.*, 2021). It exhibits a broad spectrum of applications such as immunomodulatory effects, wound and burn healing, prophylaxis against radiation-induced leucopenia, hypoglycemic activity, anticancer properties, anti-diabetic effects, anti-ulcer, antifungal, antibacterial, anti-inflammatory activities, and inhibits prostaglandin synthesis through anthraquinone-type compounds and suppresses the acquired immune deficiency syndrome (AIDS) virus via acemannan (Bai *et al.*, 2023; Darzi *et al.*, 2021; Sánchez *et al.*, 2020; Maan *et al.*, 2018). The leaves of *A. vera* include many minerals, anthraquinones, emodin, salicylic acid, and various enzymes in addition to lipids, carbohydrates, proteins, and 18 essential amino acids. Among the secondary metabolites, there are glucomannan, alkaloids, lectins, saponins, tannins, phenolic compounds, and lignin (Usman *et al.*, 2020; Sánchez *et al.*, 2020). Bangladesh's herbal medicine business is valued at BDT 300 crore annually, with monthly usage topping 20 tons, and one-fourth of medications are obtained from medicinal plants. The pharmaceutical sector in Bangladesh is primarily characterized by branded generic drugs, which account for over 80% of local production. The top ten pharmaceutical firms collectively comprise 70% of the domestic market share (Rashid, 2023). If this plant can be cultivated systematically on a larger scale, the country can save substantial money on imports. In this context, the integrated use of cow dung and inorganic fertilizers would be advantageous for the production of high-quality *A. vera* gel, since this organic amendment is more accessible in our nation. Moreover, the average value of organic carbon content in cow dung is much more than that in some other organic supplements (Hoque *et al.*, 2022), and the organic acids released during decomposition have a solubilizing effect on native soil nutrients, which in turn leads to improved growth and qualities (Ahmad *et al.*, 2016).

However, no research work has been published in Bangladesh on integrated nutrient management practices, particularly inorganic fertilizer and cow dung requirements of *A. vera* with respect to nutrition and soil fertility. So, it is necessary to report on integrated nutrient management practices using cow dung manure and inorganic fertilizers for *A. vera* cultivation in the agroclimatic zone of Bangladesh. Keeping the above facts in mind, the present study was conducted to determine the effect of integrated nutrient management practices on the growth, yield, nutrient, and biochemical compounds of A. vera leaf and leaf gel, along with post-harvest soil properties.

## MATERIALS AND METHODS

### Geographical location and climatic conditions

Geographically, the experimental site was located at 24.4124° N, Latitude and 88.9756° E Longitude at an elevation of 23.25 meters above sea level. The site belonged to the Non-calcareous Dark Grey Floodplain soil under the Agro-Ecological Zone of Old Brahmaputra Floodplain (AEZ-11). The climate of the experimental area is under the sub-tropical climatic zone, which is characterized by moderate to high temperature, heavy rainfall, high humidity, and relatively long days during Kharif (April to September) and scanty rainfall, low humidity, low temperature, and short-day period during *Rabi* season (October to March). The general soil type of this area is non-calcareous, and the cropping pattern is rice-rice.

### Experimental design, treatments, and data collection

Twelve-month-old *A. vera* seedlings were collected from Oshudhi village, Natore sadar, Natore, and used for the experiments. Randomized complete block design (RCBD) was used with three replications. The treatment details are presented in Table 1. The standard dose (10 t ha$^{-1}$) for *A. vera* was used to calculate the amount of cow dung for the integrated application of the treatments. Among the inorganic fertilizers, nitrogen was calculated at a rate of 200 kg ha$^{-1}$ from urea, which was applied in three installments: during land preparation, and at 60 and 120 days after transplanting (DAT). Other fertilizers, including TSP, MoP, gypsum, boric acid, and zinc sulfate, were applied as basal doses at rates of 80, 120, 40, 1, and 3 kg ha$^{-1}$ for phosphorus, potassium, sulfur, boron, and zinc, respectively. The land was adequately prepared through four cross ploughings, soil clog breakdown, and laddering. Soil loosening, hand weeding, and other intercultural operations were conducted as necessary. The *A. vera* leaf was harvested at 180 DAT. The leaf height of each plant was measured in centimeters (cm) from the ground to the leaf apex at 30, 60, 90, 120, 150 DAT, and at harvest. During the harvest, the total leaf number was recorded. The leaf area index was determined by dividing the total leaf area by the ground area after harvest using destructive sampling and measurement (Fang *et al.*, 2019). For each plot, a representative leaf was selected to measure area and then converted to total leaf area by considering the total leaf number in each plot. The leaf biomass yield and fresh gel weight were determined for each plot and finally expressed in t ha$^{-1}$.

**Table 1.** Treatment details of this experiment.

| Treatments symbol | Integrated doses of CD and IF |
|---|---|
| IF0CD0 | 0% CD + 0% IF |
| IF100CD0 | 0% CD +100% IF |
| IF75CD25 | 25% CD + 75% IF |
| IF50CD50 | 50% CD + 50% IF |
| IF40CD60 | 60% CD + 40% IF |
| IF30CD70 | 70% CD + 30% IF |
| IF20CD80 | 80% CD + 20% IF |
| IF10CD90 | 90% CD + 10% IF |
| IF0CD100 | 100% CD + 0% IF |

CD= Cow dung, IF= Inorganic Fertilizer

### Nutrient extraction and chemical analysis of leaf, gel, and post-harvest soil

For the extraction of leaf and leaf gel nutrients, oven-dried samples were subjected to the wet oxidation method with a di-acid mixture ($HNO_3$: $HClO_4$) in a 2:1 ratio using Jackson's methodology (Jackson, 1973). The post-harvest soil exchangeable K using 1N ammonium acetate ($CH_3COONH_4$) solution at a pH of 7.0, available P using 0.05 M $NaHCO_3$ solution at a pH of 8.5 (modified Olsen's method), and S using 0.01 M Calcium bi phosphate [($Ca(H_2PO_4)_2$] solution was extracted following established procedure (Page *et al.*, 1982) at the laboratories of the departments of Agricultural Chemistry, Professor Muhammed Hussain Central Laboratory (PMHCL), BAU, Mymensingh. The total N content of leaf, gel, and soil was determined by the semi-micro-Kjeldahl method (Page *et al.*, 1982) following the detail of Chowdhury *et al.* (2020) and calculated by the standard formula:

$$\% N = (T-B) \times N \times 1.4/W \quad (1)$$

Where, T = Titre value for sample (mL), B = Titre value for blank (mL), N = Normality of $H_2SO_4$ solution (0.01 N), W= Sample weight (g)

The extracted P of the plant and soil samples were determined calorimetrically using stannous chloride as a reductant, following the procedure stated by Jackson (1973), using a spectrophotometer (Model: TG-60 U) at 660 nm wavelength. Sulphur was estimated by the turbidimetric method (Model: TG-60 U) at a wavelength of 425 nm (Tandon, 2005). Potassium of plant and soil samples was determined by flame emission spectrophotometer (Model: JENWAY-PFP7) at 589 nm, as suggested by Ghosh *et al.* (1983). Calcium and magnesium of leaf and gel samples were determined by the complexometric method of titration using 0.01M $Na_2EDTA$ solution (Page *et al.*, 1982). The determination of soil-extracted Zn was done by using an atomic absorption spectrophotometer (AAS) (Shimadzo, AA7000, Japan). Soil pH was determined by using a reference pH meter using a soil and water ratio of 1:5 (WP 80 Reference pH Meter). Soil organic carbon (OC) was determined using the wet oxidation method (Black, 1958). The soil samples were digested using a 1N $K_2Cr_2O_7$ solution in the presence of $H_2SO_4$ and $H_3PO_4$. The unused $K_2Cr_2O_7$ was determined by titrating against a 1N $FeSO_4$ solution. Finally, OC content was determined by using the data. Then the OC was converted into soil organic matter by multiplying the conversion factor 1.72.

### Statistical analysis

Statistical data analysis was conducted using Minitab 2021 Version 21.0 (Minitab Inc., USA). We computed the averages for each treatment and performed an analysis of variance (ANOVA) for each variable by Tukey's range test to determine the presence of differences among the treatments. The statistical analysis of this research was done by following the methods established by Gomez & Gomez (1984).

## RESULTS AND DISCUSSION

### Plant height, leaf number, LAI, and leaf and gel yield of *A. vera*

The plant height of *A. vera* was significantly affected by different doses of inorganic fertilizer and cow dung (Figure 1) at 30, 60, 90, 120, and 150 DAT and harvesting time. Throughout the growth stages up to the final harvest, applying IF and CD in varied combinations consistently increased the height of the *A. vera* plants, irrespective of the treatments used. At 30 DAT, maximum plant height (16.60 cm) was measured when 30% inorganic fertilizer (IF) and 70% cow dung (CD) was applied, and the lowest was at IF0CD0 (12.37 cm). At 60 DAT, IF30CD70 performed best (20.61 cm), and IF0CD0 performed least (14.01 cm). At 90, 120, 150, and harvesting time, IF30CD70 always showed the highest plant height by 25.88, 32.94, 36.90, and 41.35 cm, respectively. At 120, 150 DAT, and harvesting time variation was maximum, and among them, harvesting time showed the maximum variation with a considerable difference. The gain percentage of the best treatment (IF30CD70) over control (IF0CD0) at the maximum variation stage was about 43.39%. The data showed that IF30CD70 was the best treatment followed by IF20CD80, IF100CD0, IF10CD90, IF75CD25, IF40CD60, IF50CD50, IF0CD100 and IF0CD0 treatments. Leaf number plant$^{-1}$ and LAI showed a significant difference with the addition of IF and CD (Table 2).

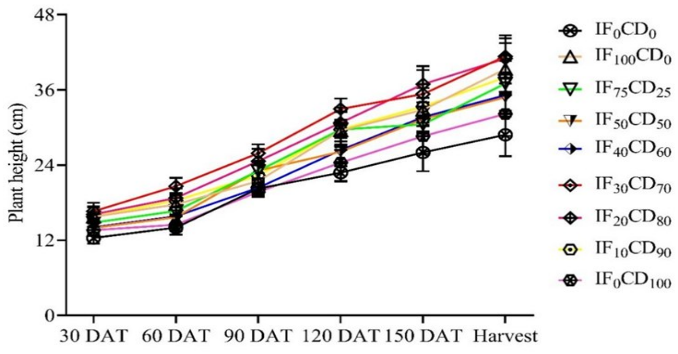


**Figure 1.** *The effect of integrated nutrient management practices on plant height at different growing stages of A. vera.*

**Table 2.** The effect of integrated nutrient management practices on the growth and yield of *A. vera*.

| Treatment | No. of leaf plant$^{-1}$ | LAI ($cm^2$) | Leaf yield (t $ha^{-1}$) | Gel yield (t $ha^{-1}$) |
|---|---|---|---|---|
| IF0CD0 | 5.00±0.58d | 171.99±6.68d | 24.00±3.61c | 10.73±0.77c |
| IF100CD0 | 11.67±0.88ab | 338.03±5.40a | 49.67±3.84ab | 22.61±2.11ab |
| IF75CD25 | 8.58±0.42bcd | 276.87±26.89abc | 42.93±3.72abc | 19.61±1.21ab |
| IF50CD50 | 7.08±1.02cd | 255.74±10.34bc | 37.22±3.65abc | 16.91±1.51bc |
| IF40CD60 | 7.67±0.68cd | 257.17±7.43bc | 40.67±5.55abc | 18.94±1.11ab |
| IF30CD70 | 14.00±0.58a | 353.70±17.29a | 54.27±3.88a | 25.07±1.04a |
| IF20CD80 | 13.00±0.58a | 343.88±15.20a | 52.93±4.78ab | 24.07±1.55a |
| IF10CD90 | 10.17±1.36abc | 298.40±9.62ab | 45.60±3.77ab | 21.44±1.80ab |
| IF0CD100 | 6.17±0.30d | 212.59±25.76cd | 34.67±1.45bc | 16.05±0.35bc |

The highest leaf number (14.00) was obtained from IF30CD70, and the lowest (5.00) was obtained from IF0CD0. The IF30CD70 was significantly different from all the treatments except IF20CD80 (13.00). Table 2 shows that IF30CD70 had the highest LAI (353.70 $cm^2$) and the lowest (171.99 $cm^2$) with the control treatment. Moreover, the treatment IF30CD70 was significantly different from the others except IF20CD80 and IF100CD0, and followed by IF10CD90, IF75CD25, IF40CD60, IF50CD50, IF0CD100, and IF0CD0, in that order. Different levels of IF and CD significantly influenced *A. vera* leaf and gel yield (Table 2). Leaf yield was maximum (54.27 t $ha^{-1}$) when 30% IF and 70% CD (IF30CD70) were applied, which was significantly different from all other treatments (Table 2). The IF0CD0 was the least performer (24.00 t $ha^{-1}$) in the case of leaf yield. On the contrary, the data in Table 2 showed the highest gel yield at IF30CD70 (25.07 t $ha^{-1}$) and the lowest at IF0CD0 (10.73 t $ha^{-1}$). The treatment IF30CD70 was significantly different from other treatments except IF20CD80 followed by IF100CD0, IF10CD90, IF75CD25, IF40CD60, IF50CD50, IF0CD100 and IF0CD0.

The application of integrated fertilizers significantly affected plant height, leaf number, LAI, and leaf and gel yield of *A. vera*. Out of all the fertilizer combinations tested, IF30CD70 had the highest values for harvestable plant height (20.61 cm), number of leaves $plant^{-1}$ (14.00), leaf area index (353.70 $cm^2$), leaf yield (54.27 t $ha^{-1}$), and gel yield (25.07 t $ha^{-1}$). Consistent with previous research (Simi & Hossain, 2023; Viyasan *et al.*, 2022; Hossain, 2022), the current investigation found that using both organic and inorganic fertilizers together improved growth and yield characteristics. Some possible explanations include the fact that it speeds up the breakdown of organic matter when mixed with IF, and where organic amendment i.e., cow dung boosts soil fertility, increases N availability, and dry matter production (Viyasan *et al.*, 2022). The combined use of both amendments also improved *A. vera* growth by supplying essential nutrients, facilitating the production of different enzymes, chlorophyll, and proteins, and transporting photosynthates, and finally leading to optimal cell growth and turgidity (Ahmad *et al.*, 2016; Simi & Hossain, 2023). This, in turn, influenced the height of the plant and the growth of its leaves. In addition, combining treatments with higher organic amendments led to increased metabolic activity, leading to higher carbohydrate and phytohormone production, which manifested as enhanced growth (Chowdhury *et al.*, 2020). Furthermore, organic fertilizers increase the organic matter in the soil, which may encourage helpful microbes in the plant root zone to decompose the fertilizers and release minerals (Priya *et al.*, 2024). In the case of using only inorganic fertilizers, the rapid release of nutrients, especially N, ensures their availability during the first stage of growth, but leaching loss, surface run-off, denitrification, and volatilization may prevent them from being accessible during the subsequent stage (Priya *et al.*, 2024). Under these conditions, the plant would have access to nutrients from cow dung and IF, although at a lower level, over a long period of time, allowing it to complete its development cycle. The application of cow dung provided plants with more readily digested nutrients and mobilized previously inaccessible nutrients by transforming them into forms that plants could use (Ahmad *et al.*, 2016; Paul *et al.*, 2023). Aloe gel production was increased due to enhanced synthesis of photosynthates and more exposure of plants to sunlight, resulting from the extended dispersion of the plants. Additionally, the higher number of leaves and leaf weight may also contribute to the increased gel yield. The IF0CD0 treatment resulted in the lowest yield of leaf gel, where no inorganic fertilizer and no cow dung were used. The higher gel content may be attributed to the enhanced absorption of root nutrients from the soil. Although the treatment IF30CD70 resulted in higher growth and yield metrics values, it was statistically identical to the treatment IF20CD80. The increased growth and yield characteristics seen in treatments IF30CD70 and IF20CD80 may be related to the application of cow dung, which releases growth substances in the rhizosphere and enhances nutrient absorption. The findings supported the observations of Gayithri *et al.* (2004), who showed that *Limonium caspia* experienced an increase in leaf area and leaf number when cultivated with both organic and inorganic fertilizations.

### Effect of integrated nutrient management practices on nutrient concentration of *A. vera*

The soil incorporation of IF and CD significantly influenced the nitrogen (N) concentration in both the leaf and gel of *A. vera* (Figure 2). For the leaf, the maximum N concentration (1.16%) was found when 100% inorganic fertilizer (IF100CD0) was used, and the lowest (0.59%) was found when no inorganic and

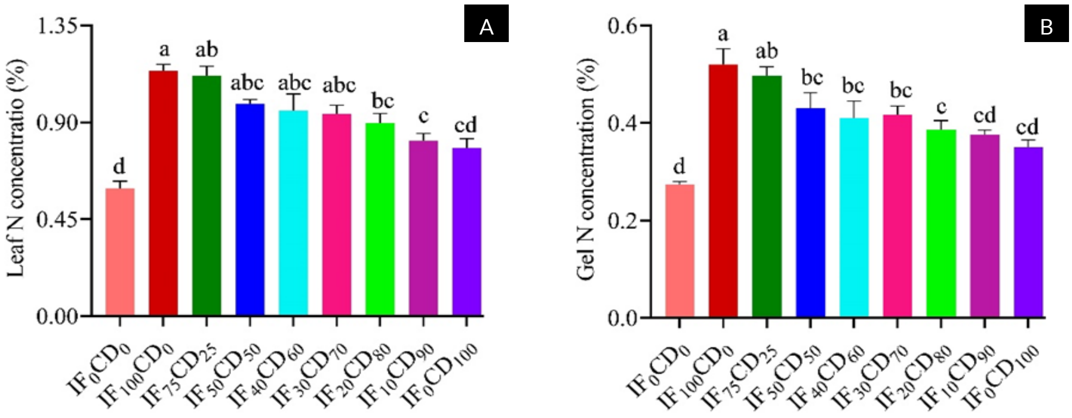


**Figure 2.** *Leaf (A) and gel (B) N concentration of A. vera under integrated nutrient management practices.*

organic fertilizer was applied (IF0CD0). The other treatments, IF75CD25, IF50CD50, IF40CD60, and IF30CD70, showed similar results with considerable differences. The highest N concentration (0.55%) was obtained for a gel with 100% IF application. However, 75% IF and 25% CD showed the second-highest N concentration (0.51%), having statistically identical results with other treatments except IF20CD80, IF10CD90, IF0CD100, and control. Phosphorus concentration in both the leaf (0.51%) and gel (1.71%) was maximum when 100% inorganic fertilizer (IF100CD0) was applied (Figure 3), whereas the control treatment (IF0CD0) showed the lowest concentration, and the other treatments showed statistically similar results with considerable effects. When 100% cow dung (IF0CD100) was applied, it showed the second highest concentration of P (1.62%) in the leaf gel of *A. vera*. The highest leaf gel K concentration (1.31%) was measured when 100% inorganic fertilizer (IF100CD0) was applied, whereas IF75CD25 treatment was responsible for the maximum leaf K (0.95%), and the lowest concentration was measured when no inorganic and organic fertilizer was applied (Figure 4 A-B). The second highest leaf K concentration (0.88%) was obtained when 50% inorganic fertilizer and 50% cow dung was applied, and the other treatment showed a considerable difference. Significant effect on the leaf and gel K concentration was found with the integrated application of IF and CD. The highest leaf (1.58%) and gel (1.23%) Ca concentration was found with 100% cow dung (IF0CD100). The application of 80% cow dung and 20% inorganic fertilizer (IF20CD80) gave the second highest Ca concentration for leaf (1.55%) and gel (1.21%), and the other treatments showed statistically similar results, while IF0CD0 had the lowest concentration of Ca (Figure 4 C-D).

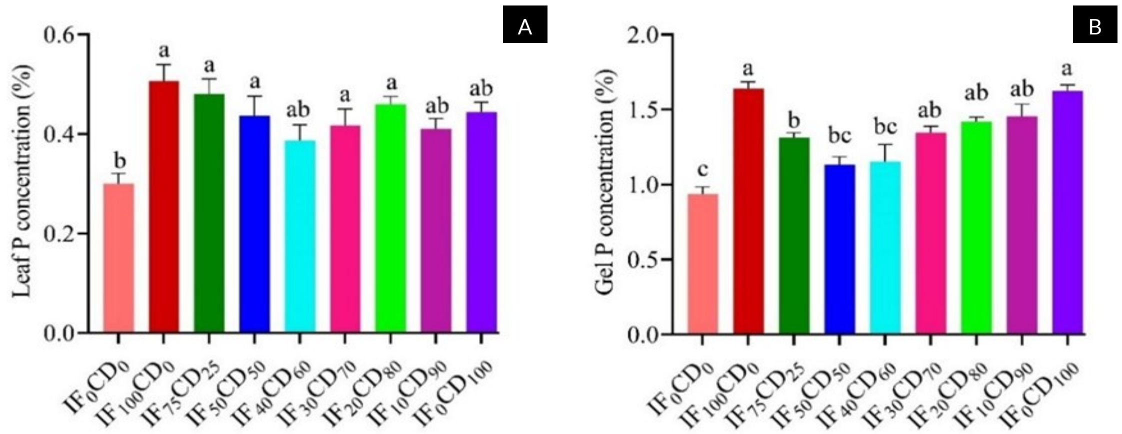


**Figure 3.** *Leaf (A) and gel (B) P concentration of A. vera under integrated nutrient management practices.*

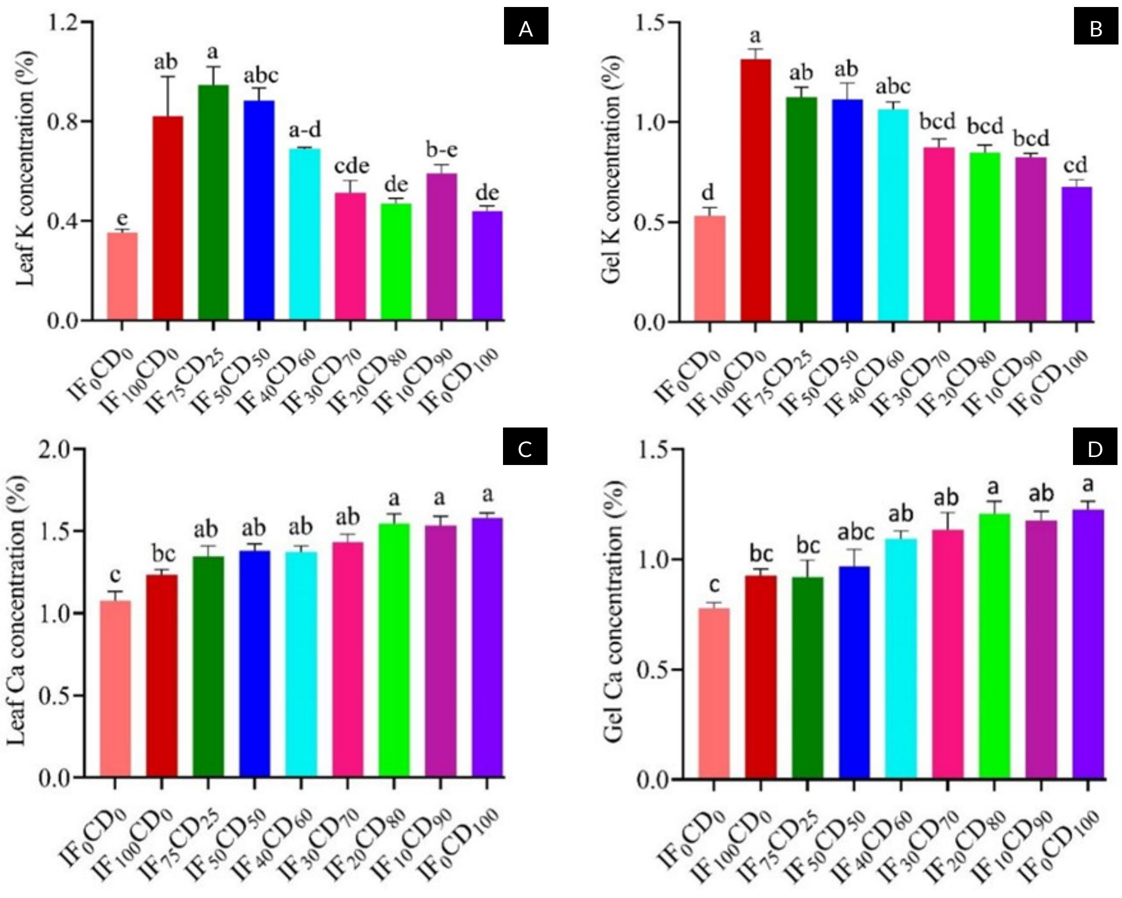


**Figure 4.** *Leaf (A), gel (B) K, leaf (C) and gel (D) Ca concentration of A. vera under integrated nutrient management practices.*

Results showed that the Mg concentration in both the leaf and gel was significantly influenced by the combined amendment of IF and CD (Figure 5 A-B). The treatment IF0CD100 showed the highest concentration (1.06%) of Mg in *A. vera* leaf, while 30% inorganic fertilizer and 70% cow dung (IF30CD70) was found to give the highest Mg in leaf gel (1.17%), and the control treatment (IF0CD0) showed the minimum result for both. Other treatments showed statistically similar data with a considerable difference. The effects of different doses of IF and CD on the leaf S concentrations varied significantly, while gel S concentration was identical (Figure 5 C-D). The application of IF100CD0 showed the maximum concentration of S in *A. vera* leaf (0.53%) and gel (0.47%), and IF0CD0 had the lowest concentration. For leaf S concentration, the treatments IF75CD25, IF50CD50, and IF40CD60 had statistically similar performances, and the rest of the treatments were statistically comparable, with a considerable difference.

The enhanced availability of nutrients from organic sources might improve physiological and metabolic functions in the plant, leading to better nutrient uptake (Ahmad *et al*., 2016). Among the major nutrients, although the N content was statistically indistinguishable from that of the IF75CD25 treated plants, it was much higher in plants that received just inorganic fertilizers. Without any fertilizer (IF0CD0), the plants exhibited the lowest concentration of N. The plants treated with only IF had identical results. Similar findings were found in previous studies on Aloe vera and other crops (Chowdhury *et al*., 2021). Fertilizer-N may be released more immediately and faster from inorganic fertilizer due to its readily solubility and higher concentration in a full dosage than organic fertilizer (Roba, 2018). Our research, however, demonstrated that the combined use of organic and inorganic fertilizers did not significantly reduce N concentration. However, previous studies showed that integrated nutrient management resulted in increased levels of various forms of N, including $NH_4^+$- N and $NO_3^-$- N. Additionally, there was an increase in net nitrification, ammonification, and N mineralization (Chowdhury *et al*., 2024). The concentration of P in A. vera gel and leaves was dramatically affected by different combinations of IF and cow dung. The treatment IF100CD0 had the highest leaf P concentrations, closely resembling the leaf gel's P concentration. A combination of 75% inorganic fertilizer and 25% cow dung produced the second-highest concentration of P in the leaves, which was identical to IF100CD0. This might be because these treatments resulted in the greatest concentration of P and the highest leaf weight harvest. The uptake of P was the lowest in control treatment, as expected. Phosphorus availability, concentration, and uptake by plants were shown to be more influenced by adding organic amendments (Huang *et al*., 2017). According to Khaim *et al*. (2014), integrating organic and inorganic fertilizers simultaneously resulted in the highest uptake of leaf P, which supports our findings. A prior investigation demonstrated that the incorporation of poultry manure enhanced P uptake and availability by augmenting the overall soil organic carbon content (Khan *et al*., 2022; Chen *et al*., 2021). Various treatments involving IF and cow dung noticeably influenced the concentrations of K in A. vera leaf gel. The highest leaf K concentration was seen in the IF75CD25 treatment, which was not significantly distinct from the other treatments but was identical to that of A. vera fertilized with IF50CD50. Even without fertilizer, the leaf still had a minimal K concentration. Previously, it was found that increased K release in soils and the plant K concentration experienced a significant increase when organic manure was used, even if with IF (Bader *et al*., 2021). In a study conducted by Sheoran *et al*. (2015), it was found that the use of both N-based IF and vermicompost had a notable impact on the uptake of K.

The amount of Ca shown by *A. vera* gel and leaves differed significantly from the control treatments. The plant treated with

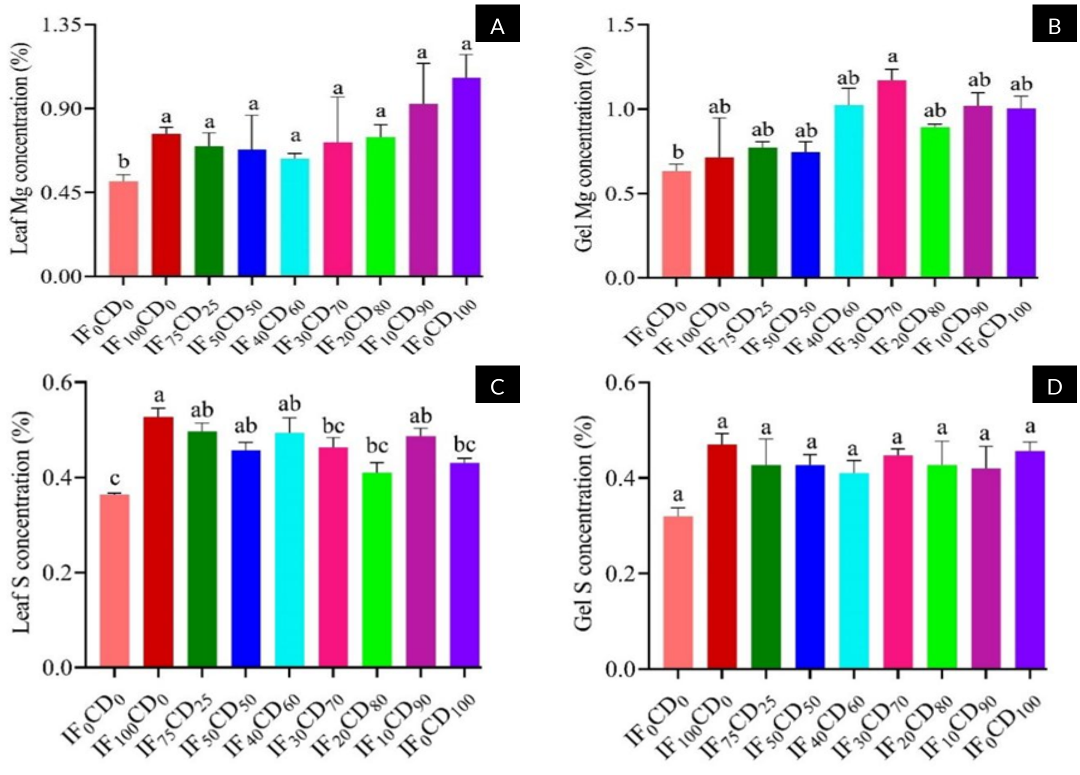


**Figure 5.** *Leaf (A), gel (B) Mg, leaf (C) and gel (D) S concentration of A. vera under integrated nutrient management practices.*

100% cow dung had the greatest Ca content, whereas the one left untreated had the lowest. Except for the control treatment, all groups showed increased Ca uptake with increasing doses of cow dung. Khan *et al*. (2022) also found that adding organic amendment significantly improved Ca uptake by squash fruit, which aligns with our findings. A previous study indicated that the addition of organic amendments increased the calcium phosphate pool by enhancing the total soil organic carbon (Khan *et al*., 2022). There were significant variations in Mg concentration in *A. vera* leaf due to various treatments. The leaf with the highest concentration of Mg was found in the plant treated with 100% cow dung. This concentration was statistically similar to the plants treated with 10% IF and 90% cow dung but different from the other treatments. The control yielded the lowest concentration. The highest concentration of Mg in *A. vera* gel was observed when a combination of 30% inorganic fertilizer and 70% cow dung was used, which was comparable to the results obtained with IF40CD60. The current study's findings were aligned with the findings of Islam & Nahar (2012) in potato, where poultry manure was applied, and Khaim *et al*. (2014) in soybean, where a combination of IF and organic manure was applied. The leaf S concentration in *A. vera* and in gel was significantly influenced by different combinations of IF and CD. Treatment IF100CD0, which was identical to IF75CD25, resulted in the maximum concentration of S in the leaf. The findings of the other treatments were not statistically different from 100% IF, which had the most considerable uptake of S in *A. vera* gel. The control treatment had the lowest S concentration in the gel. According to Zaman *et al*. (2015), the highest S content and uptake by stevia were noted when a mixture of 75% IF and vermicompost was applied at a rate of 7.5 t ha$^{-1}$, whereas the results obtained here are consistent with these findings.

## Post-harvest soil properties

The post-harvest soil showed that the pH of the soil increased with the increase of cow dung (Table 3A). Maximum pH (7.11) was observed when 100% cow dung was used. So, cow dung was mainly responsible for the pH increase. IF10CD90, IF20CD80, IF30CD70, IF40CD60, IF50CD50, IF75CD25 showed statistically similar result, whereas IF100CD0, IF0CD0 showed statistically similar result. Increased use of cow dung increased the organic matter (Table 3A). When 100% cow dung was applied, the soil showed maximum organic matter (2.08%), and when no cow dung was applied with 100% IF, organic matter was lowest in percentage (0.85%). IF10CD90, IF20CD80, IF30CD70, IF40CD60, and IF50CD50 showed statistically identical results with the maximum result-producing treatment. As the amount of cow dung increased, the amount of total %N also increased. The highest amount of N (0.650%) was found when 100% cow dung was used, and no inorganic fertilizer was used (Table 3A). It showed a similar trend as before. Total %N was lowest in amount when no IF and CD were applied. The treatments according to increased value were IF10CD90, IF20CD80, IF30CD70, IF40CD60, IF50CD50, IF75CD25, IF100CD0, and IF0CD0 which were not statistically different from IF0CD100. Potassium was measured in the post-harvest soil, and it was found that exchangeable K increased when there was more organic amendment, i.e., cow dung (Table 3A). The results showed that 100% cow dung with no inorganic fertilizer had the highest exchangeable K percentage (0.98% meq 100 g$^{-1}$). Besides, IF10CD90, IF20CD80, IF30CD70, IF40CD60, and IF50CD50 treatments showed more or less statistically similar results.

The experiment showed that the available P in the soil became higher when a larger amount of cow dung was applied (Table 3B). Based on the findings, the highest amount of available P (1.59 μg g$^{-1}$) was found with IF0CD100. The control treatment showed the lowest available P (1.02 μg g$^{-1}$) and statistically similar results with some other treatments. As the soil had more organic matter for the application of a higher dose of cow dung with a combination of inorganic fertilizers, a greater amount of available S was present there (Table 3B), and the result showed the same pattern as P. The lowest amount (7.93 μg g$^{-1}$) of available S was measured in the control treatment, and the maximum (25.45 μg g$^{-1}$) was from IF0CD100. The other treatments were statistically identical except IF0CD0 and IF100CD0. The increased level of cow dung influenced zinc availability in soil and showed a similar trend as the other nutrients found. Maximum Zn was available in IF0CD100 (13.02 μg g$^{-1}$) and the lowest availability was found in IF0CD0 (4.58 μg g$^{-1}$).

**Table 3A.** Effect of integrated nutrient management practices on post-harvest soil parameters.

| Treatment | pH | Organic matter (%) | Total N (%) | Exch. K (meq 100 g$^{-1}$) |
|---|---|---|---|---|
| IF0CD0 | 5.92 ±0.24b | 0.87±0.07b | 0.046±0.009c | 0.102±0.023c |
| IF100CD0 | 5.98 ±0.25b | 0.85±0.08b | 0.120 ±0.010bc | 0.25 ±0.025bc |
| IF75CD25 | 6.66±0.27ab | 0.97 ±0.09b | 0.180 ±0.011b | 0.39 ±0.027b |
| IF50CD50 | 6.79±0.30ab | 1.32 ±0.11ab | 0.250 ±0.015ab | 0.67 ±0.033ab |
| IF40CD60 | 6.92±0.37ab | 1.47 ±0.12ab | 0.346 ±0.021ab | 0.73 ±0.044ab |
| IF30CD70 | 6.93±0.44ab | 1.64 ±0.13ab | 0.420 ±0.028ab | 0.85 ±0.054a |
| IF20CD80 | 6.98 ±0.47a | 1.71±0.14ab | 0.460 ±0.035a | 0.89±0.059a |
| IF10CD90 | 7.05 ±0.50a | 1.97±0.15a | 0.558±0.042a | 0.93 ±0.074a |
| IF0CD100 | 7.11 ±0.52a | 2.08±0.16a | 0.650±0.043a | 0.98 ±0.085a |

**Table 3B.** Effect of integrated nutrient management practices on post-harvest soil parameters.

| Treatment | Available P (μg g$^{-1}$) | Available S (μg g$^{-1}$) | Available Zn (μg g$^{-1}$) |
|---|---|---|---|
| IF0CD0 | 1.02 ±0.12b | 7.93±0.67c | 4.58±0.54b |
| IF100CD0 | 1.12±0.13ab | 10.32±0.78b | 6.50±0.66ab |
| IF75CD25 | 1.14 ±0.13ab | 11.23±0.90ab | 7.35±0.87ab |
| IF50CD50 | 1.27±0.15ab | 13.45±1.11ab | 9.02±0.93ab |
| IF40CD60 | 1.32 ±0.17ab | 17.93±1.46ab | 11.58 ±1.23a |
| IF30CD70 | 1.39 ±0.18a | 18.32±1.76ab | 11.79±1.49a |
| IF20CD80 | 1.47±0.20a | 20.23±1.99a | 12.50±1.67a |
| IF10CD90 | 1.53 ±0.23a | 24.39±2.44a | 12.89±1.79a |
| IF0CD100 | 1.59±0.24a | 25.45±2.74a | 13.02±1.96a |

The post-harvest soil parameters are favorably affected by the combined application of organic and inorganic fertilizers, with the entire dosage of organic fertilizer showing the most beneficial effect. Despite the lack of statistical significance between the treatments, IF10CD90 and IF0CD100 exhibited higher soil pH, organic matter, N, K, S, and Zn than other fertilizer combinations. Organic matter percentage, pH, N, P, K, Na, and Zn were all the lowest in the control group and the highest in the IF0CD100. The improvement in soil qualities might be attributed to the higher nutrient availability resulting from the prolonged effects of organic amendments, which, in turn, enhanced the physiological and metabolic functions of the plant. The results support the arguments provided by Manjhi *et al*. (2014), who observed that adding manures and IF to soil significantly enhanced the amount of N availability in the soil following crop harvest, compared to the control. Instead of inorganic fertilizers, cow dung applied to the soil may be responsible for the mineralization of wholly or partly immobilized N, leading to an increase in available N (Zaman *et al*., 2015). Soil P availability may have increased due to increased native soil P mobilization, input from manures, mineralization of organic P, and formation of organic acids that boost soil P availability (Hu *et al*., 2023). The soil S, K, and Zn levels may exceed the normal range due to many factors, especially the presence of organic residues. The decomposition of the residues produces certain organic acids that have a solubilizing effect (Ahmad *et al*., 2016). Additionally, organic manures contribute to a higher availability of these elements. Integrating inorganic fertilizers with organic manure enhances nutrient release through increased microbial activity and the decomposition of organic matter, thereby improving soil properties and fertility (Aćin *et al*., 2023; Liu *et al*., 2024). The current study suggests that combining organic matter with inorganic fertilizers improves soil characteristics and growth more effectively than using either inorganic or organic fertilizers alone.

## Conclusion

The experiment showed that the application of 70% cow dung and 30% inorganic fertilizer showed the highest value of plant height, leaf number plant$^{-1}$, leaf area index, leaf yield, and gel yield. Regarding biochemical properties, some nutrients, viz., N, P, and K, were higher in *A. vera* leaf and gel when only inorganic fertilizer (100%) was applied. Again, Ca, Mg, and S concentrations were higher in organic fertilizer treatments. The application of cow dung showed a remarkable difference in the post-harvest soil fertility. Again, N, exchangeable K, available P, available S, available Zn, pH of the soil, and organic matter of all the post-harvest soil showed higher content in the sole application of organic fertilizer. However, the combined application showed a satisfactory balance among growth, yield, gel nutritional quality, and post-harvest soil parameters. Finally, the combined application of 30% inorganic fertilizer and 70% organic fertilizer was more advisable than other combinations. So, the farmers might be recommended to grow *A. vera* using integrated fertilizers having 70% cow dung at a rate of 7 t ha$^{-1}$ and 30% IF to maintain the nutritional quality of *A. vera* leaves in the agro-climatic settings of the studied area.

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## DECLARATIONS

**Author Contributions:** Authors contribution: Conceptualization: A.A.M.S., M.A.R., M.A.H.C., K.N., and B.K.S.; Methodology: A.A.M.S., M.A.R., M.A.H.C., and B.K.S.; Software and validation: K.N., M.A.R., M.A.H.C., and B.K.S.; Formal analysis: A.A.M.S., M.A.R., and M.K.U; Investigation: A.A.M.S. and M.K.U; Resources: M.A.H.C.; Data curation: A.A.M.S., K.N., and B.K.S.; Writing—original draft preparation: A.A.M.S. and M.A.R.; Writing—review and editing: M.A.R., K.N., and B.K.S.; Visualization: A.A.M.S. and M.K.U; Supervision: M.A.H.C.; Project administration: B.K.S.; Funding acquisition: B.K.S.

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