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Effect of Goat Manure and Two Biostimulant Fertilizers (Rapid-Grow and Vegimax) on Growth and Biomass Yield of Welsh Onion (*Allium fistulosum* L.) in Butembo, DRC

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Abstract

Optimizing sustainable fertilization strategies is essential for improving vegetable production in regions where declining soil fertility limits agricultural productivity. This study evaluated the effects of goat manure and two commercial biostimulants (Rapid-Grow and Vegimax) on the growth and biomass yield of Welsh onion (*Allium fistulosum* L.) under field conditions in Butembo, eastern Democratic Republic of the Congo. The experiment was conducted over two consecutive cropping seasons using a randomized complete block design with six treatments in four replications: T0 (control), T1 (goat manure), T2 (Rapid-Grow), T3 (Vegimax), T4 (goat manure + Rapid-Grow), and T5 (goat manure + Vegimax). Fertilization treatments had no significant effect on the establishment rate or most of the growth parameters. However, individual plant weight and biomass yield significantly differed between the treatments ($p < 0.05$). The highest yield at 15.85 t ha^{-1}, relative yield increase at 58.18% and agronomic efficiency at 138.81% were recorded on plots that received treatment T5, indicating strong synergistic interaction between goat manure and Vegimax. Economic analysis showed that goat manure alone achieved the highest value cost ratio (13.13), whereas, the integrated treatments remained economically profitable despite their higher input costs. The first two components of the PCA explained 75.6% of total variability and revealed strong positive associations among yield, plant weight, leaf number, and collar diameter. The results demonstrate that integrating goat manure with biostimulants significantly improves Welsh onion productivity and offers a promising strategy for sustainable vegetable production.

Keywords: *Allium fistulosum*; biostimulants; goat manure; biomass yield; sustainable fertilization, value cost ratio.

1. Introduction

Among vegetable crops, species of the genus *Allium* are widely cultivated and consumed globally due to their nutritional and medicinal properties as well as their distinctive flavour compounds [1]. Onion (*Allium cepa* L.) and leek (*Allium porrum* L.) are among the most extensively cultivated species worldwide [2], while Welsh onion (*Allium fistulosum* L.) is predominantly cultivated in East Asia. Although perennial in nature, Welsh onion is often grown as an annual or biennial crop for its green leaves and blanched pseudostems, which are morphologically and functionally similar to leek [1,2].

Welsh onion is highly valued for its nutritional and functional qualities, being rich in vitamins, essential minerals, volatile sulphur compounds, and flavonoids with strong antioxidant activity [3]. Despite these advantages, *Allium fistulosum* remains a minor crop in many provinces of the Democratic Republic of Congo (DRC), including the eastern region, where it is mainly cultivated in home gardens and small-scale production systems. Nevertheless, Welsh onion presents several agronomic advantages, including ease of cultivation, low land requirement, and relatively high yield potential under appropriate management conditions. Due to its short growth cycle, it is considered a promising alternative to onion and leek for similar culinary and nutritional uses [6].

The productivity, growth, and nutritional value of Welsh onion are strongly influenced by nutrient availability. Recommended fertilizer rates for the production of blanched pseudostems in fertile soils range from 200-300 kg N ha^{-1}, 100-200 kg P_2O_5 ha^{-1}, and 150-200 kg K_2O ha^{-1} [7]. Fertilizer applications are generally split into three or four doses to improve nutrient use efficiency and reduce losses [8]. For green leaf

production, approximately 180 kg N ha^{-1} is recommended, with about 50 kg N ha^{-1} already present in the soil in mineral form before planting [9]. Lower nitrogen rates (60-80 kg N ha^{-1}) have also been reported under certain conditions [10], while an optimal rate of 240 kg N ha^{-1} has been identified in China for early spring production of blanched pseudostems [11]. In addition, nitrate nitrogen has been shown to be more effective than ammonium nitrogen, which may inhibit plant growth under greenhouse conditions [11,12].

Despite these established recommendations, there is a significant lack of region-specific information on the nutrient requirements and fertilizer response of Welsh onion under the prevailing agroecological conditions in eastern DRC, particularly in the highland environment of Butembo. In the local production systems of Butembo, Welsh onion production has largely remained empirical where farmers rely on organic manures and commercial liquid fertilizers without sufficient evidence regarding their efficiency, optimal application rates, or combined effects. Such a situation can result in a suboptimal or over use of fertilizers leading to economic inefficiency or environmental pollution. Furthermore, comparative evaluations of organic amendments such as goat manure and commercial biostimulant fertilizers under these conditions are scarce.

This lack of locally viable information precludes the development of efficient and sustainable nutrient management strategies capable of improving crop productivity while maintaining soil fertility and reducing production costs. Therefore, the present study was carried out to evaluate the effects of complementing goat manure with two commercial liquid fertilizers (Vegimax and Rapid-Grow) on the growth and biomass yield of Welsh onion (*Allium fistulosum* L.) under the agroecological conditions of Butembo, eastern DRC.

2. Materials and Methods

2.1. Study Area

The experiment was conducted at the Centre de Recherches Agronomiques et Vétérinaires du Graben (CERAVEG) of the Université Catholique du Graben, located west of Butembo city (Figure 1). Butembo covers an area of approximately 190 km² and is situated at around 0°08′ N latitude and 29°30′ E longitude, with an average altitude of 1,750 m above sea level.

Butembo experiences an equatorial climate strongly influenced by the altitude. Mean monthly temperatures range from 17.2°C to 18.8°C, while annual rainfall is estimated at approximately 1300-1400 mm. The climate is characterized by two rainy seasons, extending from March to May and from August to November, which are driven by the seasonal passage of the Intertropical Convergence Zone (ITCZ). Two relatively dry periods occur from June to July and from January to February.

The soils of Butembo are generally rich in organic matter and are subject to intensive cultivation. However, their productive capacity is considerably limited due to severe erosion, particularly on steep slopes. These soils belong to the small group of orthic Ferralsols, developed under the Kaolisol order. Physico-chemical analyses of the experimental site (25 cm depth) revealed a slightly acidic soil with a pH (H_2O) of 5.8. The soil contains 2.18 % organic carbon, 0.10 % total nitrogen, 18.30 ppm of available phosphorus, and 98.67 ppm of potassium. The average concentrations of micronutrients were 10.40 ppm zinc, 2,00 ppm copper, 29.80 ppm manganese, 0.77 ppm magnesium, and 24.01 ppm calcium. Particle size analysis indicated that the experimental soil consisted of 12 % sand, 38 % clay, and 50 % silt corresponding to a silt clay textural class.

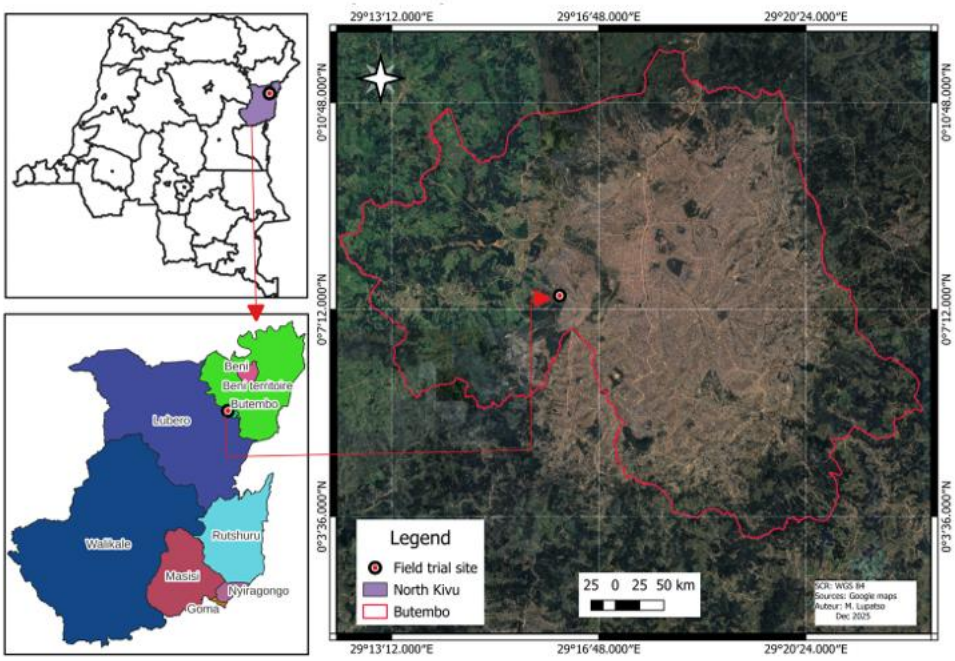

Figure 1: Map of Butembo city displaying the experimental field

2.2. Materials

The plant material used in this study consisted of uniform seedlings obtained from well-established clumps of Welsh onion (*Allium fistulosum* L.). These seedlings with one fully developed leaf were raised in a nursery and underwent a prior careful screening at transplantation to ensure homogeneity in vigour and size, thereby minimizing initial variability among experimental units. This approach was adopted to improve the reliability of treatment comparisons and to ensure that observed differences in growth and yield parameters could be attributed primarily to the applied fertilizer treatments.

Table 1 summarizes the chemical composition of the fertilizers used in the present study, providing key information on their nutrient content and relative contribution to plant nutrition under the experimental conditions.

Table 1: Comparative chemical composition of goat manure, Vegimax, and Rapid-Grow used in the study

Component	Goat manure	Vegimax	Rapid-Grow
N (%)	2.12-3.03	65.00-75.00	P
P (mg kg^{-1})	0.65-0.72	200.00-250.00	P
K (mg kg^{-1})	0.97-2.48	30.00-50.00	P
Ca (mg kg^{-1})	2.38-2.83	P	200.00-300.00
Mg (mg kg^{-1})	0.82-1.01	P	P
Al (mg kg^{-1})	9985.00-16514.00	A	A
Cu (mg kg^{-1})	42.20-63.00	P	P
Fe (mg kg^{-1})	17085.00-27172.00	P	P
Mn (mg kg^{-1})	565.00-817.00	P	P
Na (mg kg^{-1})	1423.20-5952.20	A	A
Zn (mg kg^{-1})	187.00-246.00	P	P
Organic carbon (%)	21.00-29.66	NR	NR
pH (KCl)	7.19-8.32	NR	NR
C/N ratio	15.00-25.00	NR	NR
Sources	[11]	Manufacturer technical sheet (Vegimax Organic Fertilizer)	Manufacturer technical sheet (Rapid-Grow formulation)

Legend: A = Absent, P = present, NR = Non reported

2.3. Experimental design and crop management

The experiment was conducted during two successive cropping seasons: Season A, from October 2024 to February 2025, and Season B, from March to Jun 2025. Both experiments were carried out at the same experimental station; however, each cropping season was established in a different field location within the research site. These locations had not previously been subjected to fertilisation experiments or received experimental fertilizer treatments, thereby minimizing the potential influence of residual nutrient effects from previous trials.

During each cropping season, the experiment was arranged according to a Randomized Complete Block Design (RCBD) with four replications. Each replication consisted of six experimental plots corresponding to the six fertilisation treatments, which were randomly assigned within each replication to minimize experimental bias and account for spatial variability. A distance of 1 m was maintained between replication, while adjacent plots within each replication were separated by 0.5 m to reduce border effects and potential interference among treatments.

Each experimental plot measured 2 m × 2 m, corresponding to an area of 4 m^2. Welsh onion seedlings were transplanted at a spacing of 20 cm × 20 cm, resulting in a planting density of 100 plants per experimental plot (250000 plants ha^{-1}). The experimental area covered 214.5 m^2, with overall dimensions of 16.5 m × 13 m. Six fertilization treatments were evaluated: T0 (unfertilized control), T1 (goat manure), T2 (Rapid-Grow), T3 (Vegimax), T4 (goat manure + Rapid-Grow), and T5 (goat manure + Vegimax) as illustrated in the layout of the experimental design (Figure 2).

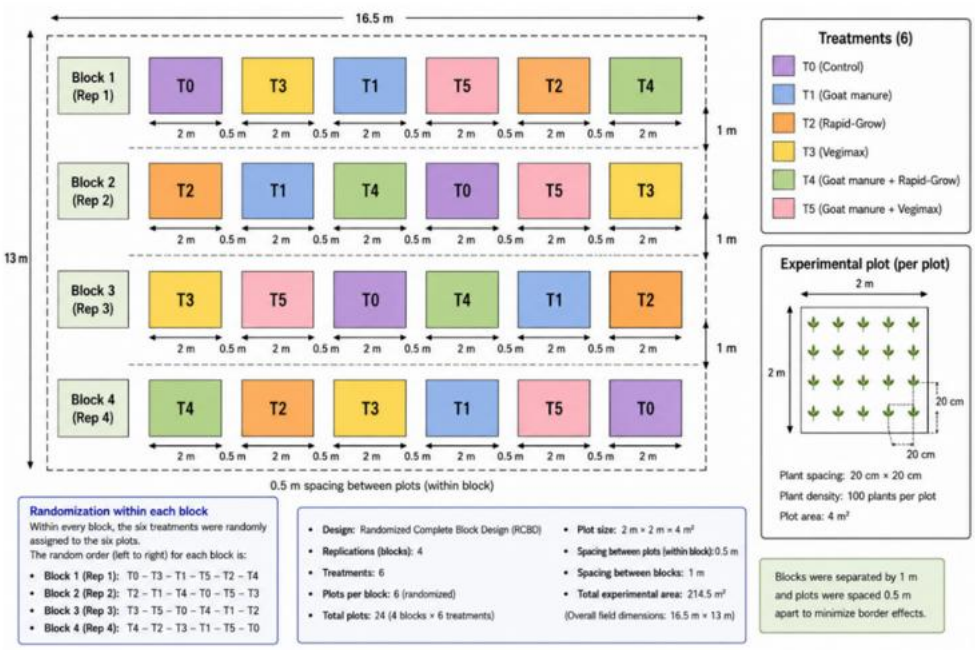

Figure 2: Experimental layout adopted for this study

Land preparation consisted of initial clearing followed by manual ploughing to a depth of approximately 25 cm, with thorough breaking of soil clods to improve soil structure, and enhance root development. Goat manure was incorporated into the soil prior to transplanting for treatments T1, T4, and T5 in both seasons at a rate of 20 t ha^{-1}. Transplanting was carried out at the beginning of each season using the same spacing arrangement (20 cm × 20 cm). Routine crop management practices included manual weeding and irrigation to ensure optimal plant growth conditions.

Fertilizer applications were carried out through weekly foliar spraying after successful crop establishment, according to the treatment allocation. Specifically, Rapid-Grow was applied to treatments T2 and T4, whereas Vegimax was applied to treatments T3 and T5. The fertilizers were applied following the manufacturer's recommended rates, with Rapid-Grow diluted at 100 mL per 20 L of water and Vegimax at 4 mL per 20 L of water. Accordingly, each experimental plot (4 m^2) received 5 L of fertilizer solution per application, equivalent to 25 mL of Rapid-Grow or 1 mL of Vegimax, depending on the treatment. A total of eight foliar spray applications were performed throughout the experiment. Consequently, each plot received a cumulative volume of 40 L of solution, corresponding to 200 mL of Rapid-Grow or 8 mL of Vegimax. On a per-hectare basis (10,000 m^2), these application rates are equivalent to 500 L of Rapid-Grow or 20 L of Vegimax, each diluted in 100,000 L of water. The final foliar application was made one week before harvest in each growing season. Harvesting was carried out at physiological maturity according to the respective harvest dates for each season.

2.4. Data collection

Observations focused on plant establishment rate, plant height, collar diameter, number of leaves per plant, number of clumps per plant, individual plant weight, and Welsh onion yield.

Plant establishment rate (%) was estimated as the ratio between established seedlings and planted seedlings times one hundred. Plant height (cm) was measured from the collar to the tip of the tallest leaf two months after planting. Collar diameter (mm) was measured using a vernier calliper. The number of clumps and leaves per plant was determined through systematic counting. Individual plant weight (g) was measured using a digital balance. Finally, Welsh onion yield (t ha^{-1}) was determined by weighing all plants harvested from the net plot area (2.56 m^2). The fresh weight, recorded in kilograms, was subsequently converted and extrapolated to tons per hectare (t ha-1).

Data on plant height, collar diameter, number of tillers per plant, number of leaves per plant, and individual plant weight were collected from a sample of ten plants randomly selected from the central area of each experimental plot.

In addition, the relative yield increase (RYI) and relative agronomic efficiency (RAE) of fertilizers and their combinations was calculated using the formulas proposed by López-Bellido and López-Bellido [13], and adapted by Ylivainio et al [14]:

$$RYI\ (\%) = \frac{Y_1 - Y_0}{Y_0} \times 100$$

$$RAE\ (\%) = \left(\frac{Y_1 - Y_0}{Y_{ref} - Y_0}\right) \times 100$$

Where: Y_1 = yield obtained from the treated plot, Y_0= yield obtained from the untreated control plot, Y_{ref} = yield obtained from the standard/reference fertilizer.

The Value Cost Ratio (VCR) was estimated as:

$$VCR = \frac{Value\ of\ additional\ yield}{Cost\ of\ fertilisation}$$

Note a VCR greater than 1 indicates that fertilizer use is profitable, while a VCR of at least 2 is generally considered the minimum threshold for farmer adoption because it provides an adequate return to offset production risks and costs. Under high-risk conditions, such as variable rainfall, pest pressure, price fluctuations, or limited access to credit, a VCR of 3-4 is recommended to encourage widespread adoption [15,16].

During the experimental period, the cost of 30 mL of Vegimax was 3 US dollars (USD), corresponding to a unit price of 100 USD L^{-1}, whereas the price of one litre of Rapid-Grow was estimated at 3 USD. Accordingly, the cost associated with the application rates per hectare, namely 20 L of Vegimax and 500 L of Rapid-Grow, amounted to 2000 USD ha^{-1} and 1500 USD ha^{-1} of Rapid-Grow, respectively.

Furthermore, a truckload containing approximatively five tonnes of goat manure, including transportation costs, was valued at 60 USD. Therefore, the goat manure required for an application rate of 20 t ha^{-1}, represented an estimated cost of 240 USD ha^{-1}. The labour associated with manure application were estimated at 80 USD ha^{-1}.

Regarding the application of foliar fertilizers, the cost of spraying was estimated at 10 USD per application. Since eight applications were performed throughout the cropping cycle, the total cast of this operation amounted to 80 USD ha^{-1}.

By integrating all costs related to fertilisation inputs, the total cost of the goat manure-based treatment was estimated at 320 USD ha^{-1}, comprising 240 USD ha^{-1} for manure acquisition and 80 USD ha^{-1} for manure application. Similarly, the total cost associated with foliar fertilizers reached 2080 USD ha^{-1} for Vegimax (2000 USD ha^{-1} for the

product and 80 USD ha^{-1} for application operations), and 1580 USD ha^{-1} for Rapid-Grow (1500 USD ha^{-1} for the product and 80 USD ha^{-1} for application operations).

Moreover, during the same study period, the market price of a bunch of Welsh onion, corresponding to an average market value of 1 USD kg^{-1}. This reference price was used to estimate the economic value of the harvested production.

2.5. Statistical data analysis

Data collected on plant growth and yield parameters were analysed according to the experimental design, namely a randomized complete block design (RCBD) with six treatments and four replications. Statistical analyses were performed using R software version 4.5.2 (R Core Team, Vienna, Austria).

The effects of fertilization treatments on the measured variables were evaluated by analysis of variance (ANOVA) using the following linear model:

$$Y_{ij} = \mu + T_i + B_j + \varepsilon_{ij}$$

Where Y_{ij} is the observed value of the response variable, μ is the overall mean, T_i is the fixed effect of the ith treatment (i = 1…6), B_j is the random effect of the jth block (j = 1…4), and ε_{ij} is the residual error assumed to be independently and normally distributed with mean zero and constant variance.

When the ANOVA indicated significant treatment effects, means were separated using Fisher's Least Significant Difference (LSD) test at the 5% probability level (α = 0.05) to compare treatment means and identify specific differences among the fertilization treatments. Prior to the analysis, the assumptions of normality of residuals and homogeneity of variances were verified using the Shapiro-Wilk and Levene's tests, respectively.

Principal Component Analysis (PCA) was performed to explore the multivariate relationships among measured agronomic traits and to identify the variables that contributed most to treatment discrimination. Prior to analysis, the data were standardized (mean = 0, standard deviation = 1) to eliminate the effects of differences in measurement scales. The PCA was conducted using the FactoMinerR package, and results were visualized with factoextra package in R software (version 4.5.2). the first principal components were retained based on the proportion of total variance explained, and the relationships among variables and treatments were interpreted using correlation circles and biplots.

3. Results

3.1. Effects of treatments on agronomic performances

Table 2 presents the effects of goat manure, biostimulant fertilizers (Rapid-Grow and Vegimax), and their combinations on the growth and yield performance of Welsh onion.

Table 2: Effects of goat manure, biostimulant fertilizers (Rapid-Grow and Vegimax), and their combinations on the growth and yield performance of Welsh onion

Treatments	PER	PH	CD	NTP	NLP	IPW	WOY
T0	95.00	40.57	10.24	2.05	10.45	52.4 ^{B}	10.02 ^{B}
T1	94.50	41.49	12.22	2.52	13.13	68.8 ^{AB}	14.22 ^{A}
T2	95.50	40.19	10.50	2.28	12.90	54.9 ^{B}	11.25 ^{B}
T3	94.75	42.36	10.84	2.68	12.30	64.6 ^{AB}	10.79 ^{B}
T4	94.50	44.48	11.86	2.78	13.53	80.8 ^{A}	14.89 ^{A}
T5	96.50	44.74	10.94	2.73	14.70	86.3 ^{A}	15.85 ^{A}
LSD (5%)	-	-	-	-	-	23.33	3.257
F-value	0.15^{NS}	1.55^{NS}	1.52^{NS}	1.22^{NS}	1.90^{NS}	3.09*	5.11**
P-value	0.976	0.233	0.243	0.347	0.155	0.041	0.006

Note: Means followed by the same letter within a column are not significantly different according to Fisher's LSD test at the 5% probability level. NS = not significant (P > 0.05); * = significant at P < 0.05; ** = highly significant at P < 0.01, PER = Plan establishment rate (%)

PH = Plant height (cm), CD = Collar diameter (mm), NTP = Number of tillers plant^{-1}, NLP = Number of leaves plant^{-1}, IPW = individual plant weight (g plant^{-1}) and, W0Y = Welsh onion yield (t ha^{-1})

Results in table 2 show that plant establishment rate (PER), plant height (PH), collar diameter (CD), number of tillers per plant (NTP), and number of leaves per plant (NLP) were not significantly affected by the fertilization treatments ($P > 0.05$). Although numerically higher values of these growth traits were generally observed under the combined application of goat manure and biostimulants, particularly in T4 and T5, the differences among treatments were not statistically significant. For example, plant height ranged from 40.19 cm in T2 to 44.74 cm in T5, while collar diameter varied between 10.24 mm in the unfertilized control (T0) and 12.22 mm in T1. Similarly, the number of tillers per plant increased from 2.05 in T0 to 2.78 in T4, and the number of leaves per plant ranged from 10.45 in T0 to 14.70 in T5. These findings suggest that, under the experimental conditions, vegetative growth traits were relatively stable and only marginally responsive to the fertilization strategies tested.

In contrast, individual plant weight (IPW) was significantly influenced by fertilization treatments ($P = 0.041$). The combined applications of goat manure with Rapid-Grow (T4) and goat manure with Vegimax (T5) produced the highest individual plant weights (80.8 and 86.3 g plant^{-1}, respectively), both significantly greater than those of the unfertilized control (52.4 g plant^{-1}) and the Rapid-Grow-alone treatment (54.9 g plant^{-1}). Treatments receiving goat manure alone (T1) or Vegimax alone (T3) produced intermediate plant weights and did not differ significantly from either the highest- or lowest-performing treatments. This response indicates that integrating organic manure with biostimulant fertilizers enhanced biomass accumulation more effectively than applying either input separately, likely through complementary improvements in nutrient availability, root activity, and plant physiological performance.

Welsh onion yield (WOY) was highly significantly affected by fertilization (P = 0.006), demonstrating that fertilizer management exerted a stronger influence on productivity than on vegetative growth. The highest yields were recorded with the combined applications of goat manure and Vegimax (T5, 15.85 t ha^{-1}) and goat manure and Rapid-Grow (T4, 14.89 t ha^{-1}), followed closely by goat manure alone (T1, 14.22 t ha^{-1}). These three treatments produced significantly higher yields than the unfertilized control (10.02 t ha^{-1}), Rapid-Grow alone (11.25 t ha^{-1}), and Vegimax alone (10.79 t ha^{-1}). The superiority of T4 and T5 suggests a synergistic interaction between goat manure and foliar biostimulants, whereby organic nutrient supply and improved physiological efficiency collectively enhanced assimilate production and partitioning toward marketable yield. The absence of a comparable response when the biostimulants were applied alone further indicates that their effectiveness depends on an adequate soil nutrient supply provided by organic manure.

3.2. Relative yield increase, agronomic efficiency and value cost ratio of fertilization treatments

Table 3 presents the relative yield increase (RYI), relative agronomic efficiency (RAE), and value cost ratio (VCR) of goat manure, biostimulant fertilizers (Rapid-Grow and Vegimax), and their combinations, providing an assessment of their agronomic and economic performance in Welsh onion produced under the agroecological conditions of Butembo.

Table 3: Relative yield increase, agronomic efficiency and value cost ratio of goat manure, biostimulant fertilizers (Rapid-Grow and Vegimax), and their combinations on Welsh onion production in Butembo

Variable	T0	T1	T2	T3	T4	T5
FQ	0 + 0	20 + 0	0 + 500	0 + 20	20 + 500	20 + 20
FC	0	320	1580	2080	1900	2400
Y	10020	14220	11250	10790	14890	15850
$Y_1 - Y_0$	-	4200	1230	770	4870	5830
VAY	-	4200	1230	770	4870	5830
RYI	-	41.92	12.28	7.68	48.60	58.18
RAE	-	100.00	29.29	18.33	115.95	138.81
VCR	-	13.13	0.78	0.37	2.56	2.43

Noted Y is yield (kg ha^{-1}), Y_0 is yield obtained from the untreated control plot (T0), Y_{ref} is yield obtained from the standard/reference fertilizer (T1), RYI is relative yield increase and RAE is relative agronomic efficiency, VCR is value cost ratio, FQ is fertilizer quantity (t ha^{-1} goat manure + L ha^{-1} biostimulant fertilizer), FC is fertilizer cost (USD), VAY is Value of additional yield (USD) (1 USD kg^{-1}), $Y_1 - Y_0$ is yield increase (kg ha^{-1}), RYI is Relative yield increase (%), RAE is Relative agronomic efficiency (%), and VCR is Value cost ratio

Results in Table 3 revealed that goat manure applied alone (T1) substantially improved Welsh onion productivity, increasing yield by 4.20 t ha^{-1} (41.92%) relative to the untreated control. As the reference treatment, it recorded a relative agronomic efficiency (RAE) of 100.00% and the highest value-cost ratio (VCR = 13.13), indicating an exceptionally profitable investment because the value of the additional yield was more than thirteen times the fertilizer cost.

In contrast, the foliar biostimulants applied alone (T2: Rapid-Grow and T3: Vegimax) produced only modest yield increases of 1.23 t ha^{-1} (12.28%) and 0.77 t ha^{-1} (7.68%), corresponding to RAE values of 29.29% and 18.33%, respectively. Their economic performance was poor, with VCR values of 0.78 and 0.37, indicating that the value of the additional yield did not cover the fertilizer costs. According to commonly accepted economic thresholds, these treatments are not economically attractive when used alone.

Combining goat manure with the biostimulants improved crop performance beyond that of goat manure alone. The combination of goat manure with Rapid-Grow (T4) increased yield by 4.87 t ha^{-1} (48.60%), achieving an RAE of 115.95%, while the combination of goat manure with Vegimax (T5) produced the greatest response, with a yield increase of 5.83 t ha^{-1} (58.18%) and the highest RAE (138.81%). These results indicate a positive interaction between goat manure and foliar biostimulants, particularly Vegimax, in enhancing nutrient use efficiency and crop productivity.

From an economic perspective, both combined treatments were profitable, with VCR values of 2.56 (T4) and 2.43 (T5). These values exceed the minimum profitability threshold of 2, indicating that combining goat manure with either biostimulant is economically viable for farmers. However, despite producing the highest yield, T5 had a slightly lower VCR than T4 because of its higher fertilizer cost.

3.3. Multivariate analysis of growth and yield parameters under different fertilization treatments

The Principal Component Analysis (PCA) was performed to examine the relationships among measured growth and yield variables and to evaluate the overall response of Welsh onion plants to different fertilization treatments (Figure 3).

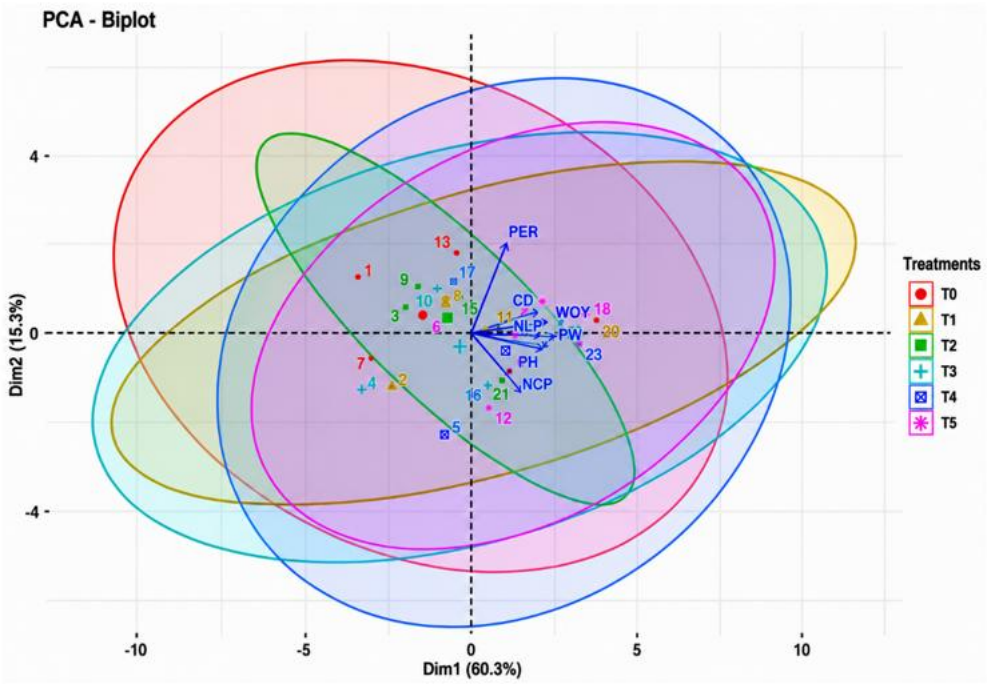

Figure 3: Principal Component Analysis (PCA) biplot showing the relationship between growth, yield parameters, and fertilization treatments in Welsh onion

The first two principal components explained 75.6% of the total variability, with Dim1 accounting for 60.3% and Dim2 accounting for 15.3%, indicating that these two axes adequately summarize most of the variation observed in the dataset.

The distribution of variables on the biplot reveals important correlations among agronomic traits. Variables including Welsh onion yield (WOY), individual plant weight (IPW), number of leaves per plant (NLP), and collar diameter (CD) are grouped closely together and oriented in the positive direction of Dim1, indicating strong positive correlations among these parameters. This suggests that plants producing more leaves and developing thicker collar diameters tend to accumulate greater biomass and ultimately achieve higher yield. The close association between individual plant weight and yield confirms that biomass accumulation at the plant level was a major determinant of productivity in the present study.

In contrast, plant establishment rate (PER) is positioned separately along the positive direction of Dim2 and shows relatively weak association with the other agronomic variables. This indicates that seedling establishment was largely independent of subsequent growth and yield performance. Physiologically, this suggests that establishment in Welsh onion is primarily determined by transplant vigour and environmental adaptation rather than nutrient availability during the early developmental stage.

The variables number of clumps per plant (NCP) and plant height (PH) are positioned in the lower right quadrant, indicating a moderate association with productivity-related traits but a weaker contribution compared with leaf number and individual plant weight. This suggests that although vegetative growth contributes to productivity, not all growth parameters contribute equally to final yield formation. In Welsh onion, biomass accumulation appears to depend more strongly on assimilatory structures such as leaves rather than simply on plant elongation.

The spatial distribution of treatment groups provides additional insight into fertilization effects. Treatments T4 (goat manure + Rapid-Grow) and T5 (goat manure + Vegimax) are predominantly distributed toward the positive side of Dim1, where yield-related variables are concentrated. This indicates a strong positive association between integrated fertilization treatments and superior agronomic performance. Their proximity to variables such as yield, plant weight, and leaf number confirms that combining organic manure with biostimulants produced the most favorable overall response.

Treatment T1 (goat manure alone) occupies an intermediate position and remains relatively associated with productivity variables, confirming that organic fertilization alone substantially improved crop performance. This observation supports earlier

results showing that goat manure significantly increased yield compared with the control and biostimulant-only treatments.

Conversely, treatments T2 (Rapid-Grow alone) and T3 (Vegimax alone) show greater dispersion and weaker association with the cluster of productivity variables, indicating relatively lower agronomic effectiveness when biostimulants were applied without an adequate nutrient base. This suggests that the physiological stimulation provided by these products was insufficient to maximize growth and yield in the absence of substantial soil nutrient improvement.

The control treatment T0 is more widely dispersed and positioned farther from the productivity-related variable cluster, confirming its association with lower growth performance and reduced yield. This reinforces the conclusion that nutrient limitation represented a major productivity constraint under the experimental conditions.

4. Discussion

The present study evaluated the effects of goat manure and two biostimulant fertilizers (Rapid-Grow and Vegimax) on Welsh onion (*Allium fistulosum* L.) growth parameters and yield under field conditions in Butembo, eastern Democratic Republic of the Congo. Overall, the results revealed a clear hierarchical response pattern in which establishment and certain growth parameters were largely insensitive to fertilization, yield formation were markedly influenced by integrated nutrient management strategies.

A consistently high establishment rate of approximately 95% across all treatments, with no significant differences, indicates that seedling survival was not directly affected by fertilization. Rather, establishment was primarily driven by transplant vigour and early

environmental conditions, suggesting a physiological buffering capacity of Welsh onion during the initial growth stage. This finding aligns with Adebayo et al. [17], who reported limited effects of fertilization on establishment in several vegetable crops, and with general physiological evidence that early plant survival depends more on seedling reserves and environmental conditions than on external nutrient inputs under non-limiting soil moisture conditions [18].

In contrast, vegetative growth traits showed a differentiated response to fertilization. Plant height responded significantly to treatments, with the highest values recorded under combined applications of goat manure with either Vegimax or Rapid-Grow. This indicates that integrated nutrient management enhances vegetative vigour more effectively than sole applications of either organic or biostimulant inputs. The observed response can be attributed to the complementary mechanisms of the inputs: goat manure improves soil physical properties, nutrient availability, and microbial activity, while biostimulants enhance physiological processes such as nutrient uptake efficiency and metabolic activity [19]. These results corroborate Gutiérrez-Benicio et al. [20] and Mohamed et al. [21], who emphasized that plant height is a complex trait governed by genotype × environment × management interactions, and align with broader evidence on nutrient-mediated regulation of vegetative growth [22].

Tiller production did not differ significantly among treatments, suggesting that this trait is largely genetically controlled in Welsh onion and exhibits limited phenotypic plasticity under the prevailing conditions. On the contrast, leaf number responded positively to fertilization, with higher values generally observed in amended treatments compared with the control. This reflects enhanced assimilatory capacity and vegetative expansion driven by improved nitrogen availability, a key driver of leaf initiation and expansion in

leafy vegetables [17,23]. Overall, these results highlight trait-specific sensitivity to nutrient management, consistent with previous findings that morphological traits vary widely in their responsiveness to fertilization [18,22].

Yield performance exhibited the strongest response to fertilization, clearly demonstrating that Welsh onion productivity was highly dependent on nutrient management. The unfertilized control produced only 9.25 t ha^{-1}, reflecting the limited inherent fertility of the experimental soil. Application of goat manure alone significantly increased yield to 13.75 t ha^{-1}, corresponding to a relative yield increase (RYI) of 48.65% and confirming the capacity of organic amendments to improve soil fertility through gradual nutrient release, enhanced microbial activity, improved soil structure, and increased nutrient retention [24,25]. Similar responses have been reported in leafy vegetables grown under tropical conditions, where organic manures consistently improve productivity by enhancing both soil quality and nutrient cycling [17].

In contrast, Rapid-Grow and Vegimax applied alone produced only modest yield gains (13.51% RYI), resulting in yields of 10.50 t ha^{-1}. This limited response confirms that biostimulants cannot compensate for insufficient nutrient availability because they primarily enhance nutrient acquisition and physiological efficiency rather than supplying nutrients directly [19,22]. Consequently, their effectiveness depends largely on the presence of an adequate nutritional base.

The superiority of integrated nutrient management was clearly demonstrated by the combined application of goat manure with biostimulants. Goat manure combined with Rapid-Grow (T4) increased yield to 14.25 t ha^{-1} (54.05% RYI), whereas goat manure combined with Vegimax (T5) produced the highest yield (15.25 t ha^{-1}), representing a relative yield increase of 64.86%. These treatments also recorded the highest relative

agronomic efficiency (RAE), reaching 111.11% and 133.33%, respectively. Agronomic efficiency values exceeding 100% indicate that combining organic manure with biostimulants generated greater productivity than the reference fertilizer alone, demonstrating a synergistic interaction rather than a simple additive effect. Such synergy is likely attributable to improved synchronization between nutrient availability from goat manure and enhanced nutrient uptake, enzyme activity, photosynthesis, and assimilate translocation stimulated by the biostimulants [19,22].

From an economic perspective, the value-cost ratio (VCR) provided additional insight into the profitability of the fertilization strategies. Goat manure applied alone achieved the highest VCR (14.06), indicating exceptional economic efficiency because the additional value of yield greatly exceeded the cost of the fertilizer. According to commonly accepted economic thresholds, a VCR greater than 2 generally indicates that a fertilizer technology is profitable and sufficiently attractive for adoption by farmers, whereas values below 2 are considered economically unattractive under normal production conditions [15,16]. Although the integrated treatments produced the highest biological yields, their VCR values were substantially lower (2.63 for T4 and 2.50 for T5) because of the higher cost associated with combining organic manure and commercial biostimulants. Nevertheless, both treatments remained economically viable since their VCR exceeded the profitability threshold. In contrast, the application of biostimulants alone resulted in VCR values below unity (0.79 for Rapid-Grow and 0.60 for Vegimax), indicating that the additional income generated was insufficient to offset the investment costs. These findings reinforce the conclusion that biostimulants should not be used as standalone inputs under nutrient-deficient conditions but rather as complementary products that enhance the efficiency of nutrient-rich fertilization systems [26].

The PCA results obtained in this study, where the first two components explained 75.6% of the total variability (Dim1 = 60.3%; Dim2 = 15.3%). Similar cumulative variances (70-85%) have been reported in studies on leafy vegetables and Allium crops, where growth and yield traits tend to be strongly intercorrelated and can therefore be effectively summarized by a reduced number of latent dimensions [27]. This suggests that the agronomic response of Welsh onion under different fertilization regimes is governed by a relatively simple structure dominated by biomass accumulation and assimilate partitioning processes.

The strong clustering of yield (WOY), individual plant weight (IPW), number of leaves per plant (NLP), and collar diameter (CD) along Dim1 reflects a tight functional relationship between vegetative growth and final productivity. This pattern is widely reported in vegetable physiology. For instance, Marschner [18] and Taiz et al. [28] emphasize that in leafy vegetables, yield is primarily a function of leaf area development and total biomass accumulation, both of which are strongly influenced by nutrient availability, particularly nitrogen. Comparable PCA structures have been observed in onion and leek studies, where yield-related traits cluster strongly with leaf number and plant biomass, indicating that assimilatory capacity is the main driver of productivity [29]. This reinforces the interpretation that in *Allium fistulosum*, improvements in vegetative vigour directly translate into yield gains.

The intermediate positioning of number of clumps per plant (NCP) and plant height (PH) aligns with previous multivariate analyses showing that structural traits often contribute moderately to variability but are less strongly correlated with yield than leaf-related traits. For example, in onion and garlic systems, plant height has been shown to be a secondary trait with indirect influence on yield, mainly through its relationship with leaf expansion rather than direct biomass accumulation [27,30,31]. This supports

the interpretation that vertical growth and clump formation play a supportive rather than central role in yield determination.

The treatment distribution observed in the PCA further corroborates established findings on nutrient management. The strong association of T4 (goat manure + Rapid-Grow) and T5 (goat manure + Vegimax) with yield-related traits is consistent with numerous studies demonstrating the superiority of integrated nutrient management over sole applications of organic or biostimulant inputs. Similar synergistic effects have been reported by Calvo et al. [19] and du Jardin [22], who highlighted that biostimulants are most effective when applied in systems already supplied with sufficient baseline nutrients. Likewise, Diacono and Montemurro [24] emphasized that organic amendments improve soil fertility gradually, but their efficiency is significantly enhanced when combined with inputs that stimulate nutrient uptake and metabolic activity.

The intermediate performance of T1 (goat manure alone) aligns with findings from long-term soil fertility studies indicating that organic amendments alone can significantly improve yield but may not maximize productivity in the short term due to slower nutrient release dynamics [26]. Conversely, the weak association of T2 and T3 (biostimulants alone) with productivity traits is consistent with the widely accepted view that biostimulants do not replace mineral or organic nutrient sources but rather enhance their utilization efficiency [19,22]. Finally, the strong separation of the control (T0) from productivity variables confirms nutrient limitation as a major constraint, a pattern frequently observed in unfertilized vegetable production systems across tropical agroecological zones [18].

Conclusion

This study demonstrated that fertilization management significantly influences the productivity of Welsh onion (*Allium fistulosum* L.) under the agroecological conditions of Butembo in eastern DRC. Although, almost morphological growth parameters were not significantly affected by fertilizer treatments, biomass accumulation and final yield responded strongly to nutrient management strategies.

The results clearly showed that goat manure applied alone substantially improved yield performance compared with the unfertilized control, confirming the important role of organic amendments in improving soil fertility and supporting crop growth. In contrast, the sole application of biostimulant fertilizers produced only limited yield improvement, indicating that these products cannot effectively substitute for an adequate nutrient supply when used independently.

The combined application of goat manure with biostimulants produced the best agronomic performance, with the goat manure + Vegimax treatment consistently achieving the highest biomass yield, relative yield increase, and agronomic efficiency. These findings demonstrate a strong synergistic interaction between organic nutrient supply and physiological stimulation provided by biostimulants, resulting in improved nutrient use efficiency and enhanced crop productivity. However, the economic assessment revealed that goat manure applied alone generated the highest value cost ratio, whereas the integrated treatments despite producing superior yield, remained economically profitable with value cost ratios exceeding the commonly accepted profitability threshold for fertilizer investment. Conversely, the low value cost ratios obtained with biostimulants applied alone indicate that their use is not economically justified in the absence of an adequate nutrient source.

Overall, the study provides strong evidence that integrated nutrient management combining organic manure with biostimulant fertilizers constitutes an effective and sustainable strategy for improving Welsh onion production under the highland agroecological conditions of eastern DRC. Further research should focus on long-term soil fertility effects, optimization of fertilizer application rates, and economic analysis of integrated fertilization systems to insightful evidence that support wider adoption by smallholder farmers.

Author contributions

KSL: Conceptualization, Investigation, Data curation, Formal analysis, Writing-original draft. **KMM**, **KKD**, **PYE**, and **KSA**: Investigation, Data curation, Validation, and Writing-review and editing. **KMB**: Conceptualization, Methodology, Supervision, Formal analysis, Project administration, Writing-review and editing. All authors read and approved the final manuscript.

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Data availability

The datasets generated and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

All authors have provided their consent for the publication of this work.

Competing interests

The authors declare no competing interests

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