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Farm Partial Budget Analysis of Onion (*Allium Cepa* L.) for the Application of Nitrogen and Spacing in Southern Tigray, Ethiopia

Abrhaley Shelema [a*], Getachew Hruy [b] and Berhan Mengesha [b]

[a] Department of Horticulture, Tigray Agricultural Research Institute, Alamata Agricultural Research Center, P. O. Box 56, Alamata, Ethiopia.
[b] Department of Dryland Crops and Horticultural Sciences, Mekelle University, P.O. Box 231, Mekelle, Ethiopia.

Authors' contributions

This work was carried out in collaboration among all authors. Author AS Formulated and planned the study, gathered and evaluated the data, and authored the manuscript. Author GH Offered direction on the research concept, assisted with data interpretation, and conducted a thorough review of the manuscript. Author BM Assisted with data interpretation, and conducted a thorough review of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

This study aimed to assess the economic viability of onion production under varying nitrogen fertilizer rates and intra-row spacing in the study area using partial budget analysis. The experiment employed a factorial arrangement in a randomized complete block design, conducted at Alamata Agricultural Research Center in Kara Adishabo in 2020. Experimental treatments included nitrogen

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**Corresponding author: Email: shelemaab@gmail.com;*

fertilizer rates (0, 23, 46, 69, and 92 Kg N ha^{-1}) and intra-row spacing (5, 10, and 15 cm) with three replications. The partial budget analysis indicated that the treatment combination of 69 kg N ha^{-1} and 5 cm intra-row spacing yielded the highest net benefit of birr 642602.3. However, based on the marginal rate of return, the recommendation of 46 Kg N ha^{-1} and 15 cm intra-row spacing, which had a lower net benefit, was rejected after residual analysis. Consequently, the recommended treatment combination is 69 Kg N ha^{-1} and 5 cm of intra-row spacing, contrary to the previous recommendation. Onion cultivation is a significant economic activity in the southern zone, playing a crucial role in the livelihoods of smallholder farmers. Consequently, understanding the production costs and analyzing the financial profitability of this on-farm business is essential in the study area to enhance crop productivity.

Keywords: Nitrogen; intra-row spacing; partial budget; residual analysis.

1. INTRODUCTION

“Onion (*Allium Cepa* L.) is a valuable crop from the Allium genus of the Alliaceae family. It likely originated in Central Asia, between Turkmenistan and Afghanistan, where some related species still grow in the wild” [1]. “Onions are rich in flavonoids, which are associated with a lower risk of cancer, heart disease, and diabetes in the human diet” [2]. “In addition, it is known for its anti-bacterial, antiviral, anti-allergenic, and anti-inflammatory potential” [3,4].

Partial budget analysis is a straightforward yet powerful method to evaluate the profitability of new technology within an established enterprise. It serves as a basis for comparing the relative profitability of different approaches, assessing their risk levels, and determining the resilience of profits when faced with fluctuating product or input prices. Economic analysis evaluates treatment feasibility through partial budget, dominance, and marginal analysis of each treatment. Partial budget analysis helps structure experimental data on the costs and benefits of different treatments. It includes average yields, adjusted yields, gross field benefit, and varying total costs for each treatment. The total costs, which can vary, encompass all costs associated with alternative treatments. The increased crop production resulting from input applications may or may not benefit farmers. As a result, it is recommended to utilize partial budget analysis [5] to determine the net benefit and marginal rate of return from different treatment options. It suggests validating the findings of a marginal analysis by examining residuals.

Onion is a highly profitable vegetable crop cultivated by smallholder farmers in the southern zone of Kara Adishabo district. Its ability for multiple harvests, high economic value, quick returns, availability of labor, land, irrigation water, and favorable climate have led to an increase in onion production, making it the primary on-farm business commodity in the area. “Nevertheless, the on-farm profitability of onion production under varying nitrogen fertilizer rates and intra-row spacing in the study area has not been investigated. Through research involving different nitrogen fertilizer rates and intra-row spacing, it was determined that analyzing financial profitability is crucial. Consequently, a partial budget analysis was chosen to assess the financial profitability. Partial budget analysis is a farm management tool that can assess the profitability of different farm management practices and estimate comparative financial returns by quantifying the net economic effects of proposed changes” [6]. Therefore, this study was conducted to evaluate the economic feasibility of onion production under different nitrogen fertilizer rates and intra row spacing in the study area through partial budget analysis.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

The research was conducted at the Alamata Agricultural Research Center experimental site in Kara Adishabo, Raya Azobo Woreda, situated in the Southern Zone of Tigray, Ethiopia. The area has a dry, semi-arid climate [7]. It is geographically located between 12°38’50" N to 12°44’36" N latitude and 39°35’10" E to 39°45’10" E longitude. It experiences an annual average precipitation of 543.6 mm, with mean monthly maximum and minimum temperatures of 29.9 °C and 15.9 °C, respectively. The altitude of the Woreda ranges from 1646 to 1670 m.a.s.l. The predominant soil types include vertisoils, nitsoils, combisols, and luvisols, with vertisol being the dominant type, covering more than 70% of the study area [8].

2.2 Experimental Treatments and Field Managements

The experiment included five nitrogen levels (0, 23, 46, 69, and 92 Kg N ha^{-1}) and three intra-row spacings (5, 10, and 15 cm), arranged in a randomized complete block design (RCBD) with three replications. The spacing between blocks and plots was 1.5 m and 1 m, respectively, resulting in a plot area of 2 m × 3 m. This setup comprised 45 plots with 15 treatment combinations covering a total area of 9 m × 59 m, each having eight harvestable rows out of the total ten rows per plot. Onion seedlings were planted in double row spacing, with a furrow spacing of 40 cm and 20 cm between double rows within a furrow, and all agronomic practices were applied based on the crop recommendations [9].

2.3 Data Collection

Data on marketable bulb yield (t/ha) was collected. This refers to the weight of healthy, free of mechanical, disease, and insect pest damage, uniform in color, and marketable bulbs that range from 20 g to 160 g in weight [10]. Data on input costs and net benefits obtained were collected and estimated on a hectare basis.

2.4 Economic Analysis

Economic analysis was conducted using the partial budget method for each treatment, following guidelines from [5]. The aim was to determine the most cost-effective combination of nitrogen fertilizer and plant spacing. The partial budget considered average yields per treatment, adjusted yields, gross field benefit, and total costs, which varied across treatments. Average yields were adjusted downward by 10% to account for potential lower yields that farmers might experience. A minimum acceptable marginal rate of return of 100% was used as the benchmark for farmer recommendations. The economic analysis procedures followed in this study are outlined below.

1. Budgets are formulated on a per-treatment basis, utilizing data from individual experiments or, ideally, from experiments aggregated by recommendation domain.
2. The average yields for each treatment are adjusted downward by a consistent percentage to account for variations in management practices and differences in yield loss resulting from earlier harvests by researchers or different harvesting techniques, reflecting the disparities between experimental and farmer yields.
3. Adjusted yields are multiplied by the field price of the product (sales price minus harvest cost, shelling cost, and transportation cost from the field to the point of sale) to calculate the gross benefit for each treatment.
4. Variable costs associated with treatment changes are deducted from gross benefits to determine the net benefits for each treatment.
5. Dominated treatments are excluded from further consideration. A treatment is deemed dominated if its net benefits are lower and its variable costs are higher than those of any other treatment simultaneously.
6. Marginal rates of return (MRR) are computed for selected treatments to assess the increase in expenditure.
7. A recommended treatment is chosen by incrementally increasing expenditure from less to more expensive treatments until the marginal rate of return (MRR) is slightly higher than the cost of capital for farmers.
8. Risk analysis.

The partial budget analysis was done by using the formulas developed by [3] and described as follows:

Gross return (GR) (ETB/ha) is calculated by multiplying the price received by farmers when they sell the adjusted yield.

Total varying cost (TVC) represents the combined cost of fertilizer (urea), seed, and labor.

Net benefit (NB) (ETB/ha) is the difference between the gross return and the total cost for each treatment.

The marginal rate of return (MRR %) is the ratio of change in net return to change in cost, expressed in percentage.

$$Marginal\ rate\ of\ return = \frac{Marginal\ Benefit}{Marginal\ Cost} \times 100$$

Dominance Analysis: Based on [5], these are the procedures for dominance analysis:

1. Before selecting dominant treatments, list the total costs that vary and the net benefits for each of the treatments in order of increasing their total costs that vary.

2. Any treatment that has net benefits that are less than or equal to those of a treatment with lower costs that vary is dominated (marked with a letter "D").

Eliminate the dominated treatment from further consideration

2.5 Analysis Using Residuals

As per [5], it is recommended to validate the conclusions of a marginal analysis by considering residuals, which represent the variance between the net benefits and the investment cost. Occasionally, the outcomes of the marginal analysis may contradict the net benefits obtained from the experiment. Treatments with higher net benefits may be disregarded if their marginal rate of return is lower compared to other treatments in the same experiments, and vice versa. In such cases, it is important to verify this through residual analysis. Farmers are primarily interested in treatments with the highest residuals. Therefore, when calculating residuals, treatments with higher residuals should be selected. Residuals are determined by subtracting the required return for farmers (the minimum rate of return multiplied by the total varying costs) from the net benefits. It is calculated as follows:

$$Residuals = Farmer's\ return - Net\ benefit$$

Return the farmer that requires represents the return that farmers would require from their investment in order to change their practice.

$$Return\ the\ farmer\ that\ requier =$$

$$Minimum\ rate\ of\ return\ (100\%) x\ Total\ variable\ costs$$

3. RESULTS AND DISCUSSION

3.1 Marketable Bulb Yield

The utilization of various agricultural inputs may or may not be advantageous for farmers. To assess the positive or negative impact of these inputs, partial budget analysis [5] was employed to determine the net benefit and marginal rate of return. This involves examining only the costs, returns, and resource requirements that change with a proposed adjustment. For each treatment combination, the total costs and net benefits were calculated. The variable costs in this experiment included the cost of nitrogen (urea), seed, and labor. These costs varied for each treatment combination. The price for 1 kg of urea was 15 ETB, and for 1 kg of seeds, it was 700 ETB. The cost for daily labor during the season was 100 ETB/day, and the field price of onion during harvesting time was 18 ETB/kg. The net benefit estimate for 15 treatments is presented in Table 1. The application of 69 Kg N ha^{-1} with intra-row spacing of 5 cm resulted in a total net benefit of 642602.3 ETB, followed by Kg N ha^{-1} and 5 cm with a total net benefit of 614035.7 ETB, and 69 Kg N ha^{-1} and 10 cm with a total net benefit of 514061.1 ETB. Conversely, the lowest net benefits were recorded for the application of 0 Kg N ha^{-1} and 15 cm of intra-row spacing, 0 Kg N ha^{-1} and 10 cm of intra-row spacing, 0 Kg N ha^{-1} and 5 cm of intra-row spacing, and 23 Kg N ha^{-1} and 15 cm of intra-row spacing, with net benefits of 242441.6 ETB, 269608.3 ETB, 287503.5 ETB, and 292931 ETB, respectively. The low net benefit obtained may be attributed to the low yield. The profitability analysis revealed that the application of 69 kg N/ha with an intra-row spacing of 5 cm yielded the highest net benefit of 642602.3 ETB. This indicates that as the total varying costs increased to a certain level, the net benefit also increased. The study was in line with the finding of [11], who stated that the application of 123 kg N ha^{-1} nitrogen to narrow-spaced plants (6 cm) recorded the highest net benefit of onion (Eth-Birr 429,569.0).

3.2 Dominance Analysis

The highest net benefits obtained from input applications for crop production may not necessarily be considered favorable by farmers. In many instances, farmers prioritize maximizing profits while minimizing costs and increasing income. Therefore, it is crucial to conduct a dominated treatment analysis. A dominated treatment refers to any treatment with net benefits lower than those of a treatment with lower, varying costs [12]. The dominance analysis procedure outlined in [3] was employed to identify potentially profitable treatments from the tested range, aiming to exclude certain treatments from further consideration and streamline the analysis. The dominant (undominated) treatments were ranked based on their varying costs, from lowest to highest (Table 2).

The dominance analysis revealed that all treatments, except for plots treated with the combined application of 0 Kg N ha^{-1} and 5 cm, 23 Kg N ha^{-1} and 5 cm, 92 Kg N ha^{-1} and 15 cm, 46 Kg N ha^{-1} and 5 cm, 92 Kg N ha^{-1} and 10 cm, and 92 Kg N ha^{-1} and 5 cm, were dominated. This indicates that the net benefit decreased as the total, varying costs exceeded those of the undominated fertilizer treatments. Consequently, farmers are unlikely to choose other dominated treatments over the undominated ones. Additionally, this helps in excluding dominated treatments from further marginal rate of return estimates. The study results match those of [13].

3.3 Marginal Rate of Return

A percentage marginal rate of return was calculated for each pair of ranked treatments. The percentage marginal rate of return between any pair of dominant treatments represents the return per unit of investment in nitrogen fertilizer and intra-row spacing, expressed as a percentage (Table 3).

Table 1. Net benefit estimate of the combined application of nitrogen fertilizer rates and intra row spacing on marketable yield of onion

Treatment combinations N (kg/ha) and spacing (cm)	MY (t/ha)	AMY (t/ha)	FP (ETB/kg)	GFB (ETB/ha)	TVC (ETB/ha)	NB (ETB/ha)
0*15	15.03	13.527	18	243486	1044.44	242441.6
0*10	16.75	15.075	18	271350	1741.67	269608.3
0*5	17.93	16.137	18	290466	2962.5	287503.5
23*15	18.2	16.38	18	294840	1909.02	292931
23*10	18.75	16.875	18	303750	2606.25	301143.8
23*5	19.42	17.478	18	314604	3827.08	310776.9
46*15	22.2	19.98	18	359640	2773.61	356866.4
46*10	23.3	20.97	18	377460	3470.84	373989.2
46*5	27	24.3	18	437400	4691.67	432708.3
69*15	24.1	21.69	18	390420	3641.66	386778.3
69*10	32	28.8	18	518400	4338.89	514061.1
69*5	40.01	36.009	18	648162	5559.72	642602.3
92*15	24.1	21.69	18	390420	4506.25	385913.8
92*10	29.63	26.667	18	480006	5203.48	474802.5
92*5	38.3	34.47	18	620460	6424.31	614035.7

MY= Marketable yield, AMY= Adjusted marketable yield, FP= Field price of onion, GFB= Gross field benefit, TVC= Total variable cost, and NB= Net benefit

Table 2. Dominance analysis of combined application of nitrogen fertilizer rates and intra row spacing on marketable yield of onion

Treatment combinations N (kg/ha) and spacing (cm)	TVC (ETB/ha)	NB (ETB/ha)
0*15	1044.44	242441.6
0*10	1741.67	269608.3
23*15	1909.02	292931
23*10	2606.25	301143.8
46*15	2773.61	356866.4
0*5	2962.5	287503.5D
46*10	3470.84	373989.2
69*15	3641.66	386778.3
23*5	3827.08	310776.9D
69*10	4338.89	514061.1
92*15	4506.25	385913.8D
46*5	4691.67	432708.3D
92*10	5203.48	474802.5D
69*5	5559.72	642602.3
92*5	6424.31	614035.7D

TVC= Total variable cost, NB= Net benefit

Table 3. Marginal rate of return of combined application of nitrogen fertilizer rates and intra row spacing on marketable yield of onion

Treatment combinations N (kg/ha) and spacing (cm)	TVC (ETB/ha)	NB (ETB/ha)	Δ NB	Δ TVC	MRR	MRR (%)
0*15	1044.44	242441.6				
0*10	1741.67	269608.3	27166.77	697.23	38.96386	3896.386
23*15	1909.02	292931	23322.65	167.35	139.3645	13936.45
23*10	2606.25	301143.8	8212.77	697.23	11.77914	1177.914
46*15	2773.61	356866.4	55722.64	167.36	332.9508	33295.08
46*10	3470.84	373989.2	17122.77	697.23	24.55828	2455.828
69*15	3641.66	386778.3	12789.18	170.82	74.86934	7486.934
69*10	4338.89	514061.1	127282.8	697.23	182.5549	18255.49
69*5	5559.72	642602.3	128541.2	1220.83	105.29	10529

TVC= Total variable cost, NB= Net benefit, Δ NB= change in net benefit, Δ TVC= change in total variable cost, MRR= Marginal rate of return

Table 4. Residual of combined application of nitrogen fertilizer rates and intra row spacing

Treatment combinations N (kg/ha) and spacing (cm)	Total variable cost (birr/ha)	Net benefit (birr/ha)	Return required (birr/ha)	Residuals (birr/ha)
0*15	1044.44	242441.6	1044.44	241397.1
0*10	1741.67	269608.3	1741.67	267866.7
23*15	1909.02	292931	1909.02	291022
23*10	2606.25	301143.8	2606.25	298537.5
46*15	2773.61	356866.4	2773.61	354092.8
46*10	3470.84	373989.2	3470.84	370518.3
69*15	3641.66	386778.3	3641.66	383136.7
69*10	4338.89	514061.1	4338.89	509722.2
69*5	5559.72	642602.3	5559.72	637042.6

Transitioning from the treatment with the lowest varying costs to the one with the highest varying costs, the marginal rate of return exceeded the minimum acceptable level. The minimum acceptable marginal rate of return (MARR %) should ideally fall between 50% and 100%, according to [5], with 100% being considered the minimum acceptable rate of return for farmer recommendations in this study. Therefore, the study revealed that the marginal rate of return surpasses 100%, indicating the economic significance of all treatment combinations as their MRR is greater than 100%. Consequently, the application of 46 Kg N ha^{-1} with an intra-row spacing of 15 cm emerged as the top recommendation, yielding a net benefit of 356866.4 ETB/ha. However, the net benefits obtained from the application of 46 Kg N ha^{-1} and 10 cm, 69 Kg N ha^{-1} and 15 cm, 69 Kg N ha^{-1} and 10 cm, and 69 Kg N ha^{-1} and 5 cm exceeded the net benefit obtained from the initial recommendation based on MRR (%). The best recommendation for treatments determined by marginal rate of return is not solely based on the highest MRR but rather on the combination of the highest net benefit and an acceptable MRR, as per [5], leading to further residual analysis.

3.4 Residual Analysis

The marginal rate of return (MRR %) analysis in the study highlighted that the combined application of 0 kg N/ha with an intra-row spacing of 10 cm yielded the highest value. However, as per [5], the findings of a marginal analysis should be validated using the concept of 'residuals,' which represent the variance between net benefits and the investment cost. Sometimes, results from marginal analysis may contradict the net benefits obtained from the experiment. Treatments with higher net benefits could be disregarded if their marginal rate of return is lower compared to other treatments in the same experiment, and vice versa. In such cases, residual analysis becomes crucial. Farmers are inclined towards treatments with the highest residuals. Therefore, when calculating residuals, it is essential to prioritize treatments with higher residual values. Residuals are computed by deducting the required return by farmers (the minimum rate of return multiplied by total varying costs) from the net benefits. The residual represents the variance between net benefits and the required return by farmers. It is important to note that the residual does not equate to profit, and the focus lies on comparing residuals rather than their absolute values. Farmers are inclined towards treatments with the highest residual value, as per [5]. In this scenario, the treatment with the highest residual is 69 Kg N ha^{-1} and 5 cm of intra-row spacing, which differs from the conclusion drawn based on the previous MRR (%). Consequently, we reject the earlier recommendation based on the marginal rate of return (%) of 46 Kg N ha^{-1} and 15 cm of intra-row spacing, yielding a net benefit of 356866.4 ETB/ha, and instead recommend the treatment combination of 69 Kg N ha^{-1} and 5 cm of intra-row spacing (Table 4).

4. CONCLUSION

The partial budget analysis of marketable bulb yield indicated that the highest net benefit of Birr 642602.3 was achieved from the treatment combination of 69 kg N/ha and an intra-row spacing of 5 cm. Despite this, the recommendations based on the marginal rate of return favored Kg N ha^{-1} and 15 cm of intra-row spacing, which had a lower net benefit. Therefore, conducting residual analysis was crucial to validating the accuracy of the MRR (%) recommendation. In this instance, the treatment with the highest residual turned out to be 69 Kg N ha^{-1} and 5 cm of intra-row spacing, while the treatment with the lowest residual was 0 Kg N ha^{-1} and 15 cm, contradicting the previous MRR (%) conclusion. Consequently, we reject the earlier recommendation based on a marginal rate of return (%) of 46 Kg N ha^{-1} and 15 cm of intra-row spacing with a net benefit of 356866.4 ETB/ha, and instead advocate for the treatment combination of 69 Kg N ha^{-1} and 5 cm of intra-row spacing. The residual recorded by plants grown at 69 Kg N ha^{-1} and 5 cm of intra-row spacing exceeded the residual obtained from plants grown at 0 Kg N ha^{-1} and 15 cm of intra-row spacing by about 164%. Hence, applying 69 Kg N ha^{-1} and 5 cm intra-row spacing for onion cultivation could be deemed optimal and more profitable in the study area.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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