



RESEARCH ARTICLE

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Dynamics of Capsaicin Content of Red Chili (*Capsicum annum* L.) under Various Nutrient and Fertilization Statuses



Okto Prandi Sihombing¹, Sarifuddin¹, Mariani Sembiring^{1,*}

Abstract

Accurate fertilization is an important factor affecting plant productivity. Indonesia currently ranks fourth among the world's largest red chili producers, but its productivity remains relatively low. Efforts to increase productivity can be achieved through soil and plant analysis to provide site-specific fertilizer recommendations tailored to plant needs. This study aims to develop site-specific fertilizer recommendations to increase red chili productivity and to analyze the relationship between plant nutrient status and capsaicin content in Lubuk Cuik Village, Lima Puluh Pesisir District, Batubara Regency. The study was conducted at an altitude of 8 m above sea level using a survey method. Plant samples were selected purposively based on differences in variety and harvest time, then analyzed in the laboratory as a basis for compiling fertilizer recommendations. The results showed that the nutrient status of red chili plants at the study site remained below optimal levels. Therefore, site-specific fertilizer recommendations were developed using a combination of three approaches: maintenance, sufficiency, and build. The fertilization guidelines were designed to achieve a yield of 21 tons/ha for the following varieties: Jitu (Urea 531 kg/ha, TSP 92 kg/ha, KCl 258 kg/ha), Laju (Urea 505 kg/ha, TSP 96 kg/ha, KCl 258 kg/ha), and local variety (Urea 513 kg/ha, TSP 94 kg/ha, KCl 255 kg/ha), assuming that crop residues are returned to the field. Multiple regression analysis indicated that the relationship between nutrient status and capsaicin content was not statistically significant ($R^2 = 0.084$). However, nitrogen (N) and sulfur (S) tended to increase capsaicin levels, whereas potassium (K) and phosphorus (P) tended to decrease them. The novelty of this study lies in the simultaneous use of three approaches to link plant nutrient status analysis with site-specific fertilizer recommendations, which is relatively new in red chili research.

Keywords: Capsaicin, Chili Varieties, Growth, Plant Nutrients, Site-Specific Fertilization

1. Introduction

Red chili peppers are a highly valuable horticultural commodity that plays a vital role in both household consumption and the processing industry. Indonesia ranks fourth among global chili pepper producers, following China, Mexico, and Turkey. However, the national productivity of red chili remains low at only 6.84 tons per hectare, significantly lower than China's 21.89 tons per hectare (BPPN, 2013).

One cause of low productivity is inaccurate fertilization. Farmers generally fertilize based on experience or general recommendations listed on fertilizer labels, without referring to site-specific soil analysis results (Widyanti and Susila, 2015). This practice not only reduces fertilizer efficiency but can also cause nutrient imbalances

that lead to yield stagnation (leveling off) (Jabri, 2013). Therefore, site-specific, balanced fertilization is key to increasing red chili productivity (Samijan et al., 2017).

In addition to productivity, the quality of red chili peppers is also determined by their capsaicin content, the bioactive compound responsible for their spiciness. Capsaicin content is influenced by genetic and environmental factors, including nutrient management (Stan et al., 2021). Das et al. (2016) reported that soil N, P, and K showed a very high regression coefficient (R^2) of 0.99, on capsaicin levels in red chili peppers in the Birbhum study area. Other soil properties, including organic carbon, fulvic acid, humic acid, soil respiration, microbial biomass, and soil enzyme activity, also influenced this relationship.

*Correspondence: marianisembiring@usu.ac.id

1) Universitas Sumatera Utara - Jl. Prof. A. Sofyan No. 3. Kampus USU, Medan, Sumatera Utara, Indonesia

Lubuk Cuik Village, located in Lima Puluh Pesisir District, Batubara Regency, is recognized as one of the primary centers of red chili production in North Sumatra. However, its productivity remains low, at 7.1 tons per hectare (BPS, 2021). Given this situation, it is essential to improve both the productivity and quality of chili crops cultivated by farmers in Lubuk Cuik Village. The government depends on this village as a key red chili production center to meet the community's demand. Enhancing productivity can be achieved by applying fertilizers according to recommendations derived from site-specific soil analysis.

2. Material and Methods

This research is planned to take place in the people's red chili garden in Lubuk Cuik Village, Lima Puluh Pesisir District, Batubara Regency, with coordinates 3°16'55.200"N 99°27'0.000"E at an altitude of 8 m above sea level. Analysis of soil properties and plant nutrient levels was conducted at the R&D center laboratory of PT. Nusa Pusaka Kencana and capsaicin content were analyzed at the Soil Chemistry laboratory of the Faculty of Agriculture, University of North Sumatra. The research was conducted from September 2024 to November 2024.

The materials needed are composite soil samples, fresh red chili pepper fruit, plastic bags, label paper and chemicals for soil fertility parameter analysis in the laboratory, as well as other supporting materials.

The tools used are the administrative map of Lubuk Cuik Village, GPS (Global Positioning System), Open Camera, soil drill, machete, hoe, measuring tape, ruler, stationery, documentation tools, and equipment for analyzing soil chemical properties in the laboratory such as Kjeldahlterm digester, UV-Visible Spectrophotometer, flame-based atomic absorption spectrophotometer (*flame AAS*) or graphite (*graphite furnace AAS*), flamephotometer, pH meter, oven, *Orbital Shaker* or *Reciprocating Shaker*, analytical balance, Erlenmeyer flask, measuring flask, beaker, burette, volumetric pipette and other measuring tools for the purposes of analyzing soil properties parameters in the laboratory.

This study used a survey method with field observations, collecting soil and red chili plant samples for laboratory analysis. The data obtained from the analysis included soil chemical properties, plant nutrient levels, and capsaicin content. The collected data were used to develop site-specific red chili plant fertilization recommendations. The relationship between plant nutrient status and capsaicin content was determined by analyzing plant nutrient levels and capsaicin content using multiple regression methods.

Data collection was conducted through direct interviews with the community, farmers, and relevant agencies. Sampling points were determined using purposive sampling, a method of selecting samples based on specific criteria relevant to the research. The sampling

points in this study were determined based on the variety and harvest time of red chili peppers, as follows:

TS1 = Jitu variety red chilies harvested before the 5th week

TS2 = Jitu variety red chilies harvested between the 5th and 7th weeks

TS3 = Jitu variety red chilies harvested after the 7th week

TS4 = Red chili variety Laju harvested before the 5th week

TS5 = Red chili variety Laju at harvest between the 5th and 7th week

TS6 = Red chili variety Laju at harvest after the 7th week

TS7 = Local variety red chilies harvested before the 5th week

TS8 = Local variety red chilies harvested between the 5th and 7th weeks

TS9 = Local variety red chilies harvested after the 7th week

so that nine sampling points were obtained.

Red chili pepper plant and fruit samples were collected at harvest from the same nine locations where soil samples were collected. A whole plant was collected from each location for nutrient analysis, yielding 9 plant samples. Chili peppers from the same plants were also collected, placed in labeled plastic bags, and then weighed for production data. Three fully ripe fruits from each sample were used for capsaicin analysis, while the remaining fruits were used for nutrient analysis.

Samples of red chili plants and fruits were washed, dried in an oven at 65 °C for 48 hours, then ground for analysis of N, P, K, and S content. Extraction was carried out with HNO₃, and N was analyzed by the Kjeldahl method (trimetry), P by spectrophotometry, K by flame photometry, and S by gravimetry. Capsaicin content was measured using a spectrophotometer at a wavelength of 281 nm based on the capsaicin standard curve (Cahyani & Suhastyo, 2020).

Fertilization efficiency was evaluated through nutrient uptake, physiological, and agronomic efficiency, without correction factors for the control treatment. Calculating these three parameters requires data on nutrient uptake, fertilizer application, and yield.

$$\text{Nutrient uptake efficiency} = \frac{\text{Nutrient absorption (g)}}{\text{Nutrient count (g)}} \times 100\%$$

$$\text{Physiological efficiency} = \frac{\text{Production (g)}}{\text{Nutrient absorption (g)}}$$

$$\text{Agronomic efficiency} = \frac{\text{Production (g)}}{\text{Nutrient count (g)}}$$

Fertilization recommendations are determined through three approaches: sufficiency, maintenance, and build. The

sufficiency method adds nutrients when the soil cannot meet plant needs optimally (Susila et al., 2009). The maintenance method replaces nutrients lost during harvest and is typically applied to soils with high nutrient levels or above critical levels. Meanwhile, the build method aims to increase soil nutrient reserves gradually and is generally used in soils with low Olsen P levels (Dinkins & Jones, 2007).

Each formula for calculating fertilizer requirements for the three approaches can be seen as follows:

Sufficiency Approach :

$$\text{Fertilizer Requirements} = \frac{(HS - HDD)}{\frac{100}{\text{fertilizer nutrient content (\%)}}}$$

Maintenance Approach

$$\text{Fertilizer Requirements} = (HTP)$$

$$x \frac{100}{\text{fertilizer nutrient content (\%)}}$$

Build Approach

$$\text{Fertilizer Requirements} = (HTP + (HS - HDD)) \times \frac{100}{\text{fertilizer nutrient content (\%)}}$$

Where,
 HTP = Harvested Nutrients
 HDD = Nutrients that can be absorbed in the soil
 HS = Medium criteria soil nutrients

Data obtained from field and laboratory analyses were analyzed and presented in tables and graphs using tools such as Microsoft Excel and IBM SPSS version 26. The flowchart of the research implementation is presented in Figure 1.

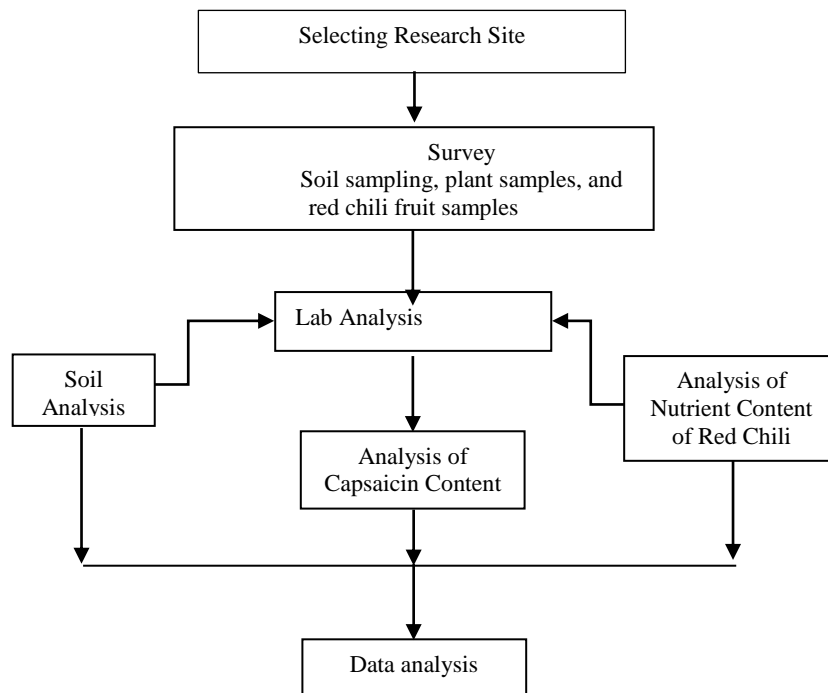


Figure 1. Research flow diagram

3. Results and Discussion

3.1. Nutrient Content of Red Chili Fruit and Plants

Observation data on the nutrient content of red chili fruit and plants in three types of varieties in the people's red chili gardens in Lubuk Cuik village, Lima Puluh Pesisir District, Batubara Regency, at different harvest times are presented in Figure 2 and Table 1.

Figure 2 shows that potassium (K) is the highest primary macronutrient in red chili peppers, with the highest levels in the Jitu variety before week 5 (3.39%) and decreased after week 5, then increased again in the Laju variety after week 7. Nitrogen (N) is in second place with a range of 2.19–2.48% (average 2.33%), followed by phosphorus (P) at 0.402–0.502% (average 0.450%), and

sulfur (S) at 0.25–0.29% (average 0.257%). Analysis of the entire plant (Table 2) shows that most nutrient levels are still below the optimum range according to Fox and Valenzuela (1992), except for S, which is above the optimum limit.

Comparison of nutrient levels in fruit and whole plants (Figure 2 and Table 1) shows a different pattern. N and P contents are higher in fruit, confirming their important role in the generative phase to support flower, fruit, and seed formation (Buckman & Brady, 1980; Veneklaas et al., 2012). Conversely, K levels are higher in vegetative tissue, averaging 3.15% compared to 3.05% in fruit. This result is consistent with K's high mobility within plant tissue and its roles in photosynthesis, enzyme activation, stomatal

regulation, sugar transport, and carbohydrate synthesis (Leigh & Jones, 1984).

These results are supported by the findings of Babanjeet et al. (2022), who reported that the highest red chili production was achieved with a fertilizer combination

of 100 kg N/ha + 30 kg K/ha, with three additional foliar applications of KNO₃. This finding demonstrates that N and K are the primary nutrients involved in biomass production, photosynthate translocation, and increased red chili productivity.

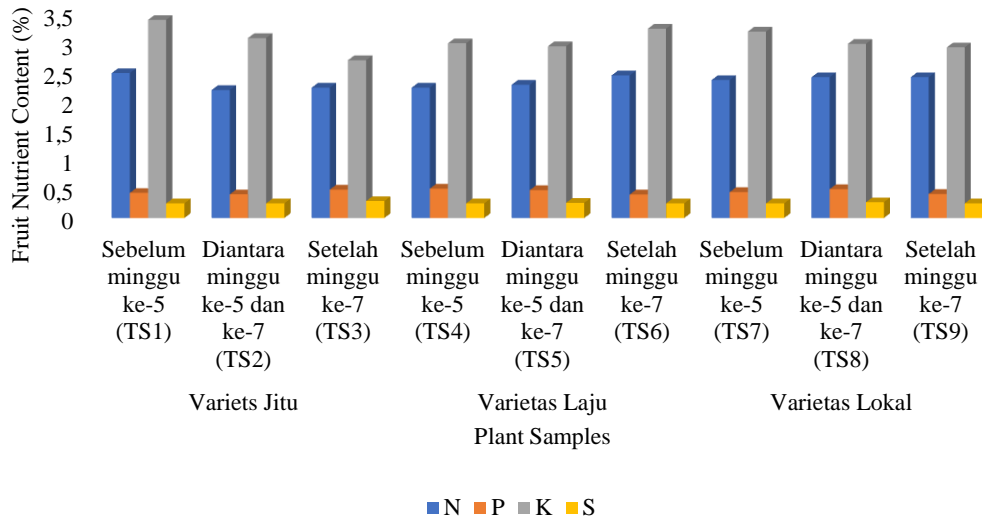


Figure 2. Nutrient content of red chilies

Table 1. Data on the nutrient content of red chili plants

Sample Point	N	P	K	S
	----- % dry weight -----			
TS1	2.59 ^B	0.188 ^B	3.07 ^B	0.39 ^A
TS2	2.49 ^B	0.199 ^B	4.32 ^A	0.34 ^A
TS3	2.03 ^B	0.289 ^B	3.23 ^B	0.50 ^A
TS4	1.77 ^B	0.214 ^B	2.86 ^B	0.54 ^A
TS5	2.27 ^B	0.247 ^B	2.96 ^B	0.57 ^A
TS6	2.13 ^B	0.199 ^B	2.70 ^B	0.37 ^A
TS7	2.56 ^B	0.236 ^B	2.60 ^B	0.48 ^A
TS8	2.25 ^B	0.258 ^B	3.37 ^B	0.63 ^A
TS9	2.42 ^B	0.220 ^B	3.28 ^B	0.35 ^A

Description: A=Above optimum conditions, B=Below optimum conditions

3.2. Capsaicin content of red chilies

Analysis of the capsaicin content of red chili peppers in three types of varieties in the people's red chili gardens in Lubuk Cuik village, Lima Puluh Pesisir District, Batubara Regency, at different harvest times is presented in Table 2.

Table 2 shows that capsaicin content in red chili peppers varies across varieties and harvest times. The highest content was found in the Laju variety (3.87 mg/g, TS5), while the lowest was found in the local variety (1.83 mg/g, TS8). The average capsaicin content was 2.96 mg/g for the Laju variety, 2.81 mg/g for the Jitu variety, and 2.10 mg/g for the local variety, respectively. When converted to Scoville Heat Units (SHU), most chili peppers were categorized as quite spicy, except for the local variety harvested in weeks 5–7 (TS8), which was classified as slightly spicy (2,941 SHU).

The pattern of capsaicin changes differed between varieties. The Jitu variety showed the highest levels at the initial harvest (3.31 mg/g), then decreased in subsequent harvests. The Laju variety had the highest levels at harvest weeks 5–7 (3.87 mg/g). Meanwhile, local varieties fluctuated, with the highest levels at the initial harvest (2.33 mg/g), the lowest at harvest weeks 5–7 (1.83 mg/g), and then increasing again after week 7 (2.15 mg/g).

3.3. The relationship between plant nutrient levels and the capsaicin content of red chilies

The results of observations on the relationship between plant nutrient levels and the capsaicin content of red chili fruit in three types of varieties in the people's red chili garden in Lubuk Cuik village, Lima Puluh Pesisir District, Batubara Regency, at different harvest times are presented in Figure 3 for N nutrients. A pattern between plant N

nutrient levels and the capsaicin content of red chilies is shown in Figure 4.

Table 2. Data on the capsaicin content of red chilies

Sample Point	Capsaicin (mg/g)	Spiciness (SHU)	Category (Weis, (2002))
TS1	3.31	5,334	Quite Spicy
TS2	2.59	4,175	Quite Spicy
TS3	2.52	4,057	Quite Spicy
TS4	2.55	4,111	Quite Spicy
TS5	3.87	6,236	Quite Spicy
TS6	2.45	3,939	Quite Spicy
TS7	2.33	3,746	Quite Spicy
TS8	1.83	2,941	A bit spicy
TS9	2.15	3,456	Quite Spicy

Description: SHU = *Scoville Heat Unit*

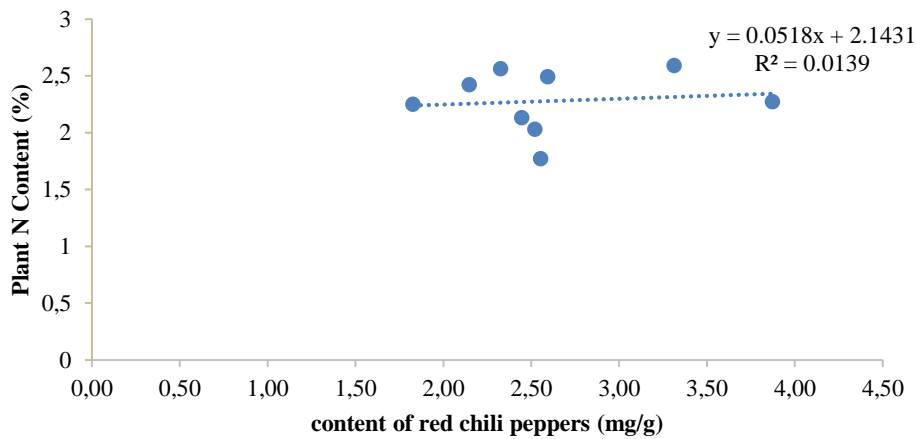


Figure 3. Relationship between plant N nutrient levels and capsaicin content in red chilies

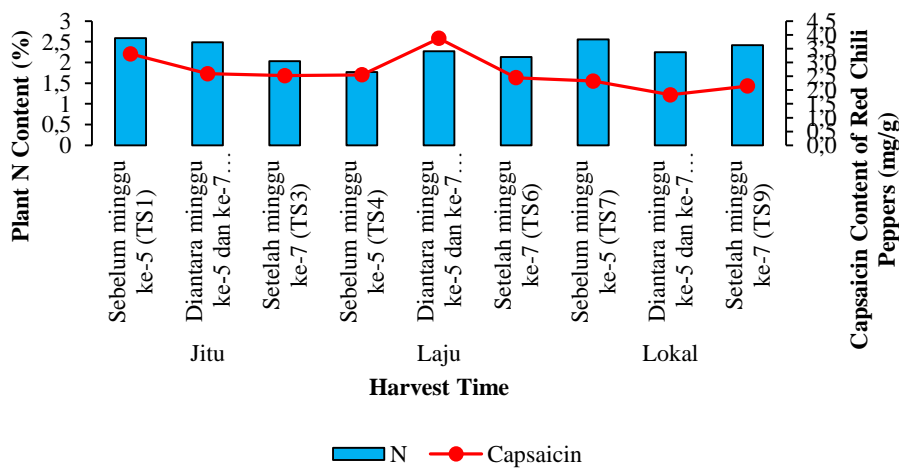


Figure 4. N nutrient levels of plants with capsaicin content in red chilies in three varieties at different harvest times.

Capsaicin is an important secondary metabolite in red chili peppers, the biosynthesis of which involves nitrogen (N) and sulfur (S). Nitrogen plays a role in the formation of amino acids, nucleic acids, pigments, and alkaloids, while sulfur plays a role in the formation of acetyl-CoA, which is

involved in the capsaicin biosynthesis pathway. Several previous studies have shown that N deficiency can reduce levels of capsaicin and dihydrocapsaicin (Zhang et al., 2020; Butnariu & Samfira, 2013). Adequate N availability is crucial for supporting capsaicinoid accumulation.

The results of this study indicate that N nutrient levels have a positive effect on capsaicin content in red chili peppers, although the effect is relatively small ($R^2 = 0.0139$). The regression equation obtained is: Capsaicin content (Y) = 2.734 + 0.383 (Nutrient content). This result indicates that an increase in plant N content is associated with higher capsaicin content, though the relationship is weak. Multiple regression tests also show that overall plant nutrient levels have not significantly affected capsaicin content in Lubuk Cuik Village ($p > 0.05$). One cause is the high variation in nutrient levels between samples, which results in a large distance between the regression line and the observed values. The correlation coefficient (R) of 0.290 also indicates that the relationship between plant nutrient levels and capsaicin content is only weakly correlated.

These findings align with a report by Da Soares *et al.* (2021) that found that N deficiency reduced capsaicin and dihydrocapsaicin levels. Other studies by Tilen *et al.* (2022) and Zhang *et al.* (2024) also showed that N application significantly increased capsaicinoid accumulation

compared to the control. In addition to N, S also plays a significant role. Kumari *et al.* (2017) found that S application at various doses increased capsaicin content, with the T4 treatment producing the highest levels. Therefore, although the effect of nutrients on capsaicin in this study was not significant, previous literature consistently indicates that N and S are essential elements in capsaicin biosynthesis.

3.4. Fertilization Efficiency of Red Chili Plants

Fertilization efficiency consisting of nutrient absorption efficiency, physiological efficiency and agronomic efficiency of red chili plants in the people's red chili garden in Lubuk Cuik village, Lima Puluh Pesisir District, Batubara Regency, on three different varieties, namely Jitu, Laju and local. Data on dry weight, nutrient absorption, and plant production are shown in Table 3, while data on fertilizer efficiency, namely nutrient absorption efficiency, physiological efficiency, and agronomic efficiency, are shown in Table 4.

Table 3. Dry weight, plant nutrient uptake, and production

Sample Point	Dry Fruit Weight	Plant Dry Weight	Production
		-----g-----	
TS1	15.43	158.13	77
TS2	10.77	98.46	54
TS3	6.99	49.56	35
TS4	27.18	127.02	136
TS5	13.68	51.43	68
TS6	37.77	87.24	189
TS7	33.53	75.31	168
TS8	36.92	82.56	185
TS9	12.11	39.98	61

Sample Point	Amount of nutrients provided			Nutrient Absorption		
	N	P	K	N	P	K
		-----g-----			--g/plant-	
TS1	7.75	2.69	7.44	4.48	0.36	5.38
TS2	6.70	2.19	6.64	2.69	0.24	4.59
TS3	6.46	2.24	6.20	1.16	0.18	1.79
TS4	7.50	2.90	6.71	2.85	0.41	4.45
TS5	7.03	2.62	6.46	1.48	0.19	1.92
TS6	9.79	2.24	6.20	2.78	0.33	3.58
TS7	5.81	2.12	4.75	2.72	0.33	3.03
TS8	5.63	1.94	5.42	2.75	0.40	3.88
TS9	8.05	1.75	6.20	1.26	0.14	1.66

Table 3 shows the variation in nutrient uptake (N, P, and K) in three red chili varieties. The highest N uptake was recorded in the Jitu variety before week 5 (TS1) at 4.48 g/plant, while the lowest was in Jitu after week 7 (TS3) at 1.16 g/plant (average 2.46 g/plant). The highest P uptake was obtained in the Laju variety before week 5 (TS4) at 0.41 g/plant, and the lowest in the local variety after week 7 (TS9) (average 0.29 g/plant). The highest K uptake was also in Jitu before week 5 (TS1) at 5.38 g/plant, while the

lowest was in the local variety after week 7 (TS9) at 1.66 g/plant (average 3.36 g/plant).

In general, differences in nutrient uptake are influenced by variations in tissue nutrient content and plant dry weight. Analysis shows that the nutrient status of N, P, and K remains below optimum levels, except for K in the Jitu variety at 5–7 WAP, which exceeds the optimum. Conversely, the S nutrient actually exceeds the optimum condition. The greatest deficiency occurs in the element N,

with an average content of 1.43% and an uptake efficiency of only 35.02%, far below the potential of $\pm 67\%$. The low N efficiency is thought to be due to leaching in former rice fields and excessive irrigation, which reduces soil N availability.

Fertilization efficiency can be assessed by examining data on nutrient uptake efficiency, physiological efficiency, and agronomic efficiency. The efficiency values for each component are shown in Table 4 below.

Table 4. Efficiency of fertilization of red chili plants

Sample Point	Absorption Efficiency		
	N	P	K
		-----%-----	
TS1	58,25	14,55	70,35
TS2	40,13	10,95	69,04
TS3	17,99	7,91	28,87
TS4	38,06	14,07	66,20
TS5	21,04	7,33	29,81
TS6	28,39	14,53	57,74
TS7	46,78	15,37	63,71
TS8	48.84	20.41	71.59
TS9	15.65	7.88	26.86

Sample Point	Physiological Efficiency		
	N	P	K
		-----g/g-----	
TS1	17,23	212,16	14.35
TS2	20.04	224.79	11.74
TS3	30.08	197,23	19.53
TS4	47.61	332.87	30.57
TS5	46,24	355.97	35.54
TS6	67.94	580,29	52.76
TS7	61.65	513.84	55.37
TS8	67.19	467.32	47.55
TS9	48.08	439.63	36,37

Sample Point	Agronomic Efficiency		
	N	P	K
		-----g/g-----	
TS1	10.04	30.87	10.09
TS2	8.04	24,61	8,11
TS3	5,41	15,61	5,64
TS4	18,12	46,82	20,24
TS5	9,73	26,10	10,59
TS6	19,29	84,32	30,47
TS7	28,84	78,96	35,28
TS8	32,82	95,40	34,04
TS9	7,52	34,66	9,77

Table 4 shows that the average nutrient uptake efficiency of red chili peppers follows the order $K > P > N$, with values of 53.80%, 35.02%, and 12.56%, respectively. The highest N uptake efficiency was found in Jitu (TS1, 58.25%), while the lowest was in the local variety after the 7th week (TS9). For P, the highest efficiency was found in the local variety (TS8) and the lowest in Laju (TS5). For K, the highest efficiency was also found in the local variety (TS8, 71.59%) and the lowest in Jitu (TS3, 7.9%).

Physiological efficiency showed the highest P value (369.35 g/g), followed by N (45.12 g/g) and K (33.75 g/g). The highest value was obtained in the Laju variety after the 7th week (TS6) for both N (67.94 g/g) and P (580.29 g/g),

while the highest K was in the local variety (TS7, 55.37 g/g).

Agronomic efficiency was also higher for P (48.60 g/g) compared to N (15.53 g/g) and K (18.25 g/g). The highest values were N = 32.82 g/g (TS8), P = 98.40 g/g (TS8), and K = 35.28 g/g (TS7), respectively, while the lowest values of all three were found in Jitu (TS3). The low P uptake efficiency (12.56%) despite high soil availability is in line with the findings of Syers et al. (2008), that only 15–30% of P can be absorbed by plants. Meanwhile, K uptake decreases during the aging phase, as also observed in soybeans (Fernandez et al., 2009), but overall K efficiency remains higher than N and P due to its moderate–high

availability and diffusion-based absorption (White et al., 2021).

A comparison of varieties showed that local varieties had the highest physiological and agronomic efficiency, meaning each gram of nutrient absorbed resulted in greater biomass and yield, as well as a better response to fertilizer application. Conversely, the Jitu variety had the lowest physiological efficiency, confirming the influence of genetic factors on plant response to fertilizer (Mastrodomenico et al., 2018).

These results confirm that high soil nutrient status does not automatically increase yields, as uptake efficiency is also significantly influenced by rhizosphere conditions.

Improvements can be achieved by adding organic matter and enhancing the role of rhizosphere microbes to support nutrient uptake (Pantigoso et al., 2022).

3.5. Fertilization Recommendations

Based on soil and plant analysis results, recommendations for red chili fertilization in Lubuk Cuik Village were determined using three approaches: *the sufficiency method*, *the maintenance method*, and *the build method*. For N, the *maintenance method* was chosen to prevent excess nitrogen, which could potentially cause eutrophication and negative environmental impacts. The recommendations for each variety are presented in Table 5.

Table 5. Transported nutrients for harvest with a target yield of 21 tons/ha

Variety	STD	STD	STD	STTD	STD	STTD
	N		P		K	
	----- kg/ha -----					
Accurate	96.60	144.97	18.49	23.09	128.38	200.63
Rate	97.30	133.73	19.32	23.22	128.38	178.68
Local	100.52	132.31	18.86	22.00	127.26	167.93

Description: STD=Remaining plants returned, STTD=Remaining plants not returned

In the Jitu variety, N nutrient transported by harvest was 96.60 kg/ha when crop residues were returned, increasing to 144.97 kg/ha when they were not returned. P elements were recorded at 18.49 vs 23.09 kg/ha, and K at 128.38 vs 200.63 kg/ha. In the Laju variety, N was 97.30 vs 133.73 kg/ha, P was 19.32 vs 23.22 kg/ha, and K was 128.38 vs 178.68 kg/ha. The difference in nutrient loss in the Local variety reached 31.79 kg/ha for N, 3.14 kg/ha for P, and 40.67 kg/ha for K.

Different treatment of crop residues affects fertilizer requirements. If crop residues are not returned, fertilizer

doses must be increased to compensate for nutrient losses. However, increasing fertilizer doses risks higher production costs and environmental pollution. Therefore, returning crop residues to the land, despite the additional labor required, is recommended to maintain soil fertility and reduce the negative impacts of overfertilization.

Based on soil and plant analysis data, fertilizer recommendations were prepared using three methods: maintenance, sufficiency, and build. These are shown in Table 8 below.

Table 6. Fertilization recommendations using three approaches

Variety	Urea (46% N)		TSP (46% P ₂ O ₅)		KCL (60% K ₂ O)	
	STD	STTD	STD	STTD	STD	STTD
	----- kg/ha -----					
Balitsa Recommendations						
	328,26		150,00		150,00	
Sufficiency Approach						
Jitu	321,10		th		Th	
Laju	293,46		th		Th	
Lokal	295,02		th		Th	
Maintenance Approach						
Jitu	210,00	315,16	92,07	114,96	257,62	402,60
Laju	211,52	290,72	96,18	115,58	257,62	358,56
Lokal	218,52	287,63	93,88	109,51	255,37	336,98
Build Approach						
Jitu	531,10	636,26	92,07	114,96	257,62	402,60
Laju	504,98	584,17	96,18	130,30	257,62	358,56
Lokal	513,54	582,65	93,88	109,51	255,37	336,98

Description: STD=Plant residue returned (only nutrients transported by fruit are replaced with fertilizer), STTD=Plant residue not returned (nutrients transported by plants and nutrients transported by fruit are replaced with fertilizer), th=not calculated (nutrient content of soil is higher than nutrient content of medium criteria soil).

Fertilization recommendations for red chili peppers in Lubuk Cuik Village are based on a combination of three

approaches: **sufficiency, maintenance, and build**, based on soil nutrient status and plant needs. The sufficiency

approach is applied to land with low nutrient status, where fertilizer is only applied to improve nutrient status to a moderate level. In this study, this method was only used for nitrogen (N), with urea fertilizer requirements of 321.10 kg/ha for the Jitu variety, 293.46 kg/ha for the Laju variety, and 295.02 kg/ha for the Lokal variety. For phosphorus (P) and potassium (K), this approach was not applied because their nutrient status was already above the moderate level.

The maintenance approach is used for soils with moderate to high nutrient status, based on calculating the amount of nutrients transported by the harvest relative to the production target. The analysis results showed that P availability at the study site was far above the critical level, while K was in the moderate-high category. Therefore, the fertilizer recommendation with the condition of returning crop residues to the land is 210.00 kg Urea/ha, 92.07 kg TSP/ha, and 257.62 kg KCl/ha for the Jitu variety; 211.52 kg Urea/ha, 96.18 kg TSP/ha, and 257.62 kg KCl/ha for the Laju variety; and 218.52 kg Urea/ha, 93.88 kg TSP/ha, and 255.37 kg KCl/ha for the Lokal variety. However, if crop residues are not returned, fertilizer requirements increase sharply. For example, the Jitu variety requires 315.16 kg of Urea/ha, 114.96 kg of TSP/ha, and 402.60 kg of KCl/ha.

Meanwhile, the build approach is generally applied to land with low nutrient status to improve long-term soil fertility. However, in this study, the build method yielded the same recommendations as maintenance because the P and K status were already in the high to very high category. Therefore, additional fertilizer beyond the nutrient requirements supplied by harvested crops was unnecessary. Therefore, in this study, N was determined using the build approach due to its low status, while P and K were determined using the maintenance method to maintain long-term soil fertility.

The calculation results show that the TSP fertilizer requirement ranges from 94.04 to 113.35 kg/ha, with the same dosage for both build and maintenance methods. Differences in fertilizer dosage between varieties are more influenced by physiological and agronomic efficiency. The

Jitu variety requires a higher fertilizer dosage than the Laju and Lokal varieties because its efficiency is lower, resulting in relatively small biomass and yield from nutrient uptake. The resulting site-specific fertilizer recommendations are 531 kg/ha of Urea, 92 kg/ha of TSP, and 258 kg/ha of KCl (equivalent to N 244.3 kg/ha; P₂ O₅ 42 kg/ha; K₂ O 154 kg/ha) for the Jitu variety; 505 kg/ha Urea, 96 kg/ha TSP, and 258 kg/ha KCl (equivalent to N 232.3 kg/ha; P₂ O₅ 44.2 kg/ha; K₂ O 154 kg/ha) for the Laju variety; and 514 kg/ha Urea, 94 kg/ha TSP, and 255 kg/ha KCl (equivalent to N 236.2 kg/ha; P₂ O₅ 43.2 kg/ha; K₂ O 153.2 kg/ha) for Local varieties.

Compared with farmers' practices, there is a gap in fertilizer dosage, particularly for N. At the research site, farmers on average apply only 138–162 kg/ha of N, far below the crop requirement of 232–244 kg/ha. This condition explains the low productivity of red chili peppers in Lubuk Cuik Village, so increasing the N fertilizer dose is one of the strategic steps to be taken. Thus, the application of site-specific fertilization based on a combination of these three approaches not only adjusts fertilizer dosage to soil nutrient status but also provides practical guidance to address the gap between scientific recommendations and farmer practices, thereby increasing red chili productivity sustainably.

4. Conclusion

The location-specific fertilization recommendations for red chili peppers in Lubuk Cuik Village, targeting a production of 21 tons/ha, are as follows: for the Jitu variety, apply 531 kg/ha of Urea, 92 kg/ha of TSP, and 258 kg/ha of KCl; for the Laju variety, apply 505 kg/ha of Urea, 96 kg/ha of TSP, and 258 kg/ha of KCl; and for local varieties, apply 513 kg/ha of Urea, 94 kg/ha of TSP, and 255 kg/ha of KCl. The efficiency of phosphorus (P) nutrient absorption is lower than that of the other two primary macronutrients, with the lowest value of 7.33%. The relationship between plant nutrient status and capsaicin content was not significant, as indicated by an R² value of 0.084.

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