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Effects of combined FGD gypsum and chemical fertilizer application based on soil analysis on peanut growth and yield

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ABSTRACT: Effective macronutrient management, informed by soil analysis results and crop requirements, is crucial for enabling farmers to sustainably reduce costs and improve yields. Additionally, the use of soil amendments containing secondary macronutrients, such as gypsum or dolomite, has been recognized for its potential to enhance yield quality. This study examined the effects of integrating flue gas desulfurization gypsum (FGD gypsum) with chemical fertilizer, based on soil analysis results (CFSA), on the production of Peanut cv. Tainan 9. The experiment utilized a 3x5 factorial design within a randomized complete block, comprising three replications. The treatments included three FGD gypsum rates: Control (NFGD), 250 kg/rai (FGD1), and 500 kg/rai (FGD2), along with five chemical fertilizer management practices: Control (NCF), 0.5 CFSA (1-10-5, 5 kg 1stUrea-DAP-MOP, 2ndUrea/rai), CFSA (2-20-10, 10 kg 1stUrea-DAP-MOP, 2ndUrea/rai), 2 times CFSA (4-40-20, 20 kg 1stUrea-DAP-MOP, 2ndUrea/rai), and chemical fertilizer as recommended by the Department of Agricultural Extension (CFDOAE) (12-24-12 fertilizer 50 kg/rai). The study found that FGD gypsum significantly increased the number of pods and seeds per plant, as well as the percentage of filled pods, thereby boosting both dry pod and seed yields. Fertilizer management practices significantly influenced plant growth, yield, and yield components. The 2 CFSA treatment led to the maximum plant height at 60 and 90 days, the highest top dry weight, and the greatest percentage of filled pods. CFSA resulted in the highest number of pods and seeds per plant. CFDOAE achieved the highest pod yield, while CFSA produced the maximum seed yield. No interaction was observed between the rates of FGD gypsum and fertilizer practices in terms of their impact on peanut growth and yield. Applying FGD gypsum and CFSA individually improved economic returns, with their combination optimizing yield and profits, demonstrating the effectiveness of integrated fertilizer management. In conclusion, combining FGD gypsum with soil analysis-based fertilizer application proved more effective in enhancing peanut yield and net revenue compared to the fertilizer management practices evaluated.

Keywords: FGD gypsum; chemical fertilizer application based on soil analysis result; peanut

Introduction

Peanuts (*Arachis hypogaea* L.), a versatile oil-seed legume, play a significant role in various aspects, from nutrition to economy (Akram et al., 2018). Peanuts can be grown in a wide variety of environments. In Thailand, plantations cover a total area of 73,863 rai, yielding 26,597 tons, which represents an average yield of 360 kg/rai. The northern region has the largest area of peanut planting, with planting area in Lampang, Chiang Mai, and Mae Hong Son provinces (Office of Agricultural Economics, 2022). However, the cultivation process is marred by several challenges each growing season, notably the scarcity of quality seeds suitable for planting. Compounded by

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disproportionately high production costs per rai, these factors culminate in yields that are frequently both low and of inferior quality. This is attributed to most farmers using inputs that are not appropriate for their area and lacking proper soil improvement. This predicament is exacerbated by the widespread reliance on traditional farming practices among peanut farmers, particularly the misapplication of chemical fertilizers without consideration for the specific nutrient content of their soil (Office of Agricultural Economics, 2022; Supama, 2015; Sirichumpan et al., 2015). To use chemical fertilizers efficiently and save on production costs, farmers should analyze nutrients in soil before planting to determine the correct fertilizer amount for the plants (Attanandana and Verapattananirund, 2015). Moreover, managing other nutrients, especially micronutrients such as calcium (Ca), magnesium (Mg), and sulfur (S), is crucial for peanut growth and yield. Intasan et al. (2017) reported that in significant peanut plantations in the North, soils often have sandy loam and clay loam textures with insufficient soil calcium and sulfur for growth. A lack of these nutrients affects yield and quality; for example, calcium is essential for pod and seed formation. Calcium deficiency in peanuts often leads pod rot and undeveloped pods, including a decreased number of seeds/plant (Yang and Jie, 2005; Jain et al., 2011). Kamara et al. (2011) reported that application of calcium fertilizer had a positive effect on the number of filled pods. It was found that the percentage of filled pod was 30% higher compared to those without calcium application (Kogram and Phusri, 1997; Sawatdikarn, 2015). Additionally, sulfur plays a role in promoting root nodule formation and seeding; if insufficient, it can significantly reduce seed development and quality (Sawatdikarn, 2015). Therefore, adding soil amendments containing calcium and sulfur can address these nutrient deficiencies.

One of the most important sources of calcium and sulfur for peanuts is gypsum, which occurs naturally and is also obtained as a by-product in coal-fired power plants' sulfur dioxide removal process, known as Flue Gas Desulfurization Gypsum (FGD gypsum) (Norton and Rhoton, 2007). Currently, FGD gypsum is increasingly used in agriculture to improve soil nourishment and as a nutrient source for crop production (Intasan et al., 2017; Sutigoolabud et al., 2017; Kaweewong et al., 2018; Inban et al., 2022). Therefore, studying the use of FGD gypsum in combination with the appropriate amount of chemical fertilizer is another approach to encourage efficient peanut production. Yadav et al. (2015) reported that combining chemical fertilizers with gypsum application resulted in different peanut growth and yield compared to those without fertilizer and gypsum. Similarly, Grichar et al. (2002) showed that proper use of gypsum with chemical fertilizers could also increase peanut yield and quality. However, few studies have been conducted on applying FGD gypsum in combination with chemical fertilizer based on soil analysis results for peanut production in Thailand. Most studies have focused on using gypsum combined with chemical fertilizers as recommended by academic papers (Thippayarugs and Ittipong, 2014; Intasan et al., 2017). Therefore, this study utilizes Flue Gas Desulfurization (FGD) Gypsum in combination with chemical fertilizer, based on soil analysis results, with the objective of evaluating the impact of FGD Gypsum on the growth, yield components, and productivity of the Thai peanut cultivar Tainan 9, cultivated in the Mae Rim soil series. The research further aims to assess the economic benefits after accounting for the costs associated with FGD Gypsum and chemical fertilizer. The outcomes are expected to provide actionable insights for peanut farmers in the region, contributing to the reduction of unnecessary chemical fertilizer use and promoting the sustainable application of by-products from coal-fired power plants in their local and broader communities.

Materials and Methods

Study location and Soil properties

The field experiment was conducted at the Integrated Agricultural Learning Center, following the royal initiatives at Lampang Rajabhat University (18.228°N, 99.484°E), from February to June 2020. Peanut cv. Tainan 9 was cultivated in Mae Rim soil series (loamy-skeletal, mixed, isohyperthermic Typic [Kandic] Paleustults) (Land Development Department, 2005). Soil samples from the area were analyzed to determine their properties, revealing less than 1% organic matter, soil pH of 6.20, and 0.03% total nitrogen. Moreover, the initial measurements of calcium (Ca) and sulfur (S) levels at the experimental site were found to be low, at 245.25 mg/kg, and medium, at 15.10 mg/kg, respectively. Other physical and chemical properties of the soil are presented in **Table 1**.

Table 1 Some selected soil properties in a depth of 0-30 cm before the experiment

Soil Texture [1/]	pH [2/]	EC [3/] (dS/m)	OM [4/] (%)	Total N [5/] (%)	Avail. P [6/] (mg/kg)	Exch. K^{+} [7/] (mg/kg)	Exch. Ca^{2+} [7/] (mg/kg)	Exch. Mg^{2+} [7/] (mg/kg)	Extr. S [8/] (mg/kg)
Sandy Loam - Sand (%): 66.06% - Silt (%): 18.00% - Clay (%): 15.94%	6.20	0.15	0.96	0.03	32.65	113.42	245.25	53.85	15.10

[1/] Pipette method, [2/] 1:2 Soil: Water, [3/] 1:5 Soil: Water, [4/] Walkley-Black Method, [5/] Kjeldahl Method, [6/] Bray II method [7/] Saturating the exchange site and displacing by 1 M NH4OAc, at pH 7.0 and measure by ASS and flame emission spectro-photometer [8/] Calcium Phosphate Extraction Method

Soil samples from the experimental plots were analyzed to determine the levels of nitrogen, phosphorus, and potassium. This analysis was conducted to ascertain the appropriate fertilizer rate based on the soil analysis values for peanuts. The analysis utilized a simple soil nutrient testing kit (Soil Test Kit), following the method described by Attanandana and Verapattananirund (2015). Utilizing the soil test kit enables rapid, on-site assessment of soil fertility, allowing for timely and appropriate adjustments to fertilizer application. This is particularly valuable in large-scale agricultural settings where timely decisions are essential. The results of the soil test kit analysis, which inform the rates of chemical fertilizers used, are detailed in **Table 2**.

Table 2 Soil analysis results using soil test kit and fertilizer recommendations based on soil analysis

Soil Sample	Nitrogen (N) level		Phosphorus (P) level	Potassium (K) level
	Ammonium (NH_4^+)	Nitrate (NO_3^-)		
Mea Rim soil series 18.229°N, 99.485°E	Low	Low	Low	Low

* Chemical Fertilizer based on soil analysis results (CFSA)

Fertilizer rates (1st), top dressing (planting date)

- Urea (46-0-0) 2 kg/rai
- Diammonium Phosphate, DAP (18-46-0) 20 kg/rai
- Muriate of Potash, MOP (0-0-60) 10 kg/rai

Fertilizer rates (2nd), 30 days after planting

- Urea (46-0-0) 10 kg/rai

CFSA application rate: 2-20-10, 10 kg 1stUrea-DAP-MOP, 2ndUrea/rai

***** Attanandana and Verapattananirund (2015)

Experimental Design

The study of effect of the combined use of FGD gypsum and chemical fertilizer based on soil analysis results on growth and yield of peanut cv. Tainan 9 was structured as a 3x5 factorial in a randomized complete block design (RCBD). The experiment comprised two factors, each with three replications. Factor 1: this involved three levels of FGD gypsum application rates: 1) Control (No Addition, NFGD), 2) 250 kg/rai (FGD1), and 3) 500 kg/rai (FGD2). These rates were determined based on research by Intasan et al. (2017) and the recommendations of the Department of Agricultural Extension (2014). Factor 2: This factor consisted of five different chemical fertilizer management practices: 1) Control (NCF), 2) use of 0.5 times CFSA (1-10-5, 5 kg 1stUrea-DAP-MOP, 2ndUrea/rai), 3) use of CFSA (2-20-10, 10 kg 1stUrea-DAP-MOP, 2ndUrea/rai), 4) use of 2 times CFSA (4-40-20, 20 kg 1stUrea-DAP-MOP, 2ndUrea/rai), and 5) chemical fertilizer according to the Department of Agricultural Extension recommendations, using a 12-24-12 formula at a rate of 50 kg/rai (CFDOAE). For the use of CFSA treatments, nitrogen was applied in the form of urea (46-0-0), phosphorus as diammonium phosphate (DAP) (18-46-0), and potassium as potassium chloride (MOP) (0-0-60), following the rates specified in the experimental plan (**Table 3**).

Table 3 FGD gypsum and chemical fertilizer application rates in each treatment

Treatment	FGD Gypsum (kg/rai)	1st Urea (46-0-0) (kg/rai)	DAP (18-46-0) (kg/rai)	MOP (0-0-60) (kg/rai)	2nd Urea (46-0-0) (kg/rai)	12-24-12 Fertilizer† (kg/rai)
Factor 1: FGD Gypsum						
- Control (NFGD)	0					
- FDG1	250					
- FDG2	500					
Factor 2: Chemical Fertilizer						
- Control (NCF)		0	0	0	0	-
- 0.5 CFSA△		1	10	5	5	-
- CFSA△		2	20	10	10	-
- 2 CFSA△		4	40	20	20	-
- CFDOAE†		-	-	-	-	50

△ Chemical Fertilizer based on soil analysis results.

† CFDOAE; Formulations of NPK compound fertilizers with a ratio of 12-24-12 according to the Department of Agricultural Extension recommendations

A total of 45 trial plots, each measuring 2x3 square meters, were established for peanut cultivation. These plots were arranged with an inter-plot spacing of 30 centimeters. To ensure consistent irrigation, a sprinkler water system was installed at 20 strategic points surrounding the trial plots. Prior to planting, Tainan 9 peanut seeds were inoculated with rhizobium. Planting was conducted using a density of three seeds per hole, adhering to a spacing of 25x25 centimeters. The initial fertilization involved applying formulas 46-0-0, 18-46-0, and 0-0-60, based on the rates determined from soil analysis results. Additionally, for CFDOAE treatment, the fertilizer formula 12-24-12 was applied at a rate of 50 kg/rai. Concurrently, FGD gypsum was incorporated with the first fertilizer application as outlined in the experimental plan. At 30 days post-planting, thinning was performed to ensure only two plants remained per hole. This was followed by a second application of nitrogen fertilizer. During the growth phase, the plots received regular watering and weed removal. These maintenance practices were continued until the commencement of the harvesting period, which was approximately 110 days after planting. Data was collected from the entire area of each 2x3 square meter.

Data recording and analysis

Data collection and analysis were conducted to assess the growth and yield of peanuts. The focus was on measuring plant height at 60 and 90 days, above-ground dry weight, the number of pods and seeds per plant, filled pod percentage, shelling percentage, harvest index (HI), and the yields of both pods and seeds. An economic analysis was also integral to this study, involving the calculation of net economic returns from peanut yields, while considering the costs of using FGD gypsum and chemical fertilizers. Analysis of variance (ANOVA) was applied to examine significant differences across all data, using Statistix version 8.0, a standard statistical software. This approach ensured a detailed evaluation of the effects of various treatments on peanut plant growth, yield, and economic viability.

Results

Growth and yield components

The effect of the combined use of FGD gypsum and chemical fertilizer based on soil analysis results (CFSA) on growth and yield components of peanut cv. Tainan 9 is presented in Tables 4 and 5. The results indicated that the application of FGD gypsum did not significantly affect the growth parameters of peanut plants, specifically in terms of plant height at 60 and 90 days, as well as the above ground dry weight. However, the different fertilizer management practices demonstrated a highly significant impact ($p \leq 0.01$) on these growth aspects. Notably, the application of chemical fertilizer at 2 CFSA (4-40-20, 20 kg 1stUrea-DAP-MOP, 2ndUrea/rai) resulted in the most pronounced growth. Specifically, plant heights at 60 and 90 days were recorded at 29.33 and 51.33 cm, respectively. Furthermore, the highest average Above ground dry weight was observed at 21.35 grams/plant (**Table 4**).

Table 4 Effect of the combined use of flue gas desulfurization gypsum (FGD gypsum) and chemical fertilizer based on soil analysis results (CFSA) on peanut growth

Treatment	Plant height (60 DAP) (cm)	Plant height (90 DAP) (cm)	Above ground dry weight (g/plant)
FGD Gypsum (FGD)			
- Control (0 kg/rai)	22.27	47.01	17.41
- FGD1 (250 kg/rai)	22.12	47.14	15.86
- FGD2 (500 kg/rai)	22.23	47.13	19.02
Chemical Fertilizer (CF)			
- Control	23.75^{c}	41.75^{c}	10.25^{b}
- 0.5 CFSA$^{\triangle}$	26.95^{b}	43.67^{c}	17.67^{a}
- CFSA$^{\triangle}$	28.55^{ab}	50.55^{a}	19.09^{a}
- 2 CFSA$^{\triangle}$	29.33^{a}	51.33^{a}	21.35^{a}
- CFDOAE†	27.44^{b}	48.16^{b}	18.53^{a}
F-test			
FGD	ns	ns	ns
CF	**	**	**
FGD x CF	ns	ns	ns
C.V. (%)	4.36	3.13	18.01

CFSA; $^{\triangle}$ Chemical Fertilizer based on soil analysis results

† CFDOAE; Formulations of NPK compound fertilizers with a ratio of 12-24-12 according to the Department of Agricultural Extension recommendations

Means followed by the same letters are not statistically different ($P \leq 0.05$) from each other according to Tukey HSD

* = significant at 0.05, ** = significant at 0.01 and ns = non-significant

In the assessment of yield components, the application of Flue Gas Desulfurization (FGD) Gypsum was observed to have no significant effect on the percentage of shelling and harvest index. However, varying levels of FGD gypsum significantly influenced the number of pods per plant and the number of seeds per plant ($p \le 0.05$), as well as the percentage of filled seed ($p \le 0.01$). Specifically, the application of FGD gypsum at a rate of 500 kg/rai (FGD2) resulted in the highest average number of seeds per plant, at 25.6 seeds, and the highest percentage of filled seed, calculated to be 91.20%. Regarding different fertilizer management practices, a significant effect was noted on the number of pods per plant and the percentage of filled seed ($p \le 0.01$), as well as on the number of seeds per plant ($p \le 0.05$). The application of CFSA (2-20-10, 10 kg 1stUrea-DAP-MOP, 2ndUrea/rai) yielded the highest average number of pods per plant and number of seeds per plant for peanuts, recorded at 15.9 pods and 28.2 seeds, respectively. Moreover, applying 2 CFSA (4-40-20, 20 kg 1stUrea-DAP-MOP, 2ndUrea/rai) led to the highest percentage of filled seeds at 90.17%. Yet, there was no significant statistical difference between CFSA (2-20-10, 10 kg 1stUrea-DAP-MOP, 2ndUrea/rai) and CFDOAE (12-24-12 fertilizer 50 kg/rai) treatments. Additionally, analyzing the interaction between FGD gypsum rates and chemical fertilizer management showed no statistical difference. (**Table 5**)

Table 5 Effect of the combined use of flue gas desulfurization gypsum (FGD gypsum) and chemical fertilizer based on soil analysis results (CFSA) yield component of peanut

Treatment	Number of Pods per plant (pods)	Number of Seeds per plant (seeds)	Filled seed (%)	Shelling (%)	HI
FGD Gypsum (FGD)					
- FGD0 (0 kg/rai)	12.6^{b}	21.8^{b}	83.08^{b}	43.49	0.30
- FGD1 (250 kg/rai)	14.6^{a}	25.5^{a}	88.73^{a}	42.45	0.37
- FGD2 (500 kg/rai)	14.6^{a}	25.6^{a}	91.20^{a}	46.46	0.34
Chemical Fertilizer (CF)					
- NCF$^{\varnothing}$	10.63^{c}	17.8^{c}	83.82^{b}	41.81	0.35
- 0.5 CFSA$^{\Delta}$	12.8^{bc}	22.0^{bc}	86.93^{ab}	43.15	0.31
- CFSA$^{\Delta}$	15.9^{a}	28.2^{a}	88.66^{a}	46.45	0.34
- 2 CFSA$^{\Delta}$	14.9^{ab}	26.3^{ab}	90.17^{a}	45.91	0.30
- CFDOAE†	15.5^{ab}	27.4^{a}	88.70^{a}	43.33	0.35
F-test					
FG	*	*	**	ns	ns
CF	**	*	**	ns	ns
FG x CF	ns	ns	ns	ns	ns
C.V. (%)	14.60	14.74	3.44	12.34	17.7

$^{\varnothing}$ NCF; No chemical fertilizer CFSA; $^{\Delta}$ Chemical Fertilizer management based on soil analysis results

† CFDOAE; Formulations of NPK compound fertilizers with a ratio of 12-24-12 according to the Department of Agricultural Extension recommendations

Means followed by the same letters are not statistically different ($P \le 0.05$) from each other according to Tukey HSD

* = significant at 0.05, ** = significant at 0.01 and ns = non-significant

Pod and seed yield

The effect of the combined use of FGD gypsum and chemical fertilizer based on soil analysis results (CFSA) on seed and pod yield of peanut cv. Tainan 9 is presented in **Tables 6.** The study revealed that the application of FGD gypsum significantly affected the weight of both pod yield and seed yield ($p \leq 0.01$). An increase in FGD gypsum application correlated with higher weights in pod and seed yields. Specifically, at an application rate of 500 kg/rai, the average weights for pod and seed yields were recorded at 144.78 kg/rai and 311.18 kg/rai, respectively. Regarding fertilizer management practices, the CFDOAE application (12-24-12 fertilizer 50 kg/rai) yielded the highest average pod weight at 328.42 kg/rai, showing no significant difference from other treatments except for the control. Conversely, applying CFSA (2-20-10, 10 kg 1stUrea-DAP-MOP, 2ndUrea/rai) yielded the highest average seed yield weight at 146.55 kg/rai. The interaction between the rate of FGD gypsum and fertilizer management practices did not significantly influence the weights of pod and seed yields.

Table 6 Effect of the combined use of flue gas desulfurization gypsum (FGD gypsum) and chemical fertilizer based on soil analysis results (CFSA) on yield of peanut and economic returns

Treatment	Seed yield (kg/rai)	Pod yield (kg/rai)	Net revenue (Baht/rai)
FGD Gypsum (FGD)			
- FGD0 (0 kg/rai)	99.59^{b}	222.90^{b}	9,611.9^{b}
- FGD1 (250 kg/rai)	125.58^{ab}	293.62^{a}	12,262. ^{ab}
- FGD2 (500 kg/rai)	144.78^{a}	311.18^{a}	12,951.3^{a}
Chemical Fertilizer (CF)			
- NCF	76.92^{b}	188.44^{b}	8,605.3^{b}
- 0.5 CFSA$^{\Delta}$	114.29^{ab}	263.71^{ab}	11,512.7^{ab}
- CFSA$^{\Delta}$	146.55^{a}	313.84^{a}	13,254.3^{a}
- 2 CFSA$^{\Delta}$	136.06^{a}	296.77^{a}	11,880.5^{ab}
- CFDOAE†	142.87^{a}	328.42^{a}	12,789.4^{ab}
F-test			
FG	**	**	**
CF	**	**	*
FG x CF	ns	ns	ns
C.V. (%)	25.18	23.70	26.32

$^{\Delta}$ CFSA; Chemical Fertilizer management based on soil analysis results

† CFDOAE; Formulations of NPK compound fertilizers with a ratio of 12-24-12 according to the Department of Agricultural Extension recommendations

Means followed by the same letters are not statistically different (P ≤ 0.05) from each other according to Tukey HSD

* = significant at 0.05, ** = significant at 0.01 and ns = non-significant

Cost and prices used in the calculation of economic dominance:

FGD gypsum = 500 baht/ton (FG1 = 0 baht/rai, FG2 = 125 baht/rai and FG3 = 250 baht/rai (Sutigoolabud, 2017)

Nitrogen fertilizer: Urea (46-0-0) = 26.14 baht/kg; Phosphorus fertilizer: Diammonium Phosphate, DAP (18-46-0) = 28.25 baht/kg; Potassium fertilizer: Muriate of Potash, MOP (0-0-60) = 28.17 baht/kg (Office of Agriculture Economics, 2023) and 12-24-12 fertilizer (formulations of NPK compound fertilizers) = 2,300 baht/kg, Price of dry pod = 30 baht/kg (Office of Agriculture Economics, 2022) with a ratio of 12-24-12 according to the Department of Agricultural Extension recommendations

The economic analysis of this experiment involved calculating the net revenue, determined by deducting the costs of FGD- Gypsum and chemical fertilizer from the total returns. Detailed cost figures, including the price of pod yield, are provided in the notes accompanying Table 6. The study found that both the application rate of FGD gypsum and the chemical fertilizer management practices significantly influenced the average pod yield of peanuts ($p \leq 0.05$). Specifically, applying FGD gypsum at a rate of 500 kg/rai resulted in an average return of 12,951.3 Baht/rai. In terms of fertilizer management, the application of CFSA (2-20-10, 10 kg 1stUrea-DAP-MOP, 2ndUrea/rai) values yielded the highest average return, calculated at 13,254.3 Baht/rai. Regarding the interaction between the rate of

FGD gypsum and fertilizer management practices, no significant effect was observed on the average return after accounting for the costs of FGD gypsum and chemical fertilizer across all treatment.

Discussion

Although the application of FGD gypsum did not significantly impact plant height and top dry weight accumulation, its application rate was found to influence the number of seeds per plants, the percentage of filled seed, and the dry weight of pods and seeds. Additionally, it tended to increase the number of pods per plant. These findings align with both national and international research, which similarly reports that the addition of gypsum, in conjunction with appropriate fertilizer, can enhance the quality and quantity of peanut yields more effectively than without gypsum (Intasan et al., 2017; Saelee et al., 2018; Adam et al., 1993; Sorensen and Butts, 2008; Yadav et al., 2015; Waitrak et al., 2006; Arnold et al., 2017; Bairagi et al., 2017). Sawatdikarn (2015) emphasized that calcium, a key component of gypsum, is crucial for pod and seed formation in peanuts. The addition of calcium to soil not only increases yields but also contributes to the development of fully formed pods by ensuring structural support through cell wall formation, facilitating nutrient transport, and activating enzymes critical for metabolic processes (Sawatdikarn, 2015). Additionally, calcium aids in the plant's response to environmental cues and stress, and improves water use efficiency, making it instrumental in the successful development of peanut pods and seeds (Pegues et al., 2019). Conversely, a calcium deficiency can lead to reduced yields and abnormal seed development, characterized by incomplete seed set in the pod. Ratanarat (1992) (as cited by Sawatdikarn, 2015) conducted a study on the Tainan 9 peanut variety in calcium-deficient soil, observing low pod emergence, reduced number of seed per plant, and predominantly atrophied and incomplete seeds within the pods. Further research by Kogram and Phusri. (1997) demonstrated that soil calcium supplementation could increase the percentage of filled seeds in peanuts to between 69.0-83.2%, compared to a maximum of 44.4% in calcium-deficient plots, corroborating findings by Gascho and Davia (1994), Murata (2003), and Sorensen and Butts (2008). These studies collectively affirm that adding soil amendments containing calcium around the peanut root zone can enhance product quality and mitigate the issue of incomplete seed development in peanut pods. This consensus across national and international research underscores the efficacy of gypsum as a calcium source in boosting the quality and quantity of peanut yields, thereby supporting the agricultural practice of calcium amendment for optimal peanut cultivation.

The application of chemical fertilizers demonstrated a significant response in terms of growth, yield component, and yield when adequate nutrients were provided to peanut plants. It was observed that almost all parameters were not statistically different from those of peanuts fertilized by other treatment, except in cases where no chemical fertilizers were applied or only half the recommended amount based on soil analysis results was used. The guidelines for applying chemical fertilizers in various forms suggest that adequate provision to plants results in better growth and yield compared to scenarios where fertilizers are either not added or added in insufficient quantities. This finding aligns with the research of Mahmowd et al. (2014), which indicated that increasing the N-P-K fertilizer rate from a ratio of 5:5:4 to 10:7.5:8 kg/area significantly enhanced the height, number of pods per plant, pod weight/plant, and seed weight/plant of peanuts grown in sandy soil by 17.77%, 50.60%, 53.06%, and 79.80%, respectively. Similarly, Ihejirika et al. (2006) studied the impact of varying N-P-K fertilizer levels on the yield of peanuts in sandy clay loam soil. They found that applying N-P-K fertilizer (formula 15-15-15) at a rate of 130 kg/ha increased the average peanut yield over two years by 44.70% and 7.64% compared to the absence of chemical fertilizers and application at less than half recommended rate. Sawatdikarn (2015) reported that in low-fertility soils, the application of chemical fertilizers, particularly nitrogen, phosphorus, and potassium, is crucial. This is further supported when peanuts are supplemented with adequate amounts of calcium, magnesium, and sulfur as micronutrients. Such nutrient provision can enhance the development and growth of peanuts to their full varietal potential. Additionally, production components such as the number of pods per plant, number of seeds per pod, number of seeds per plant, and the percentage of filled seeds are improved, resulting in higher yields than when these primary nutrients are not added (Seran, 2016; Priya et al., 2009; Bekele et al., 2019; Suwannarat et al., 1992, as cited by Sawatdikarn, 2015; Suriyaphan and Petchawee, 1995)

The study revealed that the average net revenue from peanut cultivation, after accounting for the costs of FGD gypsum and chemical fertilizers, was significantly different ($P \leq 0.05$). The application of FGD gypsum at a rate of 250 kg/rai resulted in the highest return, post deduction of chemical fertilizer costs. This outcome can be attributed to the experimental findings that adding FGD gypsum to the soil significantly increases both pod and seed weights in peanuts. Additionally, the cost-effectiveness of FGD gypsum, a by-product of coal-fired power plants priced at only 20-30 baht/ton (Sutigoolabud et al., 2017), contributes to higher net revenue in the treatments. Furthermore, applying fertilizer based on soil analysis results yielded the highest returns after accounting for the cost of chemical fertilizers. The net revenue was higher than that obtained by following the Department of Agricultural Extension's recommendations (12-24-12 formula at 50 kg/rai) and applying double the fertilizer amount as per soil analysis values, with differences amounting to 464.6 and 1,373.5 baht/rai, respectively. This finding aligns with research by Kaweewong (2020), Isuwan (2016), and Isuwan (2014), who observed that applying chemical fertilizers based on soil analysis results or in response to rice cultivation needs results in comparable returns to those obtained from increasing fertilizer application by 2-3 times, thereby enhancing net revenue post-fertilizer costs compared to other fertilizer management practices. Moreover, Khewaram (2016) conducted an experiment with Suphanburi 1 rice in the Phetchaburi soil series, applying fertilizer based on soil analysis results. It was concluded that this method offered the highest net profit return to farmers compared to traditional fertilization methods, which incurred higher rice production costs. The cost of fertilizer usage was reduced by 31.12%, corroborating the report by Attanandana and Verapattananirund (2015), who stated that applying chemical fertilizers based on soil and plant needs can decrease fertilizer costs and increase yields for farmers.

Conclusion

Using FGD gypsum notably increases the number of pods and seeds per plant, as well as the percentage of filled seeds in Peanut cv. Tainan 9, thereby enhancing both dry pod and seed yields. Chemical Fertilizer management practices significantly affected plant growth and yield. Doubling the chemical fertilizer rate based on soil analysis results in improved plant height at 60 and 90 days and maximized the top dry weight and the percentage of filled seeds. Using CFSA (2-20-10, 10 kg 1stUrea-DAP-MOP, 2ndUrea/rai) achieved the highest number of pods and seeds per plant, averaging 15.94 and 28.19, respectively. In terms of production, applying CFSA (2-20-10, 10 kg 1stUrea-DAP-MOP, 2ndUrea/rai) and CFDOAE (12-24-12 fertilizer 50 kg/rai) led to the highest yields in dry seeds and pods. There was no significant interaction between FGD gypsum application rates and fertilizer management practices on the peanut's growth and yield. Economically, applying FGD gypsum at 500 kg/rai resulted in the highest average return of 12,951.3 baht/rai, applying CFSA (2-20-10, 10 kg 1st Urea-DAP-MOP, 2nd Urea/rai) yielded the highest average return of 13,254.3 baht/rai. The combination of FGD gypsum with CFSA appeared to optimize both yield and economic returns. This synergy suggests a promising approach for enhancing agricultural productivity and profitability in peanut cultivation.

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