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RESEARCH ARTICLE

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Impact of Sulphur Application Timing and Phosphate Doses on Soluble Phosphorus, Growth, and Yield of corn in Calcareous Soil.

Muslim Rasul Arab Khoshnaw

Department of Soil and Water, College of Agricultural Engineering Sciences, Salahaddin University-Erbil, Kurdistan Region, IRAQ.

*Corresponding Author: muslim.khoshnaw@su.edu.krd.

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ABSTRACT

This study investigates the effects of sulphur application timing and phosphorus dosage on phosphorus availability, growth, and yield quality of corn in calcareous soils at the Grdarasha field, Agriculture College of Engineering Science, Salahaddin University–Erbil. The experiment was designed as a randomized complete block design (RCBD) with three replications across 12 treatment combinations, incorporating sulphur applications at varying timings (control, 15 days before planting, at planting, and 15 days after planting) at a rate of 300 kg sulphur ha^{-1} and triple super phosphate (TSP) at doses of (0, 60, and 160) kg ha^{-1}.

Results demonstrated that sulphur applied 15 days before planting significantly enhanced Growth traits, and, yield quality the highest grain yield, straw yield, total dry matter values (14.74, 8.49, 23.23) t ha^{-1}respectively, and 1000-seed weight (423 g). In contrast, the control treatment exhibited the lowest values, underscoring sulphur's critical role in nutrient availability during early growth stages. While leaf area did not show significant variation across treatments, the synergy between early sulphur application and higher phosphorus doses markedly improved other presentation, particularly with the St1P2 treatment yielding 17.23 t ha^{-1} of grain and 431.67 g for 1000-seed weight.

Phosphorus availability was significantly influenced by both sulphur timing and TSP dosage, with the highest phosphorus solubility observed in treatments where sulphur was applied 15 days before planting and in combination with 160 kg ha^{-1} TSP. This study highlights the importance of optimizing sulphur and phosphorus fertilization strategies in calcareous soils, which typically restrict phosphorus solubility due to high pH and calcium content. The findings provide valuable insights for improving fertilizer management practices to enhance crop productivity in nutrient-deficient soils.

***Keywords*:** Phosphorus Solubility, Corn yield and quality, Calcareous Soils, Sulphur fertilization.

INTRODUCTION

In calcareous soils, the timing of sulphur (S) application and the dosage of phosphate (P) are crucial for enhancing crop productivity. These soils, characterized by high pH and elevated calcium carbonate levels, often limit nutrient availability, particularly phosphorus. Sulphur plays a vital role in modifying soil properties, primarily by lowering pH, which enhances phosphorus solubility and availability [1]. When sulphur is applied prior to planting, it creates acidic conditions that promote the release of phosphorus that would otherwise remain bound to calcium compounds, benefiting early growth phases in crops for corn [2].

The timing of sulphur (S) application and the dosage of phosphate (P) are key factors that influence crop productivity in calcareous soils, their high pH and elevated levels of calcium carbonate, these soils typically limit the availability of certain nutrients, particularly phosphorus. Effective management of S and P is necessary to improve phosphorus solubility, foster plant development, and ultimately enhance crop yield quality [3,4]. The coordinated application of these nutrients, with careful attention to timing, can significantly impact plant responses in such nutrient-restricted environments. Phosphorus (P) is essential for the growth and productivity of plants. When there is a deficiency of P, it can cause substantial yield losses, and the ongoing depletion of phosphorus in industrial agriculture is increasingly recognized as a significant threat to food security [5].

The interaction between phosphate dosage and plant response in calcareous soils is complex. Due to phosphorus fixation by calcium carbonate, higher phosphorus applications are frequently required. However, careful management is necessary to prevent environmental issues and maximize crop uptake [5]. Recent studies suggest that moderate phosphorus applications, combined with appropriately timed sulphur applications, significantly improve phosphorus availability, enhancing nutrient uptake and promoting better crop growth and yield quality [6,7].

The combined effects of sulphur application timing and phosphate dosages are critical in influencing soluble phosphorus levels, plant growth, and yield in calcareous soils. Applying sulphur strategically, such as before planting, in rhizosphere for short time due high buffering capacity of calcareous soil, this short time decrease in pH causes increase in availability of nutrients., thereby enhancing phosphorus solubility and availability [8]. Sulphur application aligns with plant growth stages, leading to improved phosphorus uptake and increased yields [6]. By optimizing the synergy between sulphur and phosphate, effective nutrient management strategies can significantly boost crop performance [9].

Materials and methods

Soil Preparation and Experimental Design

The soil was prepared using conventional tillage methods, followed by surface softening with a rotavator. The experiment was conducted in a randomized complete block design (RCBD) with three replications, 12 treatment combinations. **Fertilization**: The fertilization regime included sulphur application timings S0=control, S1=15 days before planting, S2=at planting, and S3=15 days after planting at a rate of 80 g per plot equal 300 kg ha^{-1}.Triple super phosphate was applied at three levels: P0=control, P1=60 and P3=160 kg TSP ha^{-1}. Each plot area was 3 m^2, and there were 12 plots per replication. Corn plants were arranged with 16 plants per plot, spaced in two rows of eight. Soil samples were collected before planting from a 0–30 cm depth across ten locations within the experimental field, using a soil auger, for subsequent chemical and physical analyses.

Soil Sampling and Analysis

Composite soil samples were collected from the 0–30 cm depth before planting. The samples were air-dried, sieved through a 2 mm mesh, to both analysis physical and chemical analyses.

Physical Analyses:

Physical properties of the soil were assessed, including particle size distribution using the pipette method [10] and soil moisture content at field capacity (0.33 kPa) and permanent wilting point (1500 kPa). **Chemical Analyses:**

The chemical properties of the soil were evaluated for several key parameters. Total nitrogen was determined using the Kjeldahl method [11], while available phosphorus was measured using the method of [12]. Potassium content was analysed by flame photometry [11], and calcium and magnesium were determined through EDTA-2Na titration. Soil pH was measured with a pH meter, and electrical conductivity (EC) was analysed in a saturated soil extract. Organic matter content was quantified using the Walleye-Black method, and both total and active calcium carbonate content were determined by acid neutralization and titration methods [13] as shown in table (1

Table 1: Some chemical and physical properties of the studied soils

Physical properties		Value	Unit
	Sand	99.0	
Particle Size Distribution	Silt	521.5	g Kg^{-1}
	Clay	379.5	
Textural name	Silty clay loam		
Chemical properties	Amount		Unit
pH	7.81		
ECe	0.65		dS m^{-1}
Organic matter	9.13		g Kg^{-1}
Carbonate mineral$CaCO_3$	230		g Kg^{-1}
Active $CaCO_3$	14.8		g Kg^{-1}
Total Nitrogen	0.32		g Kg^{-1}
Available Phosphorus	2.73		mg Kg^{-1}
CEC	24.18		Cmolc K g^{-1}
cations			meq L^{-1}
Calcium	4		
Magnesium	1.9		
Anions			meq L^{-1}
Chloride	2.1		
Bicarbonate	3.75		

Determination of soluble Phosphorus for solubility diagram:

Phosphorus in soil has been extracted by using distilled water with 0.01 M KCl and determined spectrometric ally according to [12]. The chemical analysis and calculations for drawing solubility diagram reported by [14]**.** Double function parameters consisting of phosphate potential ($logH_2PO^-_4$-pH) and lime potential (log Ca^{2+} + 2pH) against lime potential (pH – ½ PCa) were used to construct a solubility diagram for calcium phosphate minerals. It was assumed that the free ion activity of $H_2PO^-_4$ was controlled by lime potential and pH based on published solubility product (Ksp). It was also assumed that the solubility of phosphate in calcareous soils is controlled by a solid phase of calcium phosphate minerals listed in tables 2 and 3. [15]

Table 2: Calcium phosphate phases, reactions and Ksp used in the construction of a phosphate solubility diagram.

Mineral	Formulae	Equation	Ksp

Monocalcium phosphate (MCP)	$Ca(H2PO._4)_2.H_2O$	$Ca\ (H_2PO_4)_2.\ H_2O \leftrightarrow Ca^{2+} + 2H_2PO_4^- + H_2O$ $*2H^+ {=}{=}{=}{=}{=} 2H^+$ $Log\ H_2PO_4^- - pH = -0.575 - 0.5\ (Log\ Ca^{2+} + 2pH)$	-1.15
Dicalcium phosphate (DCP)	$CaHPO_4$	$CaHPO_4 + H^+ \rightleftharpoons Ca^{+2} + H_2PO_4^-$ $H^+ {=}{=}{=}{=}{=} H^+$ $Log\ H_2PO_{4-} - pH \rightleftharpoons 0.3 - (LogCa^{2+} + pH)$	0.3
Brushite (DCPD)	$CaHPO_4.2H_2O$	$CaHPO_4.2H_2O + H^+ \rightleftharpoons Ca^{+2} + H_2PO_{4-} + 2H_2O$ $H+ {=}{=}{=}{=}{=}{=} H+$ $Log\ H_2PO_{4-} - pH = 0.63 - (LogCa^{2+} + 2pH)$	0.63
β-Tricalcium phosphate	$Ca_3(PO_4)_2$	$Ca_3(PO4)_2 + 4H^+ \rightleftharpoons 3Ca^{2+} + 2H_2PO_{4-}$ $2H^+ {=}{=}{=}{=}{=}{=} 2H^+$ $Log\ H_2PO_{4-} - pH \rightleftharpoons 5.09 - 1.5\ (Log\ Ca_{2+} + 2pH)$	10.18
Octacalcium phosphate (OCP)	$Ca_4H(PO_4)3.2.5H_2O$	$Ca_4H(PO_4)_3.2.5H_2O + 5H^+ \rightleftharpoons 4\ Ca^{+2} + 3H_2PO_4^- + 2.5H_2O$ $3H^+ {=}{=}{=}{=}{=}{=} 3H^+$ $Log\ H_2PO_4^- - pH = -11.76 - (Log\ Ca^{2+} + 2pH)$	11.76
Hydroxyapatite (HA)	$Ca5(PO4)_3OH$	$Ca_5(PO_4)_3OH + 7H^+ \rightleftharpoons 5Ca^{2+} + 3H_2PO_4^- + H_2O$ $3H^+ {=}{=}{=}{=}{=}{=} 3H^+$ $Log\ H_2PO_4^- - pH = 4.82 - 1.66\ (Log\ Ca^{2+} + 2pH)$	14.46

*H ion added to both side of equations in order to calculate lime potential [21]

Ionic strength: -

Ionic strengths were done according to [16] by using the following equation:

I = EC* 0.013 ……… Equation 1

The ionic strength (I) Mol L^{-1}

Activity coefficient: -

Activity (a) ions were calculated according to the Lewis equation as described by [17]

$a_i = c_i * fi$ …… Equation 2

Where

a_i: ion activity species (Ca)

c_i: Ion concentration in $Mol.L^{-1}$

*f*i: ion activity coefficient

Table 3. pH, (calcium and phosphorus activity), P-potential and lime potential for studied combination treatments.

Code	pH	Soluble P (mg/L	Ca	P mole /L	Ca	$Log\ H_2PO^-_4$	$Log\ Ca^{+2}$	$LogCa^{+2}+2pH$	$Log\ H_2PO^-_4$-pH
St0P0	7.88	0.09	45	3.05E-06	0.001125	-5.51635903	-2.948847478	12.80315252	-13.39235903
St0P1	7.79	0.13	51	4.03E-06	0.001275	-5.394451681	-2.894489815	12.67865018	-13.18102168
St0P2	7.71	0.17	53	5.54E-06	0.001325	-5.25667572	-2.877784122	12.54154921	-12.96634239
St1P0	7.42	0.09	104.33	2.97E-06	0.002608	-5.527259274	-2.583636909	12.25502976	-12.94659261
St1P1	7.41	0.21	126.33	6.89E-06	0.003158	-5.161543623	-2.500542036	12.32412463	-12.57387696
St1P2	7.35	0.37	131.67	1.20E-05	0.003292	-4.919304867	-2.48258415	12.22674918	-12.27397153
St02P0	7.77	0.10	47	3.07E-06	0.001175	-5.512846414	-2.929962133	12.60123787	-13.27844641
St2P1	7.65	0.12	53	4.02E-06	0.001325	-5.39549524	-2.877784122	12.42221588	-13.04549524
St2P2	7.68	0.23	56	7.33E-06	0.0014	-5.134698574	-2.853871964	12.49946137	-12.81136524
St3P0	7.77	0.09	67.67	2.94E-06	0.001692	-5.531125648	-2.771685208	12.76164813	-13.29779231
St3P1	7.60	0.12	73.67	3.78E-06	0.001842	-5.422434082	-2.734788972	12.47187769	-13.02576742
TSt3P2	7.67	0.19	71	6.15E-06	0.001775	-5.210897147	-2.750801643	12.58253169	-12.87756381

Results and discussion

Impact of Sulphur Application Timing on Growth Parameters of corn plant in Calcareous Soil

The results in table (4) illustrate the impact of sulphur application timing (St) on growth parameters such as leaf area, grain yield, straw yield, total dry matter, and weight of 1000 seeds.

The data show significant variations among treatments, suggesting that sulphur application timing is critical in optimizing corn growth in calcareous soils. The highest mean values were recorded for

Grain yield, Straw yield, total dry matter, and weight of 1000 seeds except leaf area values exhibited a significant response to sulphur application timing, with the highest grain yield, Straw yield, total dry matter, and weight of 1000 seeds values (14.74, 8.49, 23.23) t ha^{-1} and (423.11) g respectively recorded when sulphur was applied 15 days before planting (St1). This timing ensured optimal sulphur availability during crucial phases of plant development. In contrast, the lowest grain yield, Straw yield, total dry matter, and weight of 1000 seeds values (10.15, 6.86, 17.01) t ha^{-1} and (345) g respectively was observed in the control (St0), which received or zero sulphur application, demonstrating the detrimental effects of sulphur deficiency during the early stages of growth on grain formation. [18] also reported that sulphur application before planting improved nutrient uptake and grain yield in wheat, supporting these findings.

The differences in leaf area between treatments were not statistically significant, with values ranging from 0.60 to 0.66 across different sulphur application timings. This observation is consistent with studies by [17, 6], which reported minimal changes in leaf area with sulphur application, indicating that its influence is more critical in enhancing yield components rather than vegetative growth.

The findings of [19] highlight the critical role of sulphur in promoting the structural growth of cereals, which in turn contributes to higher straw biomass. This aligns with [20], which showed that early sulphur supplementation enhances biomass accumulation and nutrient partitioning in cereals, ultimately leading to increased overall plant productivity.

[21] confirmed that sulphur application improves nutrient uptake and translocation to grains, thereby enhancing seed quality and increasing the weight of 1000 seeds.

Finally, the data clearly demonstrate that applying sulphur 15 days before planting (St1) yields superior results across all growth parameters, including grain yield, straw yield,

total dry matter, and weight of 1000 seeds. The importance of sulphur during early growth stages is evident, as it plays a crucial role in protein synthesis, enzyme activity, and nutrient availability. [22] emphasized that sulphur deficiency during the early stages of plant growth can restrict photosynthesis and nutrient transport, negatively affecting both vegetative and reproductive development.

Table 4: Sulphur Application Timing (St) effect on the leaf area, grain, straw, total dry mater and , weight of 1000 seeds on Corn in Calcareous Soil.,

Levels	Leaf area m^2	Grain	straw t ha^{-1}	total dry matter	weight of 1000 seeds g
St0 (control	0.60a	10.15d	6.86d	17.01d	345.89c
St1`	0.65a	14.74a	8.49a	23.23a	423.11a
St2	0.66a	11.63b	7.56b	19.20b	342.89c
St3	0.66a	11.01c	7.30c	18.31c	361.56b

The same letter or letters for each column means non-significant difference and vice versa.

Effect of Triple Super Phosphate (TSP) on Growth Parameters of corn in Calcareous Soil

Table (5) shows the impact of different doses of triple super phosphate (TSP) on growth parameters, including leaf area, grain yield, straw yield, total dry matter, and weight of 1000 grains of corn in calcareous soil. The results indicate significant differences among the treatments, importance role of phosphate application in improving crop growth. The application of TSP had a notable impact on leaf area. TSP2 resulted in the largest leaf area (0.68), followed by TSP2 (0.65). The control (TSP0) had the smallest leaf area (0.60), showing that phosphate plays a role in enhancing vegetative growth. which is critical for photosynthetic capacity [23, 12]

Grain yield, straw yield, total dry matter, and 1000-seed weight increased significantly with higher TSP doses. TSP3 yielded the highest grain yield, straw yield, total dry matter, and 1000-seed weight (13.08, 7.75, 20.83) t ha^{-1}, and 396.33g) respectively, while the control produced the lowest grain yield, straw yield, total dry matter, and weight of 1000 seeds (10.84, 7.34, 18.18) t ha^{-1}, and 345g) respectively. This emphasizes the critical role of phosphorus in grain formation and nutrient uptake, consistent with the findings of [7]. Increased straw yield correlates with better nutrient availability and utilization [5]. indicating that phosphorus is vital for overall plant growth [12]. This indicates phosphate application enhances seed filling and nutrient partitioning [25, 26].

Table 5: Triple super phosphate (TSP) effect on the leaf area, grain, straw, total dry mater and , Weight1000 Seed in Calcareous Soil

Levels	Leaf Area) m^2	Grain	Straw t ha^{-1}	Total dry matter	weight of 1000 seeds g
TSP0(control)	0.60b	10.84c	7.34c	18.18c	345.83c
TSP2	0.65a	11.73b	7.57b	19.30b	362.92b
TSP3	0.68a	13.08a	7.75a	20.83a	396.33a

The same letter or letters for each column means non-significant difference and vice versa.

Combination effect of sulphur application timing and phosphate doses on growth parameters of corn plant in calcareous soil

In table (6) findings indicate that sulphur application timing and phosphate doses moderately influenced leaf area, with no significant differences among most treatment combinations. The St3P1 treatment yielded the highest leaf area (0.71), while the control (St0P0) showed one of the lowest values (0.58). This suggests a potential enhancement in vegetative growth from the sulphur-phosphorus interaction; however, leaf area alone may not be a reliable indicator of nutrient efficiency, as several treatments (St0P0, St1P0, St1P1) exhibited similar moderate values. [17] Noted that sulphur application had a more significant impact on yield-related traits than on leaf area in calcareous soils.

Grain yield, straw yield, total dry matter, and 1000-seed weight were significantly influenced by the interaction of sulphur timing and phosphate doses. The St1P2 treatment (sulphur applied 15 days before planting with the highest phosphorus dose) produced the highest values: grain yield (17.23 t ha^{-1}), straw yield (8.78 t ha^{-1}), total dry matter (26.01 t ha^{-1}), and weight of 1000 seeds (431.67 g). In contrast, the control (St0P0) had the lowest metrics (9.24 t ha^{-1} grain, 6.67 t ha^{-1} straw, 15.91 t ha^{-1} dry matter, 320.33 g seed weight). These results highlight the synergistic effect of early sulphur application and phosphorus fertilization on crop productivity.

Applying sulphur before planting appears to improve phosphorus availability during critical growth stages, aligning with [18], who found that early sulphur and phosphorus application enhances nutrient uptake efficiency, particularly in phosphorus-deficient soils. The observed improvement in straw yield is likely due to enhanced nitrogen metabolism facilitated by sulphur, which is essential for structural growth in cereals. This is supported by [30, 12], who demonstrated that sulphur increases grain and straw yields by improving nutrient use efficiency.

Additionally, better dry matter accumulation indicates enhanced nutrient availability and partitioning, allowing plants to allocate resources effectively to both vegetative and reproductive growth. [20] also noted that sulphur application boosts overall biomass in cereals grown in calcareous soils, where nutrient availability is often limited. [21, and 28] reported similar outcomes, confirming that sulphur and phosphorus fertilization significantly improve seed weight by enhancing nutrient uptake and allocation to reproductive organs. [22, 29, and 30].

Table 6 :Impact of Sulphur Application Timing and Phosphate Doses on ,the leaf area, grain, straw, total dry mater and , weight of 1000 seeds on corn in Calcareous Soil

Treatment combination	Leaf Area m^2	Grain	Straw t ha^{-1}	Total dry matter	weight of 1000 seeds g
St0P0	0.58ab	9.24f	6.67g	15.91h	320.33fg
St0P1	0.58ab	9.96ef	6.92fg	16.88gh	332.67e
St0P2	0.65ab	11.27cd	6.99efg	18.25ef	384.67c
St1P0	0.61ab	12.33c	8.26b	20.59c	414.33b
St1P1	0.64ab	14.67b	8.42ab	23.08b	423.33ab
St1P2	0.7ab	17.23a	8.78a	26.01a	431.67a
St2P0	0.65ab	11.83cd	7.34cde	19.17de	314.00g
St2P1	0.68ab	11.43cd	7.65cd	19.09de	330.33ef
St2P2	0.66ab	11.63cd	7.69c	19.33cde	384.33c
St3P0	0.56b	9.97ef	7.07ef	17.04fgh	334.67e
St3P1	0.71a	10.87de	7.29def	18.15efg	365.33d
TSt3P2	0.70ab	12.20c	7.54cd	19.74cd	384.67c

The same letter or letters for each column means non-significant difference and vice versa.

Interaction between sulphur application timing and phosphorus doses on phosphorus availability in calcareous soil.

Figure (1) and table (4,6, and 6) illustrates the interaction between sulphur application timing and phosphorus doses on phosphorus availability in calcareous soil.

Sulphur Timing application and Phosphorus Availability:

The timing of sulphur application plays a critical role in enhancing phosphorus solubility. In the (St1) treatment, where sulphur was applied 15 days before planting, there was a notable shift in the treatment points closer to the OCP and DCP lines. This reflects increased phosphorus availability due to a reduction in soil, for there more the highest means value was recorded (14.74, 8.49, 23.23) ton $ha^{-1}$and, 423g) for (grain, straw, total dry matter and weight of 1000 seeds) respectively table (3). Earlier sulphur application (St1) allows more time for pH to decrease, thus improving the solubility of calcium-phosphate compounds in calcareous soils. In contrast, sulphur applied at planting (St2) or 15 days after planting (St3) was less effective, as evidenced by the treatment points lying farther from the OCP and DCP solubility lines, suggesting reduced phosphorus availability. The lowest means value was recorded (10.15, 6.86, 17.01) tonha^{-1}, 345g) for (grain, straw, total dry matter and weight of 1000 seeds) respectively.

The calcareous soil's high pH typically reduces phosphorus availability due to phosphorus fixation with calcium, forming insoluble compounds (19, 31). This experiment explored how sulphur application and phosphorus doses can mitigate these effects.

Phosphorus Doses application and Phosphorus Availability:

Phosphorus treatments also significantly influenced phosphorus availability. The higher phosphorus dose (P3: 160

kg TSP/ha) shifted treatment points closer to the OCP and DCP lines compared to lower phosphorus doses (P1: 60 kg TSP/ha) and the control (P0). The highest mean value was recorded (13.08, 7.75, 20.83) ton ha^{-1}, and 362g) for (grain, straw,
total dry matter and weight of 1000 seed) respectively in treatment (TSP3), while the lowest mean value was recorded (10.84, 7.34, 18.18) ton ha^{-1}, and 345g) for (grain, straw, total dry matter and weight of 1000 seeds) respectively in control (table (4). This confirms that higher phosphorus applications are necessary to overcome the high calcium concentrations in calcareous soils that bind phosphorus, reducing its availability to plants [32, 21, 33, 15]. Increasing phosphorus application improves the concentration of soluble phosphorus, enhancing plant uptake and promoting better crop growth [34].

Effect of Sulphur and Phosphorus Combinations:

The combination of sulphur and phosphorus treatments further highlights their interactive effects. For instance, the St1P2 treatment combination (sulphur applied 15 days before planting with 160 kg ton ha^{-1}) resulted in the most favourable phosphorus availability, as shown by the closest proximity to the OCP and DCP lines. The highest mean value was recorded in the St1P2 treatment combination (sulphur applied 15 days before planting with 160 kg ton ha^{-1}) values (17.23, 8.78, 26.01) ton ha^{-1}, and 431.67 g) for (grain, straw, total dry matter and weight of 1000 seeds) respectively, while the lowest mean value was recorded (9.24, 6.67, 15.91) ton ha^{-1}, 320g) for (grain, straw, total dry matter and weight of 1000 seed) respectively in control (table, 5).

This supports that sulphur-induced pH reduction enhances the availability of applied phosphorus, particularly at higher doses [32]. On the other hand, the combination of late sulphur application (St3) with lower phosphorus doses (P0 or P1) was less effective, as shown by the treatment points falling farther from the solubility lines. This demonstrates that both early sulphur application and higher phosphorus doses are crucial for optimizing phosphorus availability in calcareous soils (3, and 31]. It means shifting the points or treatment combinations towards the upper part of the solubility diagram means an increase in phosphorus availability and vice versa.

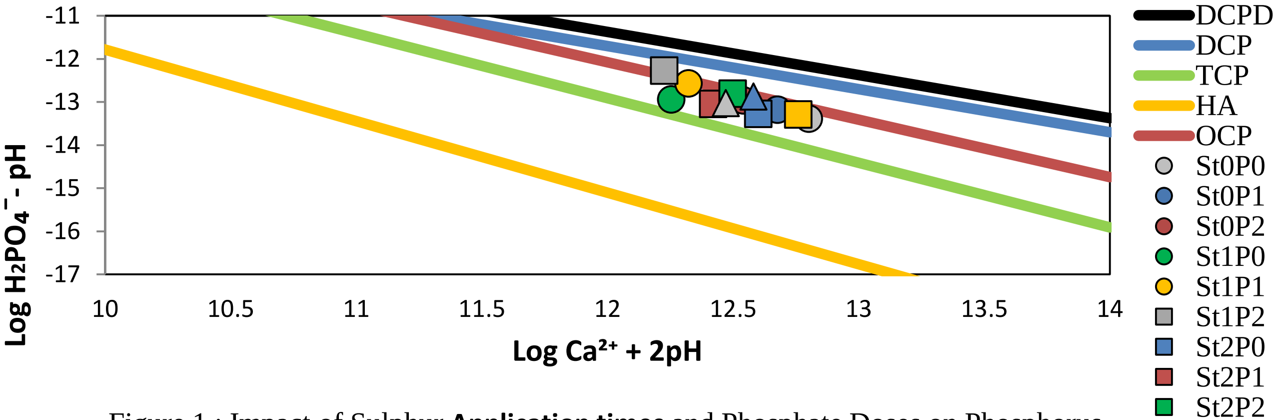

Figure 1 : Impact of Sulphur **Application times** and Phosphate Doses on Phosphorus Availability in Calcareous Soil

Conclusion

The results clearly demonstrate the critical importance of both sulphur application times and phosphorus dosage in enhancing phosphorus availability in calcareous soils. The most effective strategy involves applying sulphur 15 days before planting, significantly improving nutrient solubility and crop performance. This early application leads to a reduction in soil pH, thus enhancing the availability of calcium-phosphate compounds. Additionally, higher phosphorus doses (160 kg TSP/ha) further improve phosphorus solubility, confirming the need for adequate phosphorus to counteract its fixation in high-calcium environments. The combination of early sulphur application and higher phosphorus doses optimizes nutrient uptake, resulting in better growth and yield outcomes for crops.

These findings offer practical implications for fertilizer management in calcareous soils, suggesting that strategic adjustments to sulphur and phosphorus application rates can effectively enhance crop phosphorus uptake and overall productivity.

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تأثير توقيت إضافة الكبريت وجرعات الفوسفات على الفسفور الذائب ونمو وإنتاجية الذرة الصفراء في التربة الكلسية.

مسلم رسول عارب خوشناو

قسم التربة والمياه، كلية علوم الهندسة الزراعية، جامعة صلاح الدين ، أربيل، إقليم كردستان، العراق.

الخلاصة

أجريت هذه الدراسة تأثيرات توقيت تطبيق الكبريت وجرعة الفوسفور على توافر الفوسفور، والنمو، وجودة المحصول من الذرة في التربة الكلسية في حقل گرده ره شه، كلية علوم الهندسة الزراعية، جامعة صلاح الدين – أربيل. وصممت التجربة على أساس القطاعات العشوائية الكاملة العاملية و بثلاث مكررات عبر 12 تركيبة علاجية، تضمنت تطبيق الكبريت بتوقيتات مختلفة (التحكم، 15 يوماً قبل الزراعة، عند الزراعة، و15 يوماً بعد الزراعة) بمعدل 300 كجم كبريت لكل هكتار، وفوسفات ثلاثي سوبر بجرعات (0، 60، و160) كجم لكل هكتار..

أظهرت النتائج أن تطبيق الكبريت 15 يوماً قبل الزراعة حسّن بشكل كبير من مؤشرات النمو الأساسية وجودة المحصول، حيث سجلت أعلى إنتاجية للحبوب (14.74 طن/هكتار)، وإنتاجية القش (8.49 طن/هكتار)، والقيم الإجمالية للكتلة الجافة (23.23 طن/هكتار) على التوالي، ووزن 1000 بذور (423 جرام). بينما، أظهرت معالجة التحكم أقل القيم، مما يبرز الدور الحاسم للكبريت في توافر العناصر الغذائية خلال مراحل النمو المبكرة. وعلى الرغم من عدم وجود تغييرات ملحوظة في مساحة الأوراق بين العلاجات، فإن التفاعل بين تطبيق الكبريت المبكر وجرعات الفوسفور العالية حسّن بشكل ملحوظ من الأداء العام، حيث سجلت معالجة St1P2 إنتاجية قدرها 17.23 طن/هكتار من الحبوب و431.67 جرام لوزن 1000 بذور.

كان لتوافر الفوسفور تأثير كبير من كل من توقيت الكبريت وجرعةTSP ، حيث تم ملاحظة أعلى قابلية ذوبان للفوسفور في المعالجات التي تم فيها تطبيق الكبريت قبل 15 يوماً من الزراعة وبالتزامن مع 160 كجم لكل هكتار من .TSP تبرز هذه الدراسة أهمية تحسين استراتيجيات التسميد بالكبريت والفوسفور في التربة الجيرية، التي تحد عادةً من ذوبان الفوسفور بسبب ارتفاع الرقم الهيدروجيني ومحتوى الكالسيوم. توفر النتائج رؤى قيمة لتحسين ممارسات إدارة الأسمدة بهدف تعزيز إنتاجية المحاصيل في التربة التي تعاني من نقص العناصر الغذائية..

الكلمات المفتاحية: ذوبان الفوسفور، محصول الذرة وجودتها، التربة الكلسية، التسميد الكبر