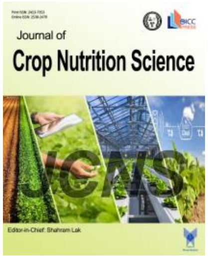

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Research Article

Evaluation Effects of Sulphate Fertilizers on Soil pH, Fe and Mn Uptake by Rice (*Oryza sativa* L.) Under Water Logged and Calcareous Soils Conditions

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Abstract

Background: Under calcareous soils where soil pH is high, micro-elements content is deficient in the crop body. It is because of its precipitation on the clay soils and less uptake by the Rice.

Objectives: The present research, studies the effect of basic, Sulphur powder and micro-element fertilizers on soil pH in the paddy field and uptake of Fe and Mn elements by Rice crop.

Methods: Current study were carried out according split-split plot experiment based on randomized complete block design with 3 replications. The main plot included Macro-elements in two levels (1-control and 2-NPK-fertilizers as basic fertilizer) and Sulphur as sub plot in two levels (1-control and 2-S-powder) also micro-elements belonged to sub-sub plot in five levels (1-control, 2-Zn, 3-Cu, 4-Mn and 5-Zn, Cu, Mn-Sulphate fertilizers).

Result: This research has shown that, Sulphur and microelements has affected soil pH at tillering, panicle initiation and seed maturity stages, significantly. These fertilizers have also affected Fe and Mn content in the leaves and grains, significantly. The results showed that with decreasing soil pH, Fe and Mn uptake and grain yield increased.

Conclusion: The least soil pH at all three stages and the most Fe and Mn content in grains were attained when NPK+S+Zn, Cu, Mn-Sulphate fertilizers applied together in this research. Thus, to obtain minimum soil pH and maximum Fe and Mn content in Rice grain under calcareous soils conditions, this treatment can be recommended.

Keywords: Grain, Macro and Microelements, Nutrition, Paddy field, Sulphur

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1. Background

Rice (*Oryza sativa* L.) crop is one of the important staple foods and main source of energy for more than 50% of the world population (Peng et al., 2023). Rice supplies 20% of the world's dietary energy supply. In some Asian countries, Rice provides over 70% of calorie supply (Purseglove 1972; GRiSP, 2013). Moreover, Rice is the key staple food for the world's undernourished people living in Asia and Africa; not only linked with global food security but also closely connected with employment, economic growth and regional peace (Yadev and Kumar, 2018). However, after the 1980s, yield stagnated or declined (Bhandari et al., 2002) and some researchers have shown that Rice production and research has faced unprecedented challenges in recent years' performance (Mobasser et al., 2024; Peng et al., 2023). The use of adding microelements to the fertilizers can help to achieve a substantial increase in the Rice yield and improve its quality in terms of the enrichment in these microelements (Ziaeeyan and Malakoti, 1997). There is deficiency of micronutrients such as Zn, Cu, Mn and Fe in agronomic soils because of the excessive use of phosphate fertilizers and the existence of alkaline soils in Iran (Parvizi and Ronaghi, 2000). Triple super phosphate is the case of deficient of micronutrients in the crop body. This fertilizer includes calcium element which increases soil pH. On the other hand, the studied field soils are belonged to calcareous soils, so under this condition the crop cannot uptake micro-elements. There is one kind of disease in Iranian population entitled "Iranian anemia" that was created by micronutrient deficiency especially Fe element in dietary. It is because of high soil pH and lowering microelements uptake by crop crop. Thus, correct use of nutrients, especially micronutrients and providing of ideal condition for their availability and uptake, are important factor for increase of crop's yield and increase of micronutrient content in the crop production (Malakoti and Tehrani, 1999; Qasempour Alamdari, 2004).

2. Objectives

It is thought of interest to study the effect of Sulphur powder and various elements on soil pH and uptake of Fe and Mn by the Rice under calcareous soils. Under this condition, Rice crop can uptake more micro-elements from the soil because Sulphur powder and other Sulphate fertilizers can lower soil pH. Since, the studied soils are belonged to calcareous soils where microelements are precipitated on the soil as Zn phosphate, Cu phosphate etc.

3. Materials and methods

3.1. Field and Treatments Information

The experiment was conducted as split-split plot experiment based on randomized complete block design with three replications. There were three factors in this experiment which are Macro-elements as main plot in two levels (1-control and 2-NPK-fertilizers as basic fertilizer) and Sulphur as sub plot in two levels (1-control and 2-S-powder) and Micro-elements as sub-sub plot in five levels (1-control, 2-Zn, 3-Cu, 4-Mn and 5-Zn, Cu, Mn-Sulphate fertilizers). Thus, there were 20 treatments (2×2×5) that were located in each plot and each of these were replicated three times (60 plots). Basic fertilizer (NPK-fertilizers), microelement fertilizers and Sulphur powder were applied to the plots area as recommended by routine soil analysis (Ma-lakoti and Gheybi, 1997). Each plot was trampled and mixed with fertilizers in soil for bal-ance and perfect distribution of fertilizers in to the soil. N, P and K-fertilizers were as Urea (50 $kg.ha^{-1}$), Triple Superphosphate (50 $kg.ha^{-1}$) and Potassium Sulphate (25 kg ha^{-1}), respec-tively. Zn, Cu and Mn-fertilizers were as Zn Sulphate (30 $kg.ha^{-1}$), Cu Sulphate (10 $kg.ha^{-1}$) and Mn Sulphate (20 $kg.ha^{-1}$), respectively. Sulphur powder has also been chosen at the rate of 100 kg ha^{-1}. Fe content in to the studied soils was more than critical level for Rice as rou-tine soil analysis. Afterwards, the Rice seedling was transplanted when it was at 15 cm height. Distance of transplanting hill was 25×25 cm and was cultivated 4 stems in each hill. The type of Rice variety was Taroom. The field was irrigated and flooded four days after transplanting. The field was dried at 4 stages during Rice growing. These stages were: 1) two days before and four days after transplanting, 2) 20 days after transplanting, 3) 40 days after transplanting and 4) after Rice flowering. The aim of the field drying was: a) volatilization of harmful gases like Methane and H2S, b) availability of oxygen in deep soil (Qasempour Alamdari and Khodabandeh, 2004), c) enhancing growth of Rice roots and absorption of nu-trients, and d) decomposition of Sulphur and decrease in soil pH by production of Sulphuric acid (decomposer bacteria of Sulphur means Tiu-bacillus will be activated under dried field and soil aerobic conditions).

3.2. Measured Traits

3.2.1. *Determination of the soil pH*

To measure soil pH, 5-soil samples were collected per plots and mixed and 1 kg of these has chosen to measure soil pH. It is measured at three stages: a) at the tillering stage (about 1 month after transplanting), b) at the panicle initiation stage and c) at the crop maturity stage. To determine soil pH, 100 cc distilled water was added to 10 gm of soil sample and mixed. After 24 hours, the pH of soil solution was recorded with pH-meter having temperature com-pensation adjustment.

3.2.2. *Determination of Fe and Mn contents in the leaves and grains*

Fe and Mn contents of the Rice were measured by atomic adsorption spectrophotometer technique (Malakoti and Gheybi, 1997) at three stages: a) in the leaves at tillering stage, b) in the leaves at the panicle initiation and c) in the grains after crop harvesting. At tillering and panicle initiation stages, needed leaves were chosen as randomized from several plants per each plot. At physiological maturity stage, Rice was also harvested 2 m2 of center each plot and grains separated by combine machine. All of these samples were chopped, dried and powdered. Then, 1 gm of powdered sample was warmed in the heater at about 500-

550 0C for 5-6 hours, to ash the sample. After that, 2 N HCl was added to it and after 1 hour, the dis-tilled water was added to this solution to make volume 100 cc. Then, after filtration of the solution, Fe and Mn concentration of it were determined by Atomic Absorption Analysis technique using PERKIN-ELMER, model-2380 instrument.

3.3. Statistical analysis

Analysis of variance and mean comparisons were done via SAS (Ver.8) software and Duncan multiple range test at 5% probability level (Gomez and Gomez, 1984).

4. Results and discussion

4.1. Soil pH

Analysis of variance of soil pH is shown in table 1 and mean soil pH at tillering, panicle initia-tion and seed maturity stages are shown in table 2 and Fig. 1. As can be seen from table 1, there is a very significant difference on soil pH when NPK-fertilizers applied at panicle initiation stage. S powder significantly affected soil pH at panicle initiation stage. This treatment also influenced soil pH at tillering and seed maturity stages, very significantly. Analysis of variance in table 1 also shows that microelement fertilizers affected soil pH at tillering and seed maturity stages significantly and very significantly, respectively. Interaction effects be-tween S powder and microelement fertilizers and interaction effects between all of the applied fertilizers were significant on soil pH. The results showed that S powder and Microele-ments-Sulphate fertilizers lowered soil pH due to creation of Sulphuric acid in to the soil. Table 2 shows that using all of the microelement fertilizers and S powder decreased soil pH at all three stages compared with control plot, significantly. A decrease in pH also observed when S powder and micronutrient fertilizers (Treatment No.10) were applied together. It shows that use of S powder and Zn, Cu, Mn-Sulphate fertilizers can decrease soil pH under paddy field water-logged conditions. It was found that soil pH at both three stages is in the order when: S powder (Treatment No.6) < microelement fertilizers (Treatment No.5 < NPK fertilizers (Treatment No.11) applied. As can be seen in table 2 the minimum soil pH was at-tained when NPK + S + Zn, Cu, Mn-Sulphate fertilizers (Treatment No. 20) applied together at all three stages. The results obtained at treatment No. 17, is at the same value with treatment No.20, statistically. Soil pH decreased around 0.4 unit by treatment No.20 (7.13) compared with control plot (7.53) at both tillering and seed maturity stages. Lowering soil pH at the rate of 0.4 unit is very significant compared with other treatments, statistically. This is in agreement with observations by Slaton et al. (2001), Sharma and Swarup (1996). Fig. 1 shows that soil pH decreased by different Sulphate fertilizers at all three stages. It varies at the range of 7.53-7.13, 7.65-7.36 and 7.53-7.13 and their average values are 7.25, 7.48 and 7.28 at tillering, panicle initiation and seed maturity stages, respectively. It was found that the range and average soil pH at panicle initiation stage is more than other stages. The experimental field soil was under water-logged condition at tillering stage that could be lowered soil pH by tampon properties of the water. At seed maturity stage, the most amount of S powder and Sulphate fertilizers decomposed by bacteria and changed to Sulphuric acid that may be low-ered soil pH. In this research, grain yield was also measured at control plot (2810 $kg.ha^{-1}$) and treatment No.20. (4093 $kg.ha^{-1}$). It was found that with lowering soil pH at treatment No.20, grain yield increased significantly compared with control plot. These findings are in agree-ment with those reported by Turner (2000) ; Fajeria et al. (1999); Chapma (1980) and Moore et al. (1994).

Table 1. Analysis of Variance of soil pH and Fe and Mn concentration in the leaves and seed of Rice plant at different stages of the growth

Treatments	df	Soil pH			Fe	
		Tillering	Panicle initiation	Seed maturity	Tillering	Panicle initiation
Replication	2	0.0056 ns	0.0672*	0.0114 ns	216.27 ns	2.3555 ns
NPK(a)	1	0.096 ns	0.1392**	0.148 ns	370.02 ns	168.67 ns
E (a)	2	0.0104	0.0011	0.0112	117.07	84.651
S(b)	1	0.1972**	0.1279*	0.2089**	799.35*	361.13 ns
NPK*S	1	0.001 ns	0.0034 ns	0.0002 ns	70.417 ns	5.8907 ns
E(b)	4	0.002	0.0072	0.009	98.933	77.153
Zn, Cu, Mn (c)	4	0.0213*	0.0106 ns	0.0117**	223.11**	118.69 ns
NPK*Zn,Cu,Mn	4	0.0015 ns	0.0014 ns	0.002 ns	28.142 ns	29.181 ns
S*Zn,Cu,Mn	4	0.0155 ns	0.0072 ns	0.0069*	108.31 ns	20.869 ns
NPK*S*Zn,Cu,Mn	4	0.0084 ns	0.003 ns	0.0065*	135.04*	23.606 ns
E(c)	32	0.0062	0.0056	0.0018	50.3	47.787
C.V(%)	---	1.52	1.45	1.39	9.75	8.99

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Continue table 1.

Treatments	df	Fe	Mn		
		Grain	Tillering	Panicle Initiation	Grain
Replication	2	1.1722 ns	99.017 ns	228.05 ns	27.315 ns
NPK(a)	1	163.35 ns	2148.1**	141.07 ns	322.02 ns
E (a)	2	40.25	14.517	308.12	32.098
S(b)	1	379.01*	552.07**	4133.4 ns	230.5 ns
NPK*S	1	0.0427 ns	35.267 ns	666.67 ns	91.761 ns
E(b)	4	29.023	8.4667	1466.6	67.453
Zn, Cu, Mn (c)	4	62.555 ns	684.71**	6112.6**	360.55**
NPK*Zn,Cu,Mn	4	12.034 ns	121.44 ns	398.11 ns	13.895 ns
S*Zn,Cu,Mn	4	136.31**	49.442 ns	603.44 ns	137.15 *
NPK*S*Zn,Cu,Mn	4	211.4**	157.31*	105.38 ns	259.06**
E(c)	32	26.393	55.2	944.48	43.041
C.V(%)	---	14.39	8.95	7.99	11.20

ns, * and **: Non significant, significant and very significant at the level of 5% and 1%, respectively.

4.2. Fe content in the leaves and grains

The results showed that the effect of S powder and interaction effects of NPK, S and Zn, Cu, Mn-Sulphate fertilizers were significant on Fe uptake by the Rice leaves at tillering stage, statistically. Fe uptake by the Rice leaves was not significantly affected by any fertilizers ap-plied at panicle initiation stage (Table 1).

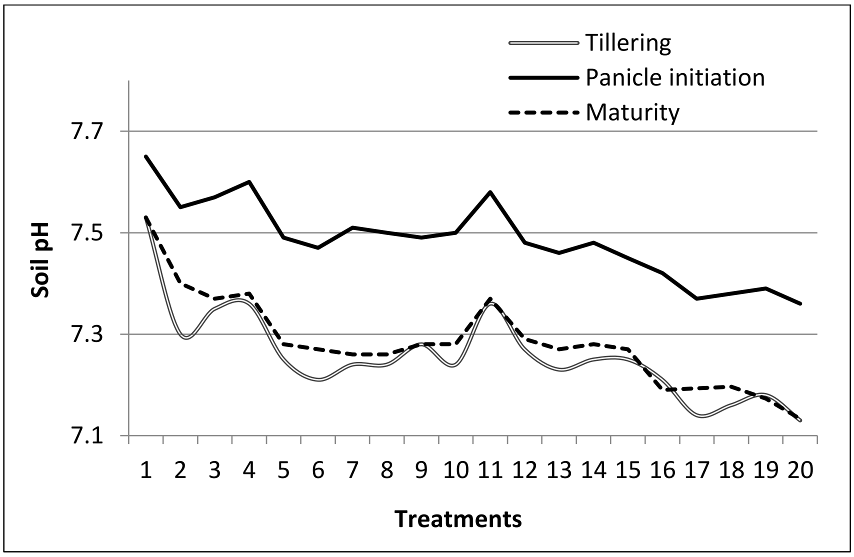

Figure 1. Soil pH at tillering, panicle initiation and seed maturity stages

As can be seen at Fig. 1, the average value of soil pH at panicle initiation stage (7.48) is more than tillering (7.25) and seed maturity (7.28) stages that is because of the less effect of Sul-phate fertilizers on soil pH. Accordingly, Fe uptake by the Rice leaves was not significantly affected by different fertilizers applied at this stage. It can be concluded that soil pH effects on Fe uptake, directly. This is in agreement with earlier work by Foth (1984). Table 1 also shows that S powder has significant effect on Fe uptake by the Rice grains, statistically. In-teraction effects between S powder with microelement fertilizers and interaction effects be-tween NPK, S powder and microelement Sulphate fertilizers were also very significantly on Fe uptake by the Rice grains, statistically. Mean comparison of treatments in table 2 shows that Fe uptake by the leaves decreased compared with the control at tillering stage when Zn and Cu fertilizers applied, but it increased significantly by other fertilizers. Gang war and Mann (1972) found that the concentration of Fe decreased with increasing Zn applied. Fe up-take also increased

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significantly by the leaves at panicle initiation stage and grain of the Rice compared with the control when NPK, S powder and microelement Sulphate fertilizers ap-plied. It was observed that Mn-Sulphate has significantly increased Fe uptake by the leaves at both two stages and grain compared with Zn and Cu Sulphate applied. It was also found that Fe uptake by the leaves at both two stages and grain is in the order when: S powder (Treatment No.6) > microelement fertilizers (Treatment No.5 > NPK fertilizers (Treatment No.11) applied. The maximum Fe uptake by the leaves at tillering (122 ppm), panicle initiation (93 ppm) stages and grain (67 ppm) were obtained when NPK + S + Zn, Cu, Mn-Sulphate ferti-lizers applied together (Treatment No. 20). Fig. 2 shows that Fe concentration in all of the treatments is in the order: leaves at tillering (varies 90-120 ppm) > leaves at panicle initiation (varies 60-90 ppm) > grain (varies 30-60 ppm, approximately). It shows that with increasing the period of Rice growth from tillering stage until seed maturity stage, Fe content gradually decreases into the crop body. It can be resulted that Fe mobility is very slowly into the crop body, which belongs to the semi-immobilization element.

Table 2. Mean comparison of soil pH and Fe and Mn concentration in the leaves and seed of Rice at different growth stages

Treatments	Soil pH			Fe (ppm)		
	Tillering	Panicle initiation	Seed maturity	Tillering	Panicle initiation	Grain
1-Witness	7.53^{*n}	7.65^{m-q}	7.53^{kl}	94^{f-l}	80^{b-i}	39^{j-k}
2-Zn	7.3^{e-k}	7.55^{e-m}	7.4^{h-k}	93^{f-m}	82^{a-g}	44^{e-j}
3-Cu	7.35^{g-l}	7.57^{f-n}	7.37^{hi}	91^{f-n}	79^{b-j}	48^{c-h}
4-Mn	7.36^{i-m}	7.6^{g-p}	7.38^{hij}	107^{bcd}	84^{a-f}	52^{c-f}
5-Zn,Cu,Mn	7.25^{c-h}	7.49^{a-j}	7.28^{def}	100^{b-h}	84^{a-f}	53^{b-e}
6-S	7.21^{a-e}	7.47^{a-h}	7.27^{cde}	108^{bc}	87^{a-d}	56^{bc}
7-S+Zn	7.24^{b-g}	7.51^{b-l}	7.26^{cd}	99^{b-i}	89^{abc}	55^{bcd}
8-S+Cu	7.24^{b-g}	7.5^{a-k}	7.26^{cd}	96^{d-k}	84^{a-f}	49^{c-g}
9-S+Mn	7.28^{e-j}	7.49^{a-j}	7.28^{def}	107^{bcd}	86^{a-e}	47^{d-i}
10-S+Zn,Cu,Mn	7.24^{b-g}	7.5^{a-k}	7.28^{def}	101^{b-g}	90^{ab}	53^{b-e}
11-NPK	7.36^{i-m}	7.58^{f-o}	7.33^{d-h}	101^{b-g}	78^{d-k}	47^{d-i}
12-NPK+Zn	7.27^{d-i}	7.48^{a-i}	7.29^{d-g}	102^{b-f}	77^{d-l}	47^{d-i}
13-NPK+Cu	7.23^{a-f}	7.46^{a-g}	7.27^{cde}	97^{c-j}	77^{d-l}	56^{bc}
14-NPK+Mn	7.25^{c-h}	7.48^{a-i}	7.28^{def}	107^{bcd}	82^{a-g}	55^{bcd}
15-NPK+Zn,Cu,Mn	7.25^{c-h}	7.45^{a-f}	7.27^{cde}	93^{f-m}	81^{b-h}	47^{d-i}
16-NPK+S	7.21^{a-e}	7.42^{a-e}	7.19^{abc}	110^{b}	78^{d-k}	49^{c-g}
17-NPK+S+Zn	7.14^{ab}	7.37^{ab}	7.19^{abc}	106^{b-e}	82^{a-g}	61^{ab}
18-NPK+S+Cu	7.16^{abc}	7.38^{abc}	7.19^{abc}	100^{b-h}	77^{d-l}	48^{c-h}
19-NPK+S+Mn	7.18^{a-d}	7.39^{a-d}	7.17^{ab}	108^{bc}	87^{a-d}	52^{c-f}
20-NPK+S+Zn,Cu,Mn	7.13^{a}	7.36^{a}	7.13^{a}	122^{a}	93^{a}	67^{a}

*A given means per each column with the same letters, have not significant difference, statistically ($p<0.05$) via Duncan test

Thus, less Fe content in grains compared with leaves is due to its immobilization and serious depending to low soil pH. Most of the farmers in Northern Iran, who cultivate Rice in these areas do not use any Sulphate fertilizers in to the soil of paddy field. As mentioned in the sec-tion of introduction the paddy field soil of Northern Iran belongs to calcareous soils and contain high soil pH. Under this condition, all of crop cultivated have microelements deficiency especially Fe element. Fig. 4 shows that Fe uptake by the Rice in the grain has increased with decrease of soil pH. This observation is in agreement with earlier workers (Adams 1981; Hue et al., 2001 and Gao et al., 1972). It was found that Fe content (67 ppm) under soil pH of 7.13 unit increased around 1.7 times equals 28 ppm in grain at treatment No. 20 compared with control (39 ppm) under soil pH of 7.53 unit, which was arisen with decreasing 0.4 unit soil pH (Table 2 and Fig. 4). Soltania et al. (2024) reported that Foliar spray of glycine-chelated zinc (Zn) and iron (Fe) lowered the effect of macronutrient deficiencies and en-hanced Rice yield components, yield, and grain biofortification. This value of Fe content in the Rice grain is very important that can be helped to improve dietary and remove anemia dis-ease in human communities especially "Iranian anemia".

Continue table 2.

Treatments	Mn (ppm)		
	Tillering	Panicle Initiation	Grain
1-Witness	134 e-k	410 d-p	71 j-n
2-Zn	116 m-p	416 d-k	78 h-l
3-Cu	121 l-o	410 d-p	81 e-j
4-Mn	148 a-d	426 b-i	92 bcd
5-Zn,Cu,Mn	121 l-o	440 b-g	91 b-e
6-S	139 d-h	428 b-h	87 c-h
7-S+Zn	125 i-n	415 d-l	83 d-i
8-S+Cu	132 e-l	440 b-g	78 h-l
9-S+Mn	152 abc	459 bcd	94 abc
10-S+Zn,Cu,Mn	127 h-m	477 b	79 g-k
11-NPK	143 b-f	414 d-m	81 e-j
12-NPK+Zn	136 d-i	416 d-k	87 c-h
13-NPK+Cu	135 e-j	416 d-k	87 c-h
14-NPK+Mn	144 b-e	449 b-f	90 b-f
15-NPK+Zn,Cu,Mn	136 d-i	455 b-e	79 g-k
16-NPK+S	140 c-g	419 d-j	89 c-g
17-NPK+S+Zn	139 d-h	412 d-o	87 c-h
18-NPK+S+Cu	139 d-h	413 d-n	77 h-m
19-NPK+S+Mn	160 a	473 bc	100 ab
20-NPK+S+Zn,Cu,Mn	153 ab	483 a	104 a

*A given means per each column with the same letters, have not significant difference, statistically ($p<0.05$) via Duncan test.

4.3. Mn content in the leaves and grains

The results showed that the effect of basic fertilizers (NPK) and S powder added on the studied soils was very significant on Mn uptake by leaves at tillering stage.

Microelement fertilizers applied affected Mn uptake by leaves at both stages and grain, very significantly. In-teraction effect of S powder and microelement fertilizers applied together was significant on Mn uptake by grain. Mn uptake by leaves at tillering stage and grain were influenced by interaction effects of basic, S powder and microelement fertilizers applied together significantly and very significantly, respectively (Table 1).

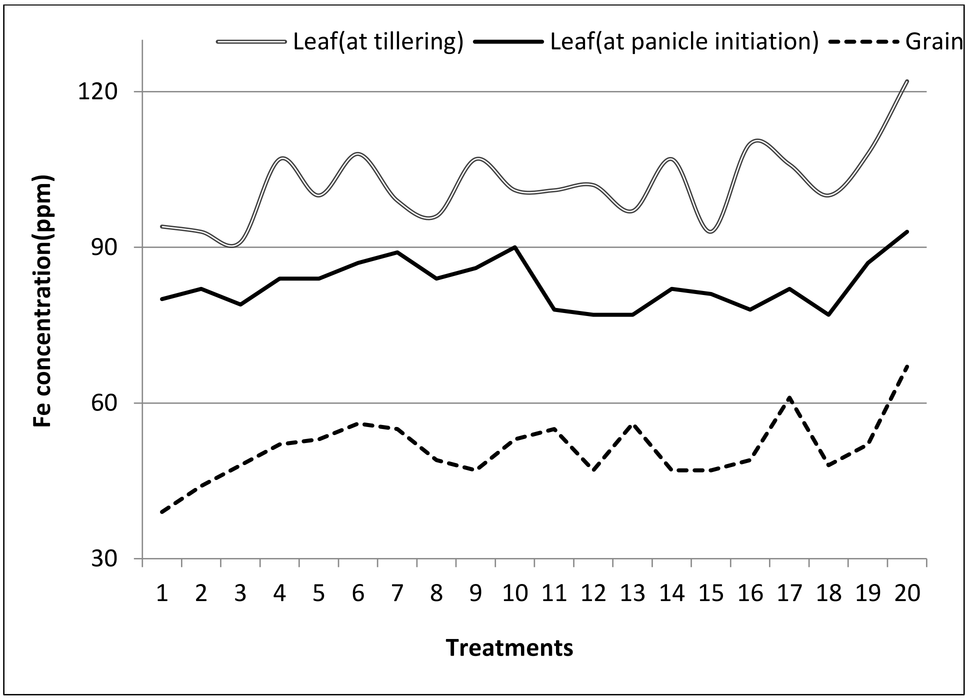

Figure 2. Fe content in the leaves at tillering and panicle initiation and grains at maturity stages

Mean comparison of treatment in table 2 shows that Mn uptake like Fe decreased by the leaves at tillering stage compared with control when Zn and Cu fertilizers applied, but it in-creased significantly by other fertilizers. Zhao et al. (2023) reported that in farmland has been the application of mineral elements (P, Zn, Ca, Mn, Fe, S) can reduce Cd accumulation in Rice and inhibit its bioavailability in Cd-contaminated farmlands. However, Gangwar and Mann (1972) found that the concentration of Fe and Mn decreased with increasing Zn applied. It was observed that Mn-Sulphate has significantly increased Mn uptake like Fe by the leaves at both two stages and grain compared with Zn and Cu Sulphate applied. It was also found that Mn uptake by the leaves at both two stages and grain is in the order when: micro-element fertilizers (Treatment No.5 > S powder (Treatment No.6) > NPK fertilizers (Treat-ment No.11) applied. The maximum Mn uptake by the leaves at tillering stage (160 ppm) was obtained when NPK+S+Mn-sulafet fertilizer applied together (Treatment No.19). Mn uptake was also reached to the maximum value by the leaves at panicle initiation (483 ppm) stage and grain (104 ppm) when NPK+S+Zn, Cu, Mn-Sulphate fertilizers applied together (Treatment No.20). Fig. 3 shows that Mn concentration in all of the treatments is in the order: leaves at panicle initiation (varies 400-450 ppm) > leaves at tillering (Varies 100-150 ppm) > grain (var-ies 50-100 ppm, approximately). It was found that Mn uptake by the crop in the leaf at the panicle initiation had increased compared to that at the tillering stage, which increased around 4 times compared tillering stage. It can be resulted that Mn mobility is a little more than Fe into the body, which belongs to the semi-mobilization element. Mn accumulates in roots be-fore it moves to above ground shoots at the seedling stages. There is some translocation of Mn from old to young leaves (Dobermann and Fairhurst, 2000). The results also showed that Mn content in grain decreased compared with leaves at panicle initiation stage. It can be re-sulted that Mn element accumulates into the leaves at this stage, which consumed by cells at photosynthesis process and transferred to the grain during the period of grain filling and re-mobilization of substances.

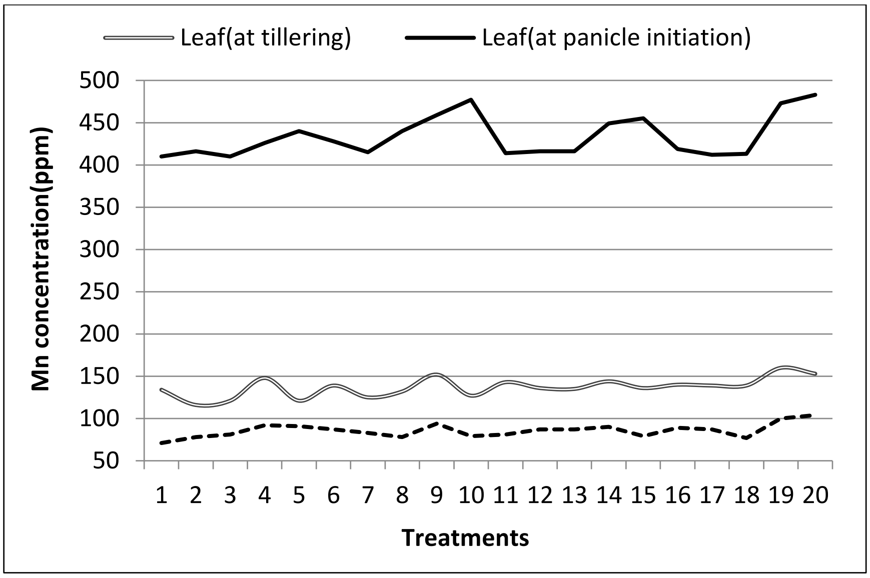

Figure 3. Mn content in the leaves at tillering and panicle initiation and grains at maturity stages

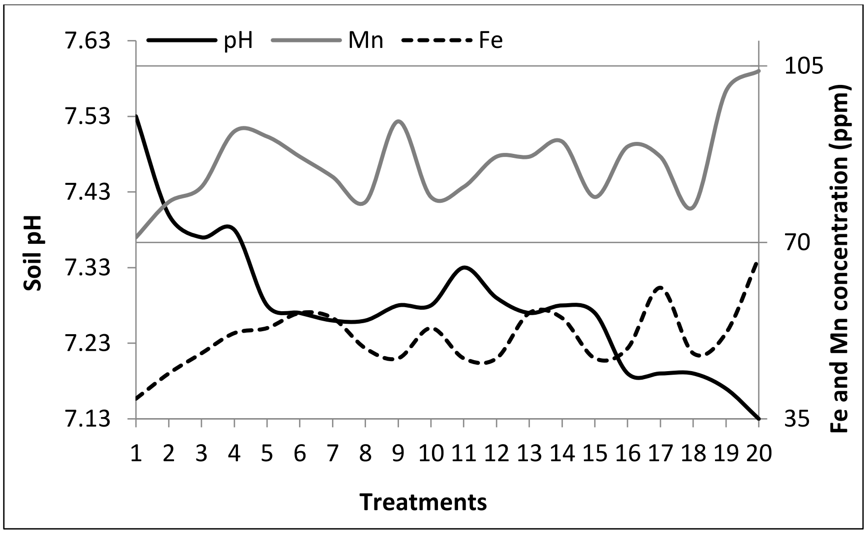

Figure 4. Relationship of soil pH at seed maturity stage and Fe and Mn content in grains

Fig. 4 shows that with decreasing soil pH at seed maturity stage Mn concentration increases in grains like Fe. This result is also in agreement with earlier workers (Adams 1981; Hue et al., 2001 and Gao et al., 1972). It was found that Mn content (104 ppm) under soil pH 7.13 unit increased around 1.5 times equals 33 ppm in grain at treatment No. 20 compared with control (71 ppm) under soil pH 7.51 unit, which was arisen with decreasing 0.4 unit soil pH (Table 2 and Fig. 4). Since Rice are highly resistant to Mn (Khuong et al., 2022) they can take up and accumulate high concentrations of Mn2+. As a result, the crop will suffer from a variety of problems. Excessive Mn in Rice is commonly manifested by the presence of brown spots in

chlorotic interveinal, necrotic areas of older leaves (Schmidt et al., 2016). The growth of shoots and roots will also be stunted (Khuong et al., 2022; Schmidt et al., 2016).

5. Conclusion

It can be concluded that, using S powder and Sulphate fertilizers, soil pH can be lowered at the calcareous soils under paddy field water-logged conditions and micro-elements (Fe and Mn) can be taken up more and easier by the Rice. Therefore, the Rice grain yield is also increased. So, under calcareous or alkaline soils where soil pH is high, S powder or any Sulphate fertilizers can be used to decrease soil pH and increase grain nutrient and yield. The least soil pH at all three stages and the most Fe and Mn content in grains were attained when NPK+S+Zn, Cu, Mn-Sulphate fertilizers applied together, which can be recommended at the same paddy field soils conditions of the present study.

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AUTHORS' CONTRIBUTION:

Majid Qasempour Alamdari: Data curation Methodology, Software, Formal analysis, Investigation, Writing original draft. Nilimma Rajurkar: Conceptualization, writing review and editing, Validation, Writing original draft, Supervision, Project administration, Funding acquisition. Ashok Patwardhan: Conceptualization, Validation. Supervision, Project administration, Funding acquisition.

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