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EFFECTS OF PHOSPHOGYPSUM WASTE APPLICATION ON CORN (*ZEA MAYS* L.) YIELD AND NUTRIENT CONTENTS

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ABSTRACT

The transformation of agro-industrial wastes into value-added commodity is among the best approches to a greener and more sustainable future. The aim of in this study was to examine the effects of phosphogypsum waste (PGW) as fertilizer to improve yield and nutrient content in the grain, stem and leaves of corn (*Zea mays* L.). A randomized experiment via a complete plot design was applied using four different triplicated doses of PGW (0, 1, 5 and 10 tons ha^{-1}). It was shown that improvement in corn yield was proportional to the increase in PGW dose, corresponding to 46.19%, 38.76% and 39.65% for 1, 5, and 10 ton ha^{-1} of PGW, respectively. A 5.85 ton ha^{-1} PGW dose was optimal in yielding a 8.63 ton ha^{-1} of corn despite a 8.26 ton ha^{-1} the production yield using 5 ton ha^{-1} PGW, as the latter was statistically borderline significant. The approach adopted here also yielded corns with higher macro- and micronutrient contents compared to the control. The analysis of variance data illustrated that the improved contents of N, P, K, Ca, Zn and B per 1 ton ha^{-1}, and Mg per 5 ton ha^{-1} were also significant (*P<0.05*). It can be construed that the recommended dose of PGW as fertilizer between 1−5 tons ha^{-1} can lead to substantial improvements in yield and nutrient contents in corn.

KEYWORDS:
Phosphogypsum waste, grain yield, leaf, stem, nutrient contents, *Zea mays* L.

INTRODUCTION

Corn (*Zea mays* L.) is one of the world's most important silage crops owing to high production yield and palatability in comparison to other forage crops, as well as providing a large amount of energy and protein in the animal diet [1]. According to recent statistics, the agricultural area devoted to corn plantation is 682.000 ha per annum, constituting □ 4% of cereal cultivation land in Turkey [2]. However, the quality and yield of corn is very much affected by a combination of several factors, for instance, environmental, genetic, and cultural dynamics. The gradual rise in demand for corn is a matter of concern as it has elevated the cost of silage and grain production [3]. This issue warrants the attention of the agricultural and scientific community, as simply leaving the ruminant livestock grazing on natural pastures is no longer adequate due to low levels of nutrition, more so during dry seasons [4, 5]. In fact, the livelihood of farmers very much depends on the amount of nutrients that are fed to their livestock as this will, in turn, affect the final quality and price of the produced meat.

The elevated production costs have somewhat to do with the decline in soil fertility as a consequent of rigorous agricultural land use that severely depletes the nutrients in soil. Nevertheless, corn farming productivity can be improved by supplementation of soil with nutrients such as nitrogen and phosphorus. It is a two-prong nutritional boost to promote forage yield of corn, and its crude protein content, in addition, the latter forms an integral portion of nucleic acid and essential for vegetative growth [6], seed, fruit quality, alongside good crop formation and maturation. The form of native soil phosphorus, *inter alia* different rates and type of applied phosphorus, as well as soil reaction are factors responsible for phosphorus availability to crops. Improvements in corn yield have been documented in response to soil supplementation with phosphorus [7, 8].

Literature has shown that phosphorus is the second most crop limiting nutrient, wherein inappropriate application rate alongside deficiency of the nutrient can adversely affect plant growth behavior and evolution [9]. This is because carbohydrates and energy formed through photosynthesis are stored in the form of phosphate in crops for future use during growth [10]. Phosphate is readily uptake, moving from older to younger tissues when the crop form cells and develop roots, stems and leaves [11]. Phosphorus deficiency is a worldwide issue and has been thought to be responsible for declines in kernel quality and quantity following production of corns with small nubbins [12]. Ali et al. [11] studied essential impacts of phosphorus additions on grain yield and reported significant increases in crop grain yield, height and number of leaves [10].

Likewise, gypsum is another important nutrient involved insoil regulatory and for boosting phosphorus resolution, in addition to its function as a regulating agent for sodic and heavy clay soils, as well as a source of calcium and sulfur for plants [13, 14]. Keerhisinghe et al. [15] reported that phosphogypsum (PG) is composed of Ca (26.88%), Mg (0.31%), K (0.02%), Fe (0.08%), Al (0.10%), S (21.9%), Si (1.13%), F (0.21%) and P (0.15%), and is sourced from the acidic aqueous by-product of phosphoric acid production with a pH between 4.5−5.0. During the last 40 years, Enamorado et al. [16] used the soil that was applied with phosphogypsum at a dose of 20-25 t ha^{-1} six times. The soil was supplementary applied with 0, 20, 60 and 200 t ha^{-1} of phosphogypsum (2.1 mg Cd kg^{-1} PG). As a result of the study that with the maximum volume of applied phosphogypsum the total amount of Mn, Co and Cu in stems was stopped, as well as the accumulation of B, Cu, Sb, Cs, Ba, Tl, Th in crop. Beside that, concentrations of Pb in the all plant were insignificant and did not pose a risk for animal and human while the content of Cd was very close to the maximum allowable value, and a continual control of Cd is required. Smith et al. [17] (1994) observed that soil enrichment with PG was useful in regulating sodic (solonetzic) and acidic soils but did little to improve crop growth and development. Conversely, Saadaoui et al. [18] found the addition of PG to be convenient for soil amendment and as a fertilizer. Another study by Mays and Mortvedt [19] showed that corn (*Zea mays* L.), soybean (*Glycine max* L.), and wheat (*Triticum aestivum* L.) that grew on PG enriched plots (112 ton ha^{-1}) were 200 times more productive than those cultivated on plots with normal rate of gypsum. An increase in grain Cd level was also reported, except for corn.

There are on-going efforts to develop techniques to effectively apply PG and other chemical constituents into soil to circumvent issues of soil and subsoil acidity. Some techniques i.e. surface and subsoil application of PG have successfully reduced the detrimental effects of subsoil acidity on crop growth [20, 21 and 22]. For instance, Lin et al. [23] used a mesh bag technique to compare between PG and lime soil application on improving root growth. Pavan et al. [24] found the combination of PG and lime in soil significantly enhanced root density of apple trees in Brazil, especially those close to the surface layer. The aluminum content was high but, most importantly, the favourable impact of this technique spread to a depth of 60 cm. Their technique inadvertently led to a higher crop yield and the trees bearing larger fruits. The outcome was invariably a consequence of the growth of a better root network and water supply.

Thus, to reap the full benefits of PG without harming the growing corn crop, development of standardized soil analyses and safe application rates for field applications of PG as fertilizer are, therefore mandatory [25]. The main objective of this study was to evaluate the effectiveness of phosphogypsum waste (PGW) application on corn (*Zea mays* L.) to result in a higher crop yield along with an improved nutritional content. This was achieved by carrying out a randomized experiment *via* a complete plot design using four different doses of PGW (0, 1, 5 and 10 tons ha^{-1}. We also examined the corns for changes in composition of macro- and micronutrient, and established the optimum dose for applying PGW as a fertilizer.

MATERIALS AND METHODS

Plant Material and Growth Conditions. Corn plants (*Zea mays* L. Cv. TTM-815) were grown in the experimental field of Black Sea Agriculture Research Institute, in Samsun city of Turkey in 2010. The field experiment was set-up in completely randomized block design with three replicates. Each plot was 6 m long and 5 m wide. The corn seeds were sown at 70 cm inter-row spacing and at 30 cm intra-row spacing. Application dosses of PGW were 0, 1, 5 and 10 ton ha^{-1}. The chemical composition of PGW was 0.027 % $Fe0_3$, 0.16 % Al_20_3, 0.22 % Cl, 32.9 % CaO, 45.6 % SO_3, 1.84 % SiO_2, 0.098 % MgO and 0.27 P_20_5 % with a pH of 2.9 [26]. The basal nitrogen (350 kg ha^{-1} from ammonium sulfate 21 % N) and phosphorus (60 kg ha^{-1} from triple superphosphate 42 % P_2O_5) was spread and mixed thoroughly before sowing to support uniform plantlet development. The second nitrogen (220 kg ha^{-1} from ammonium nitrate 33 % N) was top-dressed 6 weeks after sowing. Before sowing, the initial soil moisture content of each plot was adjusted to field capacity and it was carefully controlled with TDR (TDR 300, spectrum technologies, USA). Whole plants (5 of 7 rows from each plot) were harvested just above the soil surface at 90th day after sowing. The plant material was dried at 70°C for two days, then ground to pass 1 mm sieve to have a homogenous aliquot for determination of macro and microelement concentrations [27].

Soil Analysis. The surface soil samples were air-dried and passed through 2 mm sieve for chemical characterisation [28]. The soil parameters measured were particle size distribution [29], Na-bicarbonate extractable P [30]. Electrical conductivity [31], soil pH (1:2 soil: water suspension) and calcium carbonate equivalent [32], soil organic matter (Smith-Weldon method) [33], ammonium acetate extractable cations [34]. These measured physico-chemical parameters of the experimental soil are given in Table 1.

TABLE 1
Some physical and chemical properties of the experimental soil

Soil properties		Value
pH	(1:1)	6.95
EC	25 ºC, dS m^{-1}	0.93
Texture	-	Clay-loam
$CaCO_3$	--%--	0.38
Organic matter		1.84
K_{Ex}	-cmol kg^{-1}-	0.25
Ca_{Ex}		22.50
Mg_{Ex}		6.5
P_A	-----mg kg^{-1}----	19.57
Fe_A		25.09
Mn_A		19.22
Zn_A		1.00
Cu_A		0.75

P_A: Available Phosphorus; Fe_A: Available Iron; Mn_A: Available Manganese; Zn_A: Available Zinc; Cu_A: Available Copper; Mg_{Ex}: Exchangeable Magnesium, Ca_{Ex}: Exchangeable Calcium, K_{Ex}: Exchangeable Potassium

Plant Analysis. Plant samples were segmented into stems, leaves and grains before they were oven-dried at 70°C for two days, then ground to pass 1 mm sieve to have a homogenous aliquot for determination of macro and microelement concentrations [27]. Mineral nutrient composition of stem, leaf and grain samples was determined after wet digesting with a HNO_3-H_2O_2 acid mixture (2:3 v/v) in a microwave oven (Berg of Speedwave Microwave Digestion Equipment MWS-2) using a three steps procedure (first step: 145ºC, 75% RF, 5 min; second step: 180ºC, 90% RF, 10 min and third step: 100ºC, 40% RF, 10 min) in microwave [35]. Phosphorus, K, Ca, Mg, Fe, Mn, Zn and B concentrations of the digests were analysed using an Inductively Couple Plasma spectrophotometer (Perkin-Elmer, Optima 2100 DV, ICP/OES, USA) [36] and total N was determined by micro Kjeldahl method [27].

The data were subjected to analysis of variance (ANOVA) and mean separation was made by the Least Significant Difference (LSD) test at $P \leq 0.05$ probability level in SPSS statistical software [37].

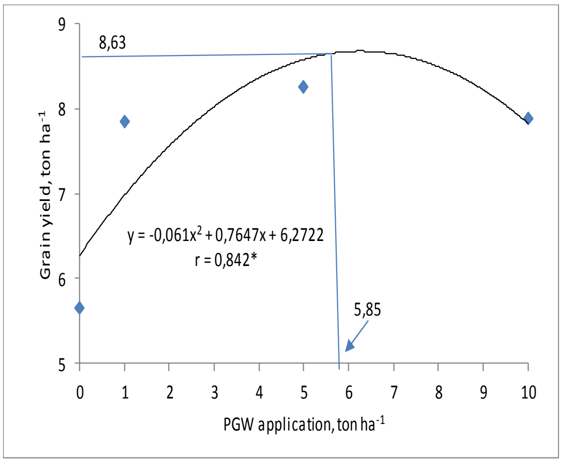

FIGURE 1
The effects of PGW application on corn grain yield

RESULTS AND DISCUSSION

Effect of phosphogypsum waste on grain yield. Increasing phopsphogypsum waste (PGW) applications significantly increased the corn grain yield compared to the control treatment (Table 2). The corn yield of 5.65 ton ha^{-1} in the control increased to 7.84 ton ha^{-1} with 1.0 ton ha^{-1} PGW application and to 8.26 ton with 5 ton ha^{-1} PGW application (P<0.05). In contrast, the highest concentration of PGW (10 ton ha^{-1}) decreased the grain yield to 7.89 tons. The highest yield was therefore obtained from the 5 ton ha^{-1} PGW application. PGW additions at 1, 5 and 10 ton ha^{-1} increased crop yield by 46.19%, 38.76% and 39.65%, respectively, compared to the control (no PGW application). The highest corn yield (8.63 ton ha$^{-1)}$, which was determined with regression analysis, was obtained at 5.85 ton ha^{-1} PGW application (Figure 1). Similarly, variance analysis showed that the most suitable dosage of PGW was 5 ton ha^{-1}. Khan et al. [38] stated that growth is the increment in mass, volume, length or area of biomass that results from the division, expansion, and differentiation of cells during crop growth. Korkmaz and Gülser [39] stated that 1.25, 5.00 and 10.00 ton ha^{-1} applications of PGW at the tillering of rice plants increased the rice stalk plus grain yield by 8.79, 19.01 and 6.56 %, respectively; they also reported that the greatest increase in yield was at 5 ton ha^{-1} PGW application. Cutcliffe [40] reported an increase of 30% rate in the beet yield at 5.50 ton ha^{-1} of phosphogypsum broadcast on soils ranging from pH 4.9 to pH 5.7. Erol and Sevimay [41] reported a significant increase (P<0.05) in forage yield in clover and smooth brome grass after phosphogypsum application. Mesic et al. [42] reported that the application of 12.5 and 25 ton ha^{-1} PGW to corn and winter wheat grown on dystric luvic semi-gley soil increased the yield by 10% and 15% compared to the control, respectively.

Effect of phosphogypsum waste on grain nutrient contents. Mineral nutrient levels in the grains of corn plant increased with PGW application in comparison to the control (Table 2; Figures 2 and 3). According to the variance analysis, while the N, P, K, Ca, Zn and B nutrition of the grains of corn were found significantly increasing (P<0.05) at the 1 ton ha^{-1} doses of PGW, and Mg nutrition was found significantly (P<0.05) increasing at the 5 ton ha^{-1} dose of PGW.

Increasing PGW applications increased nitrogen (N) content in the grains of corn, and the higher increasing obtained from 10 ton ha^{-1} PGW dose (2.06 %), but it was statistically significant (P<0.05) at 5 ton ha^{-1} PGW (2.03 %). Also, these increasing were at a rate of 4.12 % 4.64 and 6.19, respectively.

The phosphorus (P) content of the grains of corn for the three PGW applications was higher than the control, with the highest P content (0.54%) obtained with 1 ton ha^{-1} PGW application. However,

TABLE 2
Corn grain yield and grain nutrient concentrations as affected by PGW application

PGW	Grain yield	N	P	K	Ca	Mg	Fe	Mn	Zn	B
ton ha^{-1}	ton ha^{-1}	------------------------%------------------------					--------------mg kg^{-1}--------------			
Control	565^c	1.94^b	0.43^c	1.54^b	0.86^b	0.33^c	28.5	5.52	17.2^b	19.4^b
1	784^b	2.02^{ab}	0.54^a	1.67^{ab}	1.02^{ab}	0.35^c	33.3	7.04	22.2^{ab}	22.3^a
5	826^a	2.03^a	0.52^{ab}	1.86^a	1.13^a	0.49^a	43.9	7.23	20.9^{ab}	22.3^a
10	789^b	2.06^a	0.47^{bc}	1.77^a	1.06^a	0.41^b	38.8	6.85	25.4^a	22.6^a
$Lsd_{0.05}$	1.76	0.08	0.06	0.20	0.11	0.05	ns	ns	6.41	3,22

PGW: Phosphogypsum Waste; N: Nitrogen; P: Phosphorus; K: Potassium; Ca: Calcium; Mg: Magnesium; Fe: Iron; Mn: Manganese; Zn: Zinc; B: Boron

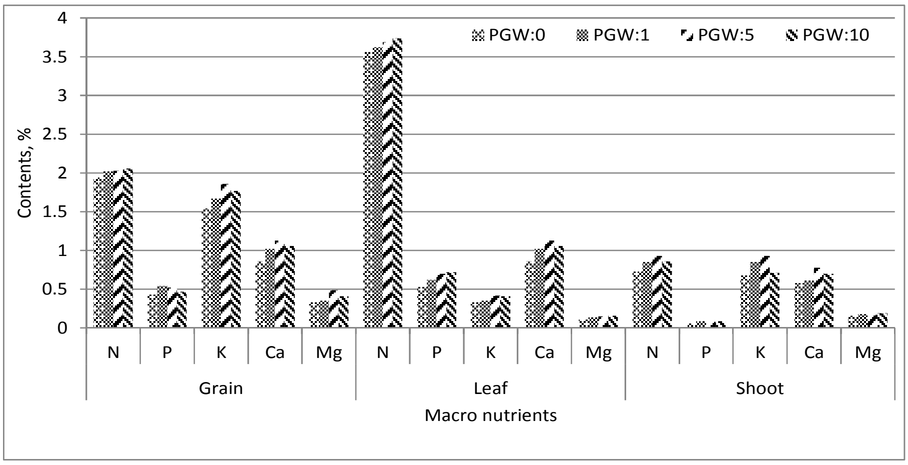

FIGURE 2
The effects of PGW on the grain of corn, leaf and stem macro nutrient contents

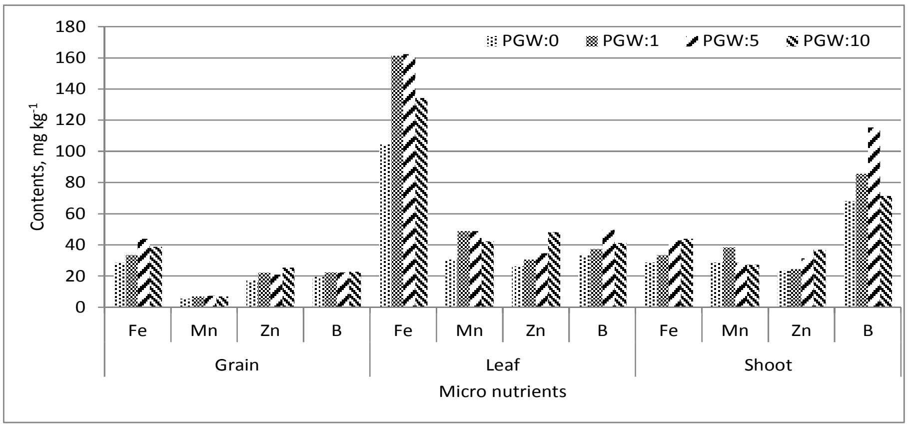

FIGURE 3
The effects of PGW on the grain of corn, leaf and stem micro nutrient contents

the curve generated with regression analysis showed the optimum P content (0.54%) at 4.30 ton ha^{-1} PGW addition (Figure 4). The phosphorus content increased by 25.58%, 20.93% and 9.30% with the 1, 5 and 10 ton ha^{-1} PGW applications, respectively, in comparison to the control. These results are in general agreement with the literature in that phosphorus application is well documented to positively influence the grain yield [43, 44, 45, 46 and 47].

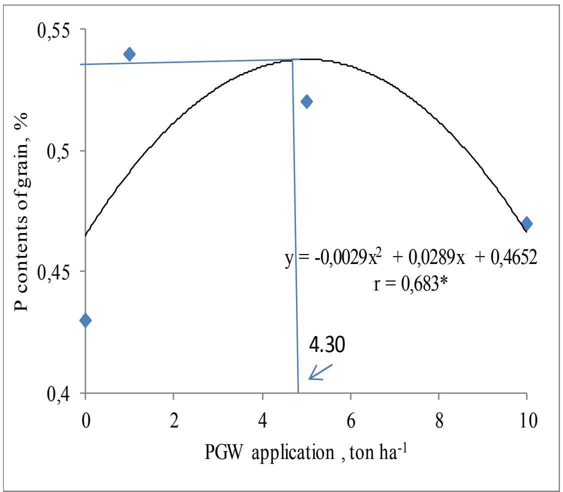

FIGURE 4
The effects of PGW on the grain of corn P contents

PGW application amounts up to 5 ton ha^{-1} increased potassium, calcium and magnesium contents of the corn grain, and the highest contents were obtained from the 5 ton ha^{-1} PGW application (1.86%, 1.13%, and 0.49% for the 5 ton ha^{-1} applications, respectively). The increments of the K, Ca, Mg contents for the 1, 5 and 10 ton ha^{-1} PGW applications were 8.44%, 20.78% and 14.94%, respectively; 18.60%, 31.39% and 23.26%, respectively; and 6.06%, 48.48% and 24.24%, respectively, in comparison to the control.

The highest iron and manganese contents of the corn grains of 43.9 mg kg^{-1} and 7.23 mg kg^{-1}, respectively, were obtained from the 5 ton ha^{-1} PGW application. The iron and manganese concentrations obtained from the 1, 5 and 10 ton ha^{-1} PGW doses in comparison to the control increased by17.15%, 54.08% and 36.30%, respectively, and 27.54%, 30.98% and 24.09%, respectively.

The highest zinc (25.41 mg kg^{-1}) and boron (22.62 mg kg^{-1}) contents in the corn grain were obtained from the 10 ton ha^{-1} PGW application. The Zn and B contents from the 1, 5 and 10 ton ha^{-1} PGW increased by 29.08%, 21.85% and 48.08%, respectively; and 14.43%, 14.95% and 16.95%, respectively, in comparison to the control.

Effect of phosphogypsum waste on leaf nutrient contents. The mineral nutrient contents of the corn plant leaves increased with increasing PGW applications in comparison to the control (Table 3) (Figures 2 and 3). Nitrogen content increased with increasing PGW doses, and the highest N content (3.74%) was obtained from the 10 ton ha^{-1} application The N contents of the leaves increased with the 1, 5, and 10 ton ha^{-1} PGW application and were 1.69%, 3.65% and 5.06%, respectively, compared with the control (no PGW application).

Phosphorus contents of the corn leaves increased with higher PGW doses, with the highest P content (0.72%) obtained from 10 ton ha^{-1} PGW applications. The increased P contents of leaves at 1, 5, and 10 ton ha^{-1} PGW were 16.98%, 32.08% and 35.85%), respectively, compared with the control (no PGW application) but the highest corn leaf P content (0.73%) obtained with regression analysis was from a 6.32 ton ha^{-1} PGW (Figure 5). The potassium and calcium contents of the corn leaves increased relative to the control at higher PGW doses, and the highest contents of 0.42% and 1.13%, respectively, were obtained from the 5 ton ha^{-1} of PGW doses. The increases in the K and Ca contents of leaves at 1, 5, and 10 ton ha^{-1} PGW application were 6.06, 27.27 and 24.23%, respectively; 18.60, 31.40 and 23.26%, respectively, compared with the control (no PGW application). Elloumi et al. [48] reported that 5% PG application to the soil under greenhouse conditions increased the K and Na concentrations in the leaves of sunflower plants compared to the control but reduced the Ca concentration.

TABLE 3
Corn leaf nutrient concentrations as affected by PGW application

PGW	N	P	K	Ca	Mg	Fe	Mn	Zn	B
ton ha^{-1}	------------------------%------------------------					--------------mg kg^{-1}--------------			
Control	3.56	0.53^b	0.33^c	0.86^b	0.11^c	104^b	30.5^b	26.1^b	33.3^d
1	3.62	0.62^a	0.35^c	1.02^a	0.14^b	161^a	48.7^a	30.6^b	37.4^c
5	3.69	0.70^a	0.42^a	1.13^a	0.15^b	162^a	48.9^a	34.8^b	49.5^a
10	3.74	0.72^{ab}	0.41^b	1.06^a	0.16^a	134^{ab}	42.3^{ab}	48.2^a	41.1^b
Lsd$_{0.05}$	ns	0.06	0.06	0.12	0.05	15.2	14.3	11.4	10.3

PGW: Phosphogypsum Waste; N: Nitrogen; P: Phosphorus; K: Potassium; Ca: Calcium; Mg: Magnesium; Fe: Iron; Mn: Manganese; Zn: Zinc; B: Boron

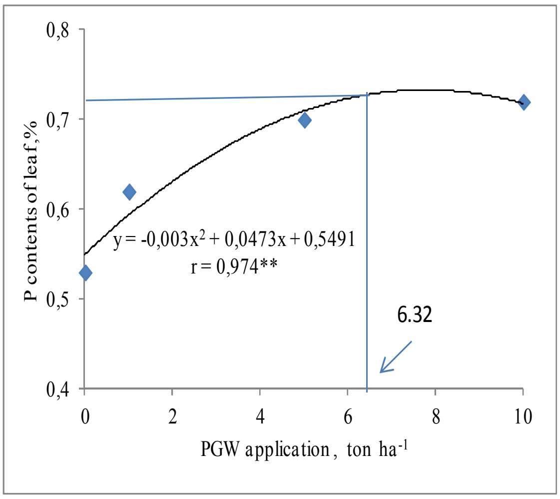

FIGURE 5
The effects of increasing PGW applications on P content of corn leaves

The highest iron (Fe) (162.2 mg kg^{-1}), manganese (Mn) (48.92 mg kg^{-1}) and boron (B) (0.49 mg kg^{-1}) contents of corn leaves were obtained at 5 ton ha^{-1} PGW. The increased percentage contents of Fe, Mn and B in leaves at 1, 5, and 10 ton ha^{-1} PGW application were 54.50, 55.36 and 28.45%, respectively; 60.03, 60.66 and 38.78%, respectively; and 12.10, 48.45 and 24.26%, respectively, in comparison to the control (no PGW application). The magnesium and zinc contents of the corn leaves obtained from 10 ton ha^{-1} PGW applications were 0.163% and 48.23 mg kg^{-1}, respectively. The Mg and Zn contents of the leaves increased at 1, 5 and 10 ton ha-1 of PGW application to 20.35, 29.20 and 44.25%, respectively; and 17.33, 33.28 and 84.93%, respectively, in comparison to the control (no PGW application). The variance analysis results showed that the P, Ca, Fe, and Mn contents of the corn leaves were significantly affected ($P<0,05$) at the 1 ton ha^{-1} application of PGW, as were the K and B contents at 5 ton ha^{-1}, and also the Mg and Zn contents at1 ton ha^{-1} of PGW.

Effect of phosphogypsum waste on stem nutrient contents. The mineral nutrient content of corn plant stems was higher for the PGW treatments than the controls (Table 4; Figures 2 and 3). The nitrogen (N) content of the stems increased for all PGW doses, and the highest N content (0.93%) was obtained at 5 ton ha^{-1} of PGW. The highest increasing at 1, 5, and 10 ton ha^{-1} of PGW applications were found by 16.44, 27.40 and 17.81%, respectively, in comparison to the control. Demir and Basalma [49] reported that the interaction of N and S had a significant effect on the N content of sunflower grains. Also, they stated that the highest grain N content was obtained at 120 kg N ha^{-1} and 150 kg S ha^{-1}.

The phosphorus content of the stems was higher for all three PGW applications than the control, with the highest P content (0.094%) was obtained from 1 ton ha^{-1} PGW. The P contents of the stems for 1, 5, and 10 ton ha^{-1} PGW application were 46.88, 26.56 and 42.19%, respectively, compared to the control. But the highest corn stem P content (0.09%) obtained through regression analysis was 7.43 ton ha^{-1} PGW (Figure 6).

The potassium and calcium contents of the stems were higher for all the PGW applications, with the highest contents obtained from the 5 ton ha^{-1} of PGW being 0.93% and 0.78%, respectively, for P and Ca, respectively. The K and Ca contents of stems at 1, 5 and 10 ton ha^{-1} PGW were 25.00, 36.76 and 4.41% higher, respectively; and 18.60, 31.40 and 23.26% higher, respectively, than the controls.

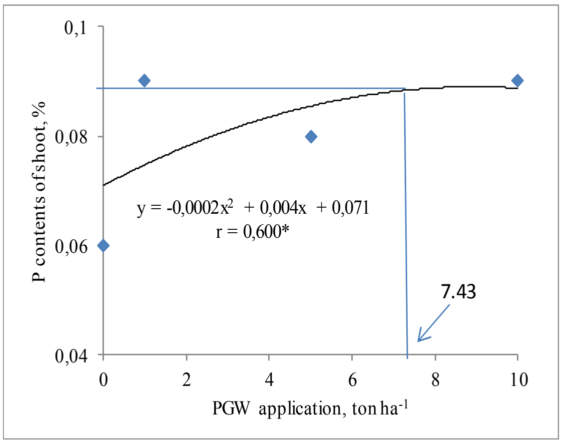

FIGURE 6
The effects of PGW on corn stem P contents

TABLE 4
Corn stem nutrient concentrations as impacted by PGW application

PGW	N	P	K	Ca	Mg	Fe	Mn	Zn	B
ton ha^{-1}	------------------------%------------------------					-------------mg kg^{-1}-------------			
Control	0.73	0.06	0.68^{b+}	0.58^{c}	0.16	28.6^{b}	28.6^{b}	23.4^{b}	68.1^{d}
1	0.85	0.09	0.85^{b}	0.61^{c}	0.18	33.3^{ab}	38.3^{a}	24.5^{b}	85.4^{b}
5	0.93	0.08	0.93^{a}	0.78^{a}	0.17	42.8^{a}	28.5^{b}	31.4^{ab}	115.3^{a}
10	0.86	0.09	0.71^{b}	0.70^{b}	0.19	43.9^{a}	27.2^{b}	36.8^{a}	71.5^{c}
$Lsd_{0.05}$	ns	ns	0.20	0.08	Ns	11.5	5.99	9.58	10.4

PGW: Phosphogypsum Waste; N: Nitrogen; P: Phosphorus; K: Potassium; Ca: Calcium; Mg: Magnesium; Fe: Iron; Mn: Manganese; Zn: Zinc; B: Boron

The highest Mg and Fe contents of the stems was obtained from 10 ton ha^{-1} PGW application, respectively 0.19 % and 43.9 mg kg^{-1}, while the highest Zn content was found as 38.3 mg kg^{-1} from 1 ton ha^{-1} PGW application. The increasing ratio of Mg, Fe, and Zn contents of the stems at 1, 5, and 10 ton ha^{-1} PGW application were 12.50, 6.25 and 18.75%, respectively; 16.45, 49.35 and 53.16%, respectively; and 4.92, 34.55 and 57.41%, respectively, higher than the control. The highest Mn and B contents of the corn stems were obtained with the 1 and 5 ton ha^{-1} PGW applications at 38.3 mg kg^{-1} and 115.3 mg kg^{-1}, respectively. In addition, the B contents of stems at 1, 5, and 10 ton ha^{-1} PGW application increased by 25.00, 69.12 and 4.41%, respectively, with respect to the controls.

According to the variance analysis results, the Fe and Mn concentrations of corn plants were significantly higher ($P<0.05$) than the controls at 1 ton ha^{-1} of PGW, and the K, Ca, Zn and B concentrations were significantly higher ($P<0.05$) at 5 ton ha^{-1}. Obtained findings were found accordantly by researchers that inform to increase the Ca, Zn and Mn uptake of PG applied the rice plant. The application of PG also increased Ca, Zn and Mn uptake when PG was applied to rice plants [33], and also increased Ca, Fe, Mn and Zn uptake in the sugar beet [40]. The concentrations of crop nutrients overall were within the critical levels [50]. Mills and Jones [51] reported that the critical nutrient range in leaves and stems for optimum corn growth were 3.0-3.5 N %; 0.2-0.4 P %; 2.0-2.5 K %; 0.2-0.5 Ca %; 0.13-0.3 Mg %; 10-200 mg Fe kg^{-1}; 15-60 mg Zn kg^{-1}; 15-300 mg Mn kg^{-1}, and 3-15 mg kg^{-1} Cu) and 3.0-5.0 N %; 0.3-0.5 P %; 2.5-4.0 K %; 0.3-0.7 Ca %; 0.15-0.45 Mg %; 50- 250 mg Fe kg^{-1}; 20-60 mg Zn kg^{-1}; 20-300 mg Mn kg^{-1}; and 4-20 mg Cu kg^{-1}, respectively.

CONCLUSIONS

The results of that present study indicate that PGW applications can significantly affect both the corn yield and mineral nutrient concentration in grain, stems and leaf parts. Corn yield increased with higher PGW doses. The highest yield was obtained from 1ton ha^{-1} PGW (8.26 ton ha^{-1}) doses by increasing approximately at rate of 46.19 %.

Macro and micro nutrient contents of corn plants increased with the different application rates of PGW. The low application dose of PGW generally increased N, P, K, Ca, Zn and B contents in leaf and grain, and Fe and Mn contents in stem of corn. On the other hand, the higher dose applications of PGW generally increased K, Mg, B, Zn content in leaf and stem of corn plant.

The results obtained show that the yield and for increasing mineral nutrition elements of corn plants should be recommended to the 1 and 5 ton ha^{-1} doses of PGW. These findings strongly suggest that PGW application increases corn yield and its mineral nutrient. Further research should be conducted on PGW application to examine the duration of its effects as well as its environmental and economic advantages for soils and plants.

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REFERENCES

[1] Ozata, E. (2019) Evaluation of Fresh Ear Yield and Quality Performance in Super Sweet Corn. International Journal of Life Sciences and Bio-Technology. 2(2), 80-94.

[2] TUIK (2018) Türkiye Istatistik Kurumu (Turkey Statistical Institute). Crop Production statistics. http//www.tuik.gov.tr.

[3] Keskin, B., Akdeniz, H., Yilmaz, I.H. and Turan, N. (2005) Yield and Quality of Forage Corn (*Zea mays* L.) as Influenced by Cultivar and Nitrogen Rate. Journal of Agronomy. 4(2), 138-141.

[4] Yolcu, H., Tan, M. (2008) General View to Turkey Forage Crops Cultivation. University of Ankara, Journal of Agriculture Science. 14, 303- 312.

[5] Bulut, S., Caglar, O. Ozturk, A. (2008) Possibilities to Grow Some Corn Cultivars in Erzurum Plain Conditions for Silage Production. University of Ataturk, Journal of Agriculture Science. 39, 83-91.

[6] Adepetu, J.A. (1983) Phosphorus fertilization of tropical crops. "*Nutrients Supply to Tropical Crops*". Institute of Tropical Agriculture, Leipzig Publication, Germany, 211-238.

[7] Amon, B.O.E. (1965) The response by crops in relation to nitrogen, phosphorus and potassium in the savanna zone of Western Nigeria. Proceedings of O.A.U STRC symposium on the maintenance of soil fertility publication Lagos, Nigeria, 152-158.

[8] Singh, V.K. and Dukey, O.P. (1991) Response of corn to the application of nitrogen and phosphorus. Current Research. Univ. Agri. Sci. Bangalore. 20, 153-154.

[9] Kaya, S.D., Higgs, D. and H. Kimak, (2001) The effect of high salinity (NaCl) and supplementary phosphorous and potassium on physiology and nutrition development of spinach. Bulgarian Journal of Plant Physiology. 27, 47–59.

[10] Ayub, M., Nadeem, M.A., Sharar, M.S. and Mahmood, N. (2002) Response of corn (*Zea mays* L.) fodder to different levels of nitrogen and phosphorus. Asian Journal of Plant Science. 1, 352-354.

[11] Ali, J., Bakht, J., Shafi, M., Khan, S. and Shah, W.A. (2002) Uptake of nitrogen as affected by various combinations of nitrogen and phosphorus. Asian Journal of Plant Science. 1, 367-369.

[12] Masood, T., Gul, R., Munsif, F., Jalal, F., Hussain, Z., Noreen, N., Khan, H., Khan, N. and Khan, H. (2011) Effect of Different Phosphorus Levels on The Yield and Yield Components of Maize. Sarhad J. Agric. 27(2), 167-170.

[13] Shainberg, I., Sumner, M.E., Miller, W.P., Farina, M.P.W., Pavan, M.A., Fey, M.V. (1989) Use of gypsum on soils: A review. Advances in Soil Science. 9, 1-111.

[14] Watts, D.B. and Torbert, H.A. (2009) Impact of gypsum applied to grass buffer strips on reducing soluble P in surface water runoff. J. Environ. Qual. 38, 1511-1517.

[15] Keerthisinghe, G., McLaughlin, M.J. and Freneey, J.R. (1991) Use of gypsum, phosphogypsum and floride to ameliorate subsurface acidity in a pasture soil. In: Wright, R.J., Baligar, V.C., Murrmann, R.P. (Eds.) Plant-Soil Interactions at Low pH: Proceedings of the Second International Symposium on Plant-Soil Interactions at Low pH. 24–29 June 1990, Kluwer Academic Publishers, Beckley West Virginia, USA, 509-517.

[16] Enamorado, S., Abril, J.M., Delgado, A., Mas, J.L., Polvillo, O. and Qunitero, J.M. (2014) Implications for food safety of the uptake by tomato of 25 trace-elements from a phosphogypsum amended soil from SW Spain. Journal of Hazardous Materials. 266, 122-131.

[17] Smith, C.J., Peoples, M.B., Keerthisinghe, G., James, T.R., Garden, D.L. and Tuomi, S.S. (1994) Effect of surface applications of lime, gypsum and phosphogypsum on the alleviating of surface and subsurface acidity in a soil under pasture. Australian Journal of Soil Research. 32, 995-1008.

[18] Saadaoui, E., Ghazel, N., Romdhane, C.B. and Massoudi, N. (2017) Phosphogypsum: Potential uses and problems - A review. International Journal of Environmental Studies. 74(4), 558-567.

[19] Mays, D.A., Mortvedt, J.J. (1986) Crop response to soil applications of phosphogypsum. Journal of Environmental Quality. 15, 78-81.

[20] Alva, A.K., Sumner, M.E. and Miller, W.P. (1990) Reactions of gypsum or phosphogypsum in highly weathered acid subsoils. Soil Science Society of America Journal. 54, 993-998.

[21] Caldwell, A.G., Hutchinson, R.L., Kennedy, C.W. and Jones, J.E. (1990) Byproduct gypsum increases cotton yield at Winnsboro. Louisiana Agriculture. 33, 23-24.

[22] McCray, J.M., Sumner, M.E., Radcliffe, D.E. and Clark, R.L. (1991) Soil Ca, Al, acidity and penetration resistance with subsoiling, lime and gypsum treatments. Soil Use Management. 7, 193-199.

[23] Lin, Z., Myhre, D.L. and Martin, H.W. (1988) Effects of lime and phosphogypsum on fibrous citrus-root growth and properties of Spodic horizon soil. Proceedings. Journal of Soil and Crop Science Society of Florida. 47, 67-72.

[24] Pavan, M.A., Bingham, F.T. and Peryea, F.J. (1987) Influence of calcium and magnesium salts on acid soil chemistry and calcium nutrition of apple. Soil Science Society of America Journal. 51, 1526-1530.

[25] Korcak, R. (1998) Agricultural uses of phosphogypsum, gypsum, and other industrial byproducts. Agricultural Uses of Municipal, Animal and Industrial Byproducts. U.S. Department of Agriculture, Agricultural Research Service, Conservation Research Report 44. Chapter 7, 120-126.

[26] Kacar, B. (2009) Fertilizer Analysis. Nobel Publications, Ankara, Turkey, 382p.

[27] Kacar, B. and Inal, A. (2008) Plant Analysis. Nobel Publications, Ankara, Turkey, 892p.

[28] Kacar, B. (1994) Plant and Soil Analysis III. Ankara University, Agriculture Faculty Publications, Ankara, Turkey, 705p.

[29] Page, A.L., Miller, R.H. and Keeney, D.R. (1982) Methods of Soil Analysis. 2nd Ed. American Society of Agronomy, Madison, WI., USA, 199-224

[30] Olsen, S.R., Cole, C.V., Watanabe, F.S. and Dean, L.A. (1954) Estimation of available phosphorus bicarbonate. Gov. USDA Circular Printing Office Washington D.C., 939, 1-19.

[31] Rhoades, J.D. (1996) Salinity: Electrical Conductivity and Total Dissolved Solids. In: Sparks, D.L. (Ed.) Methods of Soil Analysis. Part 3. Chemical Methods. Soil Science Society of America, Madison, WI., USA., 417-435.

[32] Mclean, E.O. (1982) Soil pH and Lime Requirement, Methods of Soil Analysis Part 2. Chemical and Microbiological Properties Second Edition. Agr. No: 9 Part 2. Ed., 199-224.

[33] Nelson, D.W. and Sommers, L.E. (1982) Organic Matter. Methods of Soil Analysis Part 2. Chemical and Microbiological Properties. Agronomy. No: 9 Part 2. Ed. 574-579.

[34] Thomas, G.W. (1982) Exchangeable cations. In: Page, A.L. (ed.) Methods of soil analysis. Part 2. Chemical and microbiological properties. 2nd edition. Agronomy Monograph, Madison WI 53711 USA, 159-165.
[35] Mertens, D. (2005a) AOAC Official Method 922.02. Plants Preparation of Laboratory Sample. Official Methods of Analysis. 18th ed. Horwitz, W. and Latimer, G.W. (Eds.) AOAC-International Suite 500, 481, USA. Chapter 3, 1-2.
[36] Mertens, D. (2005b) AOAC Official Method 975.03. Metal in Plants and Pet Foods. Official Methods of Analysis. 18th ed. Horwitz, W, and Latimer, G.W. (Eds.) Chapter 3, AOAC-International Suite 500, 481, 2417, USA, 3.
[37] SPSS (2004) SPSS 13.0 for Windows Evaluation version. Illinois, USA.
[38] Khan, Z.H., Khalil, S.H., Iqbal, A., Islam, B. Shah, W.A., Ahmad, A., Arif, M., Sajjad, M. and Shah, M. (2018) Growth Attributes of Sweet Corn Under Different Planting Regimes. Fresen. Environ. Bull. 27, 6945-6951.
[39] Korkmaz, A. and Gülser, C. (1995) Possibility of improving the efficiency of broadcast urea applied at tillering stage by using phosphogypsum in flooded rice soils. J. Agric. Fac. O.M.U. 10, 35-49.
[40] Cutcliffe, J.A. (1988) Effects of lime and gypsum on yields and nutrition of two cultivars of Brussels sprouts. Canadian Journal Soil Science. 68, 611-615.
[41] Erol, T., Sevimay, C.S. (2012) Effects of Gypsum Application and Mixture Rates on Forage Yields of Alfalfa (Medicago sativa L.) and Smooth Brome (Bromus inermis Leyss). Kahraman Maraş Sütçü İmam University, Journal of Natural Sciences. 15, 59-65.
[42] Mesić, M., Brezinščak, L., Zgorelec, Z., Perčin, A., Šestak, I., Bilandžıja, D., Trdenić, M. and Lisac, H. (2016) The Application of Phosphogypsum in Agriculture. Agriculturae Conspectus Scientificus. 81(1), 7-13.
[43] Khan, M.A., Khan, M.U., Ahmad, K. and Sadiq, M. (1999) Yield of corn hybrid-3335 as affected by P levels. Pakistan Journal of Biological Sciences. 2, 857-859.
[44] Maqsood, M., Abid, A.M., Iqbal, A. and Hussain, M.I. (2001) Effect of various rates of nitrogen and phosphorus on growth and yield of corn. Pakistan Journal of Biological Science. 1, 19-20.
[45] Sharma, J.P. and Sharma, U.C. (1991) Effect of nitrogen and phosphorus on the yield and severity of turcicum blight in corn Nagaland. Indian Phytopathological Society. 44, 383-385.
[46] Arain, A.S., Aslam, S.M. and Tunio, A.K.G. (1989) Performance of corn hybrids under varying NP environments. Sarhad Journal of Agriculture. 5, 623-626.
[47] Hussain, N., Khan, A.Z., Akbar, H. and Akhtar, S. (2006) Growth factors and yield of corn as influenced by phosphorus and potash fertilization. Sarhad Journal of Agriculture. 22(4), 579-583.
[48] Elloumi, N., Zouari, M., Chaari, L., Abdallah, F.B., Woodward, S. and Kallel, M. (2015) Effect of phosphogypsum on growth, physiology, and the antioxidative defense system in sunflower seedlings. Environmental Science and Pollution Research. 22(19), 14829-14840.
[49] Demir, İ. and Basalma, D. (2018) Response of Different Level of Nitrogen and Sulphur Doses on Oil Yield and Seed Nutrients Content of Sunflower (*Helianthus Annuus* L.). Fresen. Environ. Bull. 27, 6337-6342.
[50] Zengin, M. (2012) Plant Nutrition. In: Karaman, M.R. (Ed.) The Fundamental in Interpretation of Plant and Soil Analysis. Section 12. Dumat Publication. The First Edition. Ankara, 837-961.

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