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Application of Filter Mud with Potassium and Magnesium Fertilizers to Improve Sandy Soil Properties and its Productivity of Faba Bean Plant

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Field trial was conducted in the experimental farm at the Ismailia Agricultural Research Station, Agriculture Research Centre, Egypt during two winter seasons of 2018/2019 and 2019/2020. The experiments were established to study the effect of filter mud with K and Mg fertilizers on physical and chemical properties of sandy soil and its productivity of faba bean plant (*Vicia faba L.*, c.v. 843). A split-split plot design with three replicates was applied. The obtained results showed, the filter mud levels at the same K and Mg levels improved soil physical and chemical properties. There are noticeable increases in total porosity, fine capillary pores, water holding pores, available water (AV), EC, organic matter (OM), penetration resistance (PR) and soil available N, P, K and Mg. On the contrary, there was a decrease in soil pH, bulk density, hydraulic conductivity and quickly drainable pores as compared with the control. The best combined treatment for the parameters under study was at rate of 20 Mgha^{-1} (FM2) with 119 kgha^{-1} for potassium (PF2) and magnesium (MF1). Addition of filter mud integrated with potassium and magnesium fertilizers, led to an increase in all yield parameters of faba bean i.e. total yield, seeds yield and straw yield (kgfed^{-1}) as compared to the control. These results can be recommended that, using filter mud at rate of 20 Mgha^{-1} (FM2) with K and Mg fertilizers leads to improve the physiochemical properties of sandy soils and plant productivity which reduces the used of mineral fertilizers.

Keywords: Faba bean, Filter mud, Magnesium, Potassium, Sandy soils, Yield parameters.

1. Introduction

Sandy soil problems are numerous such as low water storage capacity, low contents of clay minerals, organic matter and nutrients (Elshony et al., 2019; Aboelsoud and Ahmed, 2020). In Egypt, awful mass of filter mud (FM) contain a considerable quantity of plant nutrients (Shaaban et al., 2022). Filter mud is organic waste produced from sugar factories, and is amorphous, spongy, and dark brown to brown in color (Said et al., 2010). Also, it contains some enzymes, hormones, and plant growth regulators that lead to improving agriculture soil fertility and productivity (Solimalia et al., 2001). Filter mud has been applied as organic fertilizer and it had a positive impact on plant growth and soil physicochemical properties (Wongkoon et al., 2014). Moreover, filter mud is capable of providing an adequate amount of plant nutrients, due to its positive effects on soil texture, structure, organic matter (OM), aeration, and water holding capacity (Said et al., 2010; Elsayed et al.,

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2011). This effect may be attributed to the improvement of soil physical, chemical and biological conditions (Barry et al., 2001). Addition filter mud led to improve soil OM, structure, water infiltration, and decrease pH (Said et al., 2010; El-Tayeh et al., 2019; Shaaban et al., 2022). The high amount of NPK content in filter mud makes it a valuable organic resource (Rakkiyappan et al., 2001).

Legumes are the main crops grown in the northern and Nile Delta regions of Egypt. Faba bean (*Vicia faba L.*) covers an average area of 69,720 ha, with 1896 kg/ha average yield (AOAD, 2007). Faba bean is a legume that is consumed as plant foods for both human and animal, as it is rich in protein (Mona et al., 2011). Also, it has a high symbiotic nitrogen-fixing capacity in relation with *Rhizobium leguminosarum* bv. *viciae* (Dashadi et al., 2011).
Sandy soils is characterized by a low content of potassium nutrients (Budiyanto, 2021). Moreover, potassium leaches in sandy soil because it does not contain enough OM and clay to hold potassium. Crops differ in their response to growth with potassium supply, due either to differences in their ability to absorb potassium from soil or their ability to use potassium physiologically in their metabolism (White et al., 2021). Hence, the variance of K efficiency may be due to variations in plant internal requirements or K utilization efficiency (Fageria et al., 2001).

Magnesium plays a critical role in many enzymatic reactions and therefore it is necessary for a large number of growth and developmental processes in plants (Epstein and Bloom, 2005). Magnesium performs many crucial functions in plant metabolism, and an adequate supply is important for crop high yields and quality. The low magnesium amounts are usually associated with the origin of soil such as sandy soils, which originate from granites sandstones, post glacial and sedimentary sandy deposits (Grzebisz, 2011). Lausen and Gosch (2012) found that only 25% of the light sandy soils and one-third of the heavy soils are optimally fortified with magnesium. An increase in yield cannot be obtained by adding magnesium fertilization to soils containing magnesium concentrations higher than 0.2 to 0.5 g kg^{-1} (Scheffer et al., 2002).
Treating sandy soil with filter mud resulted in a small decrease in soil pH and an increase in electrical conductivity (EC), OM, and total nitrogen (El-Tayeh et al., 2019). Sweed and Negim (2019) mentioned that, application of different filter mud rates to sandy soils increased soil porosity, field capacity, wilting point, available water, EC, and OM contents as compared to control.
The present research aimed to studying the effect of filter mud (as organic fertilizer) and mineral fertilizers of potassium and magnesium, individually or in combinations , on sandy soil physical and chemical properties and its content of available nutrients as well as the soil productivity of faba bean.

2. Materials and Methods

A field trial was implemented at Ismailia Agricultural Research Station (latitude, 30^o 36' 57.63" N and longitude, 32^o 14' 39.10" E), EL-Ismailia Governorate, Egypt, during two growing winter seasons of 2018/2019 and 2019/2020. Before planting, surface soil samples (0-30 cm) were taken air-dried, ground to pass through a 2 mm sieve and analyzed for some physical and chemical properties (Blake, 1965; Page et al., 1982; Klute and Dirksen, 1986) (Table 1). Filter mud (FM) was brought from a factory of sugarcane, Qus, Qena Governorate, Egypt. According to Page et al. (1982), the main properties of the used FM were estimated (Table 2). Before sowing, surface layer of all plots were mixed with ordinary superphosphate (15.5% P_2O_5) at rate of 477 $kgha^{-1}$. As well as all treatments received a dose of 150 $kgha^{-1}$ of ammonium sulfate (20.6% N) after 10 days from sowing**.** Seeds of faba bean (*Vicia faba L.*, c.v. 843) were planted at 2 cm soil depth/hole with cultivation distance of 15 x 70 cm. The experiment was designed in a split split plot with three replicates and the plot area was 10.5 m^2 (3 x 3.5 m). The used irrigation system was surface drip irrigation, whereas the examined treatments of FM, K and Mg fertilizers were applied as follows:

1) Three main groups (18 plots/main group) were assigned to filter mud at the rates of zero (FM0), 15 Mg ha^{-1} (FM1), and 20 Mg ha^{-1} (FM2).

2) Three subgroups (6 plots/subgroup) were assigned to potassium sulfate (48% K_2O) at the rates of zero (PF0), 95.2 kg ha^{-1} (PF1), and 119 kg ha^{-1} (PF2).

3) Two sub-sub groups (3plots/sub-sub group) were assigned to magnesium sulfate hepta hydrate (16.3% MgO) at the rates of zero (MF0) and 119 kg ha^{-1} (MF1).

Table 1. Some physical and chemical properties of the experimental soil.

Particle size distribution (%)					BD	PD	**TP** (%)	**HC** (cm h^{-1})	**PR** (kg cm^{-2})	**OM** (%)	**pH**
CS	**FS**	**Silt**	**Clay**	**Texture grade**	(g cm^{-3})						
31.82	61.61	1.22	5.35	Sandy	1.65	2.49	33.7	35.2	3.7	0.71	7.42

EC (dS m^{-1})	**Soluble cations and anions** (mmol kg^{-1})							**Available macronutrient** (mg kg^{-1})			
	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	Cl^-	SO_4^{2-}	N	P	K	Mg
1.54	4.77	4.12	6.01	0.51	1.12	4.90	9.39	13.59	3.30	155.3	15.75

CS= Coarse sand, **FS**= Fine sand, **BD**= Bulk density, **PD**= Particle density, **TP**= Total Porosity**, HC**= Hydraulic conductivity, **PR**= Penetration resistance, **OM**= Organic matter**, pH =** Soil reaction measured in 1:2.5, soil: distilled water suspension**), EC**= Electrical conductivity (measured in 1:5, soil: distilled water extraction).

Table 2. Some properties of studied filter mud.

Properties		Properties		
OM (%)	69.7	**EC** (dS m^{-1})		6.1
Total C (%)	42.5	**SP** (%)		71.0
Total N (%)	2.23	**Soluble cations and anions** (mmol kg^{-1})	Ca^{2+}	36.6
Total P (%)	3.6		Mg^{2+}	16 .0
Total K (%)	0.49		Na^{+}	5.61
Total Mg (%)	7.92		K^{+}	8.1
C/N ratio	19.0		HCO_3^-	28.3
BD (Mg m^{-3})	0.136		Cl^-	4.81
pH	6.5		SO_4^{2-}	34.5

OM= organic matter**, EC**= measured in 1:5 (filter mud: distilled water extraction), **pH=** measured in 1:5 (filter mud: water suspension), **SP**= saturation percent.

The FM was mixed to the experimental plots with ordinary super phosphate. However, K (PF) and Mg (MF) fertilizers were applied after 30 days of planting through the irrigation system (fertigation).

At harvest stage (135 d), the plants of each experimental plot were harvested above soil surface, allowed to dry in the plots under air and sun conditions. The dried plants was crushed and then the seeds were separated from straw to obtain the yield weight of both straw and seeds as kgfed^{-1}. Also, disturbed and undisturbed soil samples were taken from each replicate of soil surface and prepared to determine some physicochemical properties. Soil pH, EC, OM content, and its available N, P, K, and Mg were measured according to the methods explained by Page et al. (1982). The method reported by Blake (1965) and Vomocil (1965) was used to measure soil bulk density (BD) and total porosity (TP), respectively. Also, pore size distribution (Stakman, 1966), saturated hydraulic conductivity (Klute and Dirksen, 1986) and penetration resistance (Davidson, 1965) were estimated. Finally, soil moisture content at different suction pressures (0.1, 0.33, 0.66, 1.0, 3.0, 15.0 bar) were measured by Klute and Dirksen (1986) method. Furthermore, the available water (AW) was calculated by the subtraction of water content at field capacity (FC at 0.1 bar) and permanent wilting point (PWP, at 15.0 bar).

Statistical analysis

The split split plot ANOVA (Snedecor and Cochran, 1989) examined the effect of studied treatments on soil physiochemical properties and plant growth parameters. The least significant difference (LSD) range test was used to compare different treatment means in each group of means.

3. Results and Discussion

3.1. Soil chemical properties

Soil reaction and soil salinity

The obtained data in Table 3 revealed that, pH values after harvest stage (135 d) of faba bean plants were affected due to all different studied treatments, especially with FM additives. The application of filter mud in combination with K and Mg fertilizers to sandy soil have a significant decrease of soil pH values as compared with control treatment. This could be attributed to production of organic acidic compounds from filter mud through its decomposition processes by soil microbes (Hamed et al., 2011). The highest decrease of soil pH was resulted from the combined treatments of filter mud at rate 20 Mg ha^{-1} (FM2) with potassium and magnesium at rates 95.2 kg ha^{-1} (P1) and 119 kg ha^{-1} (M1), respectively (Figure, 1). Soil pH was clearly affected as a result of filter mud application, where mean of soil pH was decreased significantly from 7.39 to 7.12 due to the increase in applied FM from 0.0 (FM0) to 20 Mg ha^{-1} (FM2). Before that, similar results were obtained and discussed by Mansour (2002).

Regarding to the effect of K and Mg fertilizers, data indicated that the addition of K and or Mg did not show any significant effect on soil pH values. This trend was accompanying their both individual (Table 3) and combination (Figure 1) treatments. These results are in similar with those obtained by Mansour (2012), Budiyanto (2021) and Ali et al. (2022).

Also, data in Table 3 and Figure 1 indicate that, the mean values of soil EC after harvesting during two growing seasons were slightly increasing with increasing filter mud (FM) in combination with mineral K and Mg fertilizers as compared with the control. This may be attributed to high electrical conductivity of FM (5.96 dSm^{-1}). The highest increase of EC was recorded in a treatment by filter mud at rate of 20 Mg ha^{-1} (FM2) combined with potassium and magnesium at rates 119 kg ha^{-1} (P2) and 119 kg ha^{-1} (M1) respectively. The highest significant EC value (1.58 dSm^{-1}) was recorded to the filter mud (FM2) mixed with potassium (PF2) and magnesium (MF1) fertilizer. In comparison with control (FM0) no significant differences in EC values appeared among FM1 and FM2 treatments. Also, individual applications of K and Mg fertilizers have no significant effect on soil EC values compared with control treatment (Table, 3). In this respect Barry et al. (2001), Elsayed et al. (2011) and Ali et al. (2022) obtained similar results with organic manures applications.

Soil organic matter content

The data in Table 3 and Figure 1 shows that, the addition of filter mud, increased soil organic matter (OM) content significantly compared to untreated soil. This is due to the fact that, FM is rich in organic carbon. The highest values of OM content were recorded with the compound treatment of FM2+PF2+MF1, while the minimum values was reveals in the control treatment. Within different addition rates of FM, application of FM1 and FM2 increased significantly soil OM content, compared with FM0 treatments. Either FM1or FM2 application resulted in a significant increase of soil OM content, while the heights OM content was recorded when FM2 treatment was applied. Furthermore, the results of Table 3 showed the soil OM content was not significantly affected by the individual and combination of the applied PF and MF fertilizers. These results are in agreement with those obtained by Abou Hussien et al. (2017), who reported that compost applied at rates from 25 to 50 t ha^{-1} led to increases in soil organic content from 0.55 to 0.83 %. As well as Zebarth et al. (1999) and Abou Hussien et al. (2020) showed increases in soil organic matter content with other organic additives.

Table 3. Individual effect of applied filter mud mixed with K (PF) and Mg (MF) fertilizers on soil pH, EC and its content of organic matter and available macronutrients (values are average of two growing seasons)**.**

Treatments		pH -	EC (dSm^{-1})	OM (%)	Available macronutrients (mgkg^{-1})			
					N	**P**	**K**	**Mg**
FM	**FM0**	7.39a	1.44b	0.65c	15.51c	3.18c	179.28b	17.93c
	FM1	7.19b	1.51a	0.72b	16.26b	3.33b	182.36ab	19.66b
	FM2	7.12b	1.54a	0.76a	16.98a	3.78a	188.17a	20.70a
LSD $_{0.05}$ FM		**0.13**	**0.061**	**0.033**	**0.60**	**0.11**	**5.32**	**0.69**
PF	**PF0**	7.27a	1.47a	0.69b	15.83a	3.00b	170.09c	17.99b
	PF1	7.22a	1.50a	0.72a	16.45a	3.56a	178.71b	19.49a
	PF2	7.21a	1.52a	0.72a	16.47a	3.73a	201.02a	20.81a
LSD $_{0.05}$ PF		**ns**	**ns**	**0.017**	**ns**	**0.21**	**4.86**	**1.38**
MF	**MF0**	7.24a	1.49a	0.70b	15.99a	3.28b	179.84b	18.47b
	MF1	7.22a	1.49a	0.72a	16.51a	3.53a	186.71a	20.39a
LSD $_{0.05}$ MF		ns	ns	0.0098	**ns**	**0.15**	**3.99**	**0.9**
Interaction:								
FM * PF		ns	ns	ns	ns	0.31	ns	ns
FM * MF		ns	ns	ns	ns	ns	ns	ns
PF * MF		ns	ns	ns	ns	0.21	ns	ns
FM * PF * MF		ns	ns	ns	ns	ns	ns	ns

FM= filter mud, **PF**= Potassium fertilization, and **MF**= magnesium fertilization, **EC**= electrical conductivity, **OM**= organic matter, mean values within each column followed by same letters are not significantly different at 5% level of probability (n = 3 for each individual treatment).

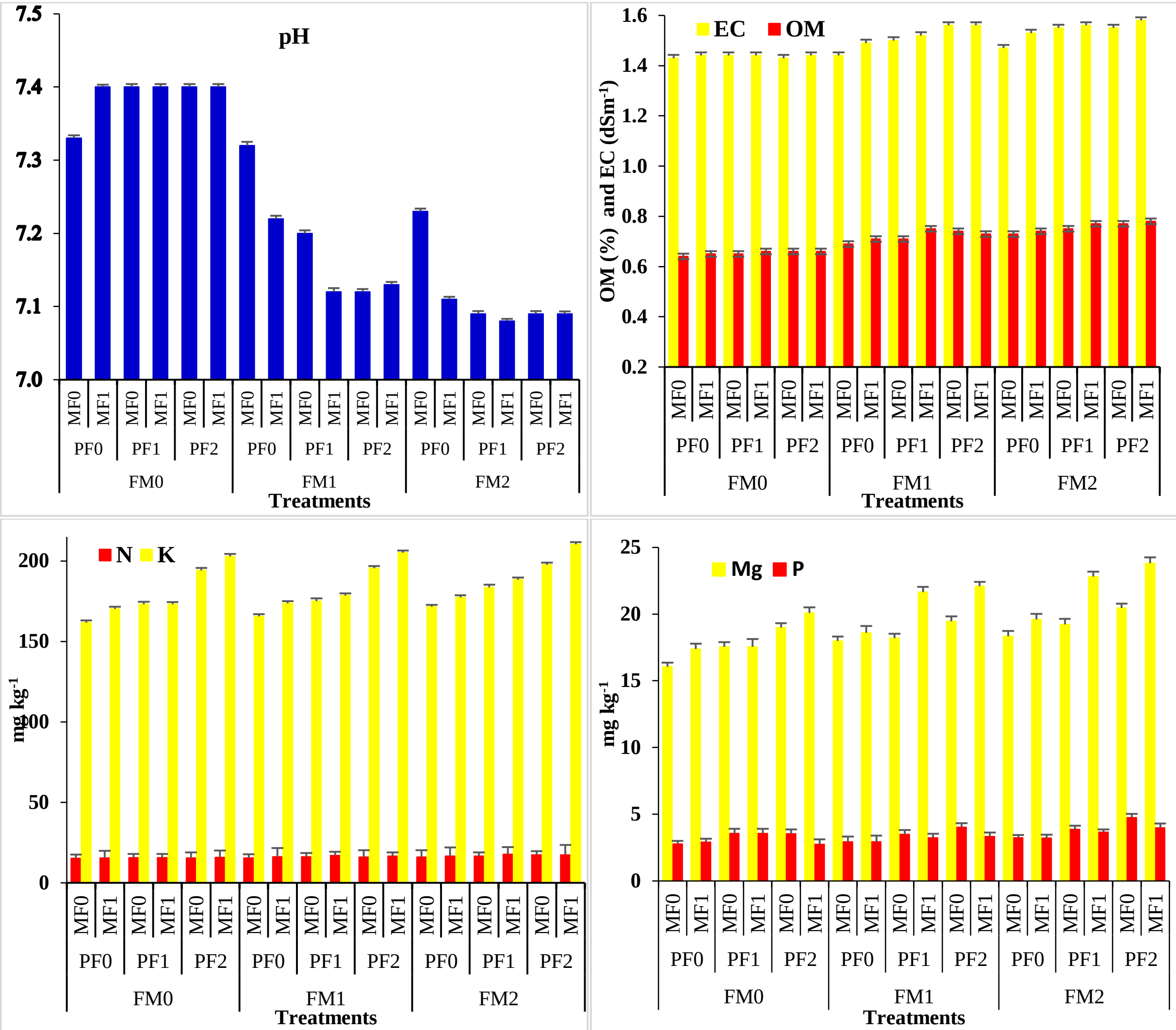

Fig. 1. The integrated effect of filter mud, potassium and magnesium fertilizers on soil pH, EC, OM and available macronutrients (n=3, the error bar on the columns is the standard deviation). FM0 = zero filter mud, FM1= = 15 Mg ha^{-1} filter mud, FM2 = 20 Mg ha^{-1} filter mud, PF0 = zero potassium, PF1 = 95.2 kg ha^{-1} potassium, PF2= 119 kg ha^{-1} potassium, MF0= zero magnesium, MF1= 119 kg ha^{-1} magnesium.

3.2. Soil content of available macronutrients

The presented data in Table 3 and Figure 1 show the effect of the studied treatments i.e. filter mud, potassium fertilizer (PF0, PF1 and PF2) and magnesium fertilizer (MF0 and MF1) on soil content of some available macronutrients (N, P, K and Mg). These data show that, the studied treatments have a significant effect on the soil content of available macronutrients under study. The individual effect of filter mud on soil available N, P, K and Mg was significant. All means values of soil available nutrients of N, P, K and Mg were increased with increasing of filter mud rates compared to the control treatment (Figure, 1). These results were supported by what had been obtained by Ali et al. (2022) who studied the combined effect of filter mud cake combined with chemical and biofertilizers to enhance potato growth and its yield. They found that, the addition of mineral fertilizers alone significantly increased the soil availability of N, P, and K nutrients. With regard to the soil content of available N, P, K and Mg, the tabulated results indicate that the addition of K and Mg as mineral fertilizers led to significant increases in the soil content of available P, K and Mg (mgkg^{-1}) as compared to the control. However, it was found non-significant increase in soil available N contents. In this respect, simulation results were obtained by EL-Sirafy et al. (2010) and Ali et al. (2022).

3.3. Soil physical properties

Soil bulk density

Generally, the data presented in Table 4 and Figure 2 shows that, increasing the application rate of filter mud alone or in combination with K and Mg led to a decrease in the bulk density (BD) values. The magnitude of reduction was increasing with the increase of application rates of FM, where reached the minimum value at FM2 compared to control. This finding can be attributed to the low specific gravity of organic material and their decomposition material, which enhance aggregation process and subsequently increase apparent soil bulk volume and decrease soil bulk density **(**El-Hamid et al., 2011). These results are in agreement with those obtained by Zebarth et al. (1999), who found that applied six different organic amendments including bio solids and food waste compost reduced bulk density.

Table 4. Individual effect of applied filter mud mixed with K and Mg fertilizers on soil bulk density, total porosity, pore size distribution, hydraulic conductivity and penetration resistance (values are average of two growing seasons).

Treatments		**BD** (Mg m^{-3})	**TP** (%)	**Pore size distribution** (%)				**HC** (cmh^{-1})	**PR** ($kgcm^{-2}$)
				QDP	**SDP**	**WHP**	**FCP**		
FM	**FM0**	1.61a	38.67a	31.49a	2.49c	2.48c	2.21c	32.94a	3.91c
	FM1	1.57ab	40.02a	31.05a	2.97b	2.95b	3.06b	31.35b	5.30b
	FM2	1.52b	41.61a	30.29a	3.53a	3.62a	4.17a	29.75c	6.49a
LSD $_{0.05}$ FM		**ns**	**ns**	**ns**	**0.18**	**0.14**	**0.18**	**1.2**	**0.14**
PF	**PF0**	1.57ab	39.11a	31.34a	2.53c	2.66c	2.59c	31.55a	4.72c
	PF1	1.56a	40.15a	30.97a	3.01b	2.96b	3.22b	31.36a	5.13b
	PF2	1.57a	41.04a	30.52a	3.45a	3.44a	3.62a	31.13a	5.86a
LSD $_{0.05}$ PF		**ns**	**ns**	**ns**	**0.14**	**0.063**	**0.12**	**ns**	**0.13**
MF	**MF0**	1.57a	38.87a	31.09a	2.88b	2.90b	3.00b	31.34a	5.07b
	MF1	1.57a	40.33a	30.80a	3.11a	3.13a	3.29a	31.35a	5.40a
LSD $_{0.05}$ MF		**ns**	**ns**	**ns**	**0.09**	**0.084**	**0.098**	**ns**	**0.1**
Interaction:									
FM * PF		ns	ns	ns	0.20	0.09	0.056	ns	0.18
FM * MF		ns	ns	ns	0.13	0.12	0.14	ns	0.15
PF * MF		ns	ns	ns	ns	ns	ns	ns	0.11
FM * PF * MF		ns	ns	ns	ns	ns	ns	ns	0.26

FM= filter mud, **PF**= Potassium fertilization, **MF**= magnesium fertilization, **BD**= bulk density, **TP**= total porosity, **QDP**= quickly drainable pores, **SDP**= slowly drainable pores, **WHP**= water holding pores, **FCP**= fine capillary pores, **HC**= hydraulic conductivity, **PR**= penetration resistance, mean values within each column followed by same letters are not significantly different at 5% level of probability (n = 3 for each individual treatment).

Total porosity

Generally, the data in Table 4 show that increasing filter mud application rates and its combination with K and Mg led to an increase in the total porosity (TP) values compared with untreated soil. This could be attributed to the rapid decomposition of the material in sandy soil. Also, in fact that fresh organic matter does not affect the TP, but the decomposition products which act as a cementing agent. The highest value of TP are found with the highest application rate of FM (Figure 2). These results may be attributed to the effect decomposition of organic fertilizer (filter mud) which encourage flocculation of soil particles leading to the formation of aggregates and in turn the decrease of the bulk density and increase total porosity (Mansour, 2002).

Pore size distribution

Pore size distribution is responsible for the limitation of water retention and movement in the soil. It is strongly influenced by soil texture and structure. An inherited properties of sandy soils is low water retention and rapid water movement. Therefore, any attempt to improve sandy soil should focus on the redistribution of pores to increase water holding pore (WHP), fine capillary pores (FCP) and slowly drainable pores (SDP) and decrease quickly drainable pores (QDP). The mean values of pore size distribution throughout two cultivations affected by different improvement and management processes as a result of adding of filter mud alone and in combination with K and Mg are presented in Table (4). The data reveal that, FCP < 0.2μ, WHP (medium pores 0.2-9μ and SDP were increased whereas, QDP (macro pores, >9μ) were decreased with increasing the application rates of FM (Figure 2). This finding is in favor of sandy soil improvement, i.e., increasing its moisture retention and decreasing its water movement. This could be attributed to production of organic acids from filter mud through decomposition processes that enhanced soil aggregation and the percentage of stable aggregates. These results are in agreement with those obtained by Mansour (2007). On the other hand, addition of K and/or Mg fertilizers led to a significant increasing in SDP, WHP, and FCP. This trend may be due to high portion of Mg and K on soil exchange sites results in accumulation of fine sand particles, leading to decreased porosity (Mateo- Marín et al., 2022). Also, the strong growth of plant roots and their organic secretions and amino acids under the influence of these fertilizers may be the reason (Reid and Goss, 1981; Hammad, 2022).

Hydraulic conductivity

The data in Table 4 and Figure 3 shows that, the values of soil hydraulic (HC) in sandy soil were significantly decreased with increasing the application rate of filter mud with K and Mg. The HC were decreased to 29.54 cmh^{-1} in treatment of FM2+PF2+MF1 as compared with untreated soil (figure 3). This could be attributed to the effect of filter mud in decreasing the macro pores and increasing the micro pores, consequently the hydraulic conductivity values were decreased. Also, this behavior could be explained by the improvement in soil aggregation and consequently increase the macro pore on the expense of micro pores as previously found. In contrast, treated soils with K and Mg fertilizers did not show any significant responses in the values of HC (Mansour, 2012).

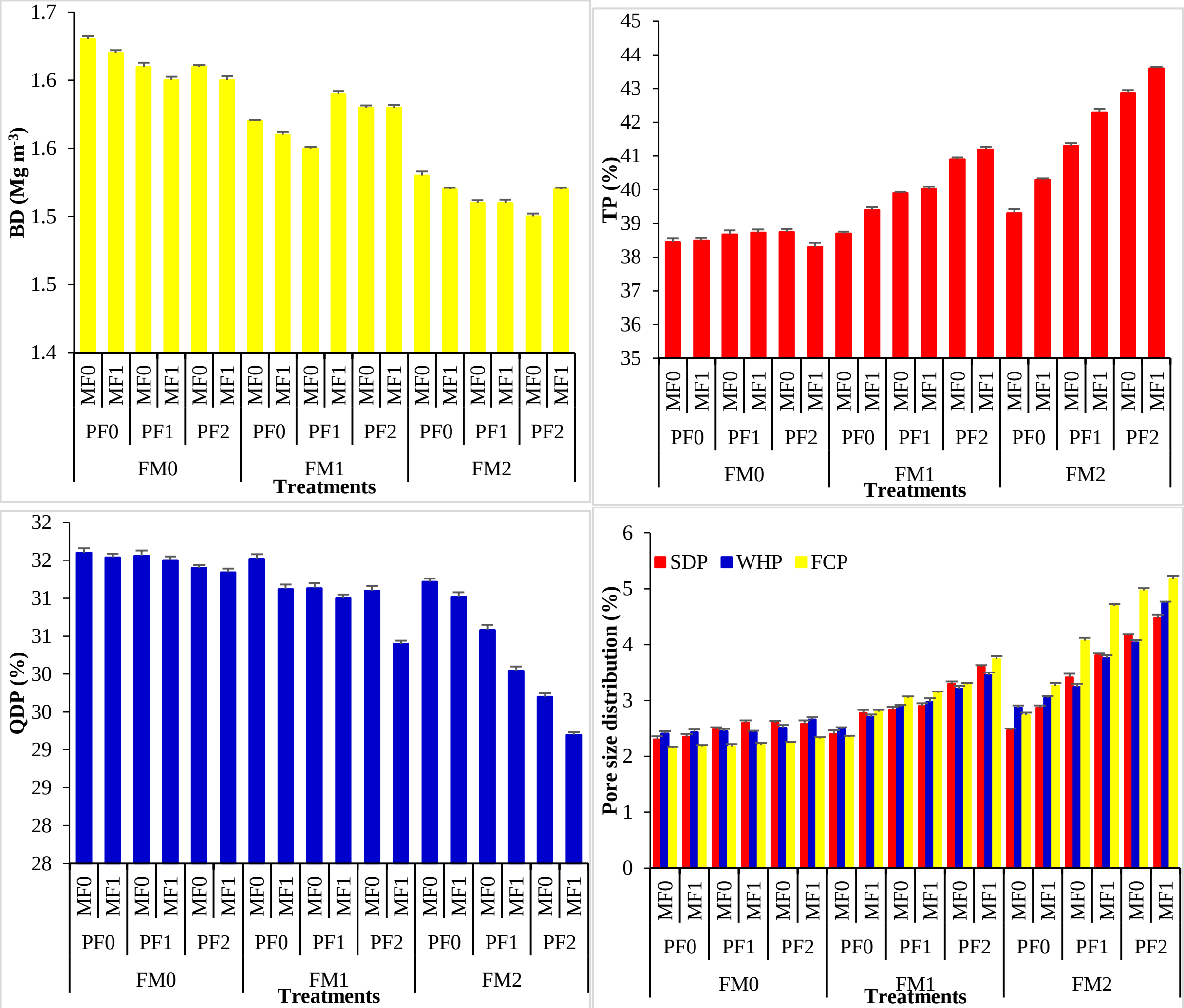

Fig. 2. The integrated effect of filter mud, potassium and magnesium fertilizers on soil bulk density (BD), Total porosity (TP) and pore size distribution (n=3, the error bar on the columns is the standard deviation). FM0 = zero filter mud, FM1= = 15 Mg ha^{-1} filter mud, FM2 = 20 Mg ha^{-1} filter mud, PF0 = zero potassium, PF1 = 95.2 kg ha^{-1} potassium, PF2= 119 kg ha^{-1} potassium, MF0= zero magnesium, MF1= 119 kg ha^{-1} magnesium, QDP= quickly drainable pores, SDP= slowly drainable pores, WHP= water holding pores, FCP= fine capillary pores.

Penetration resistance

The data in Table 4 and Figure 3 show that, the penetration resistance (PR) increase with increasing application rates of FM. This is mainly attributed to the increase in the micro pores, which lead to increase the retained moisture, increasing connection between sand particles, and consequently increases the PR in the surface layer. Moreover, this is because the sandy soil shows kind of stickiness when it was wet (El-Amir, 1987; Celik et al., 2010). Compared with control, treated soil with potassium (PF) and magnesium (MF) lead to significantly increasing on soil PR, as supported by Reid and Goss (1981) and Mateo- Marín et al. (2022).

3.4. Soil moisture retention

Data in Table 5 show the effect of applied FM with K and Mg fertilizers on the retained moisture at different suction pressure and available water (AW) after harvesting. The individual effect of FM on all levels of soil moisture (0.1, 0.33, 0.66, 1.3 and 15 bar) was significant. The retained moisture increased significantly with increasing the application rate of FM where the maximum increasing was obtained at treatment of FM2 (Figure 4). This result can be explained as follows:

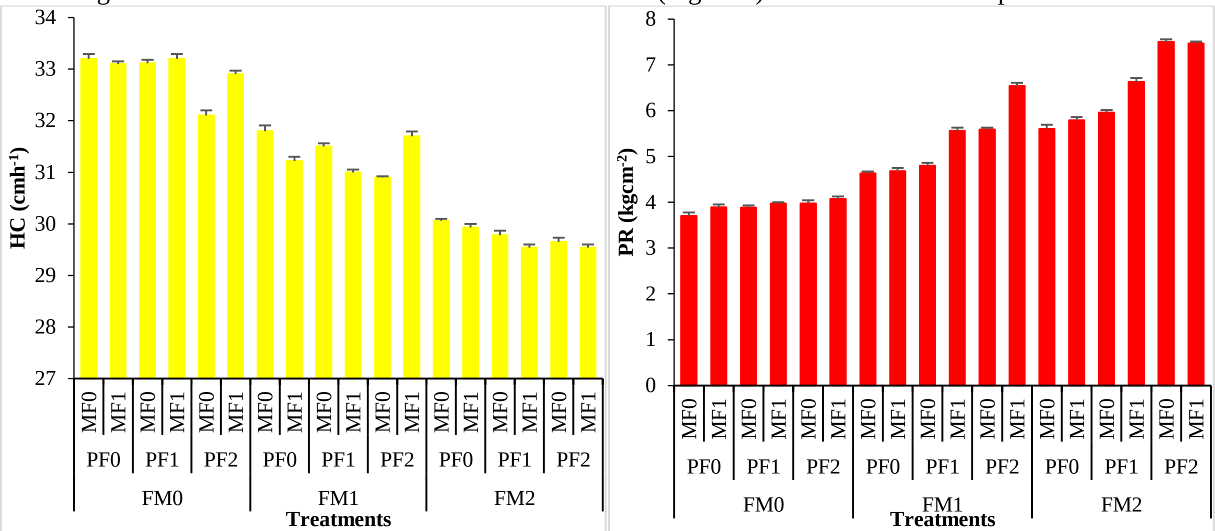

Fig. 3. The integrated effect of filter mud, potassium and magnesium fertilizers on soil hydraulic conductivity (HC) and penetration resistance (PR) (n=3, the error bar on the columns is the standard deviation). FM0 = zero filter mud, FM1= = 15 Mg ha^{-1} filter mud, FM2 = 20 Mg ha^{-1} filter mud, PF0 = zero potassium, PF1 = 95.2 kg ha^{-1} potassium, PF2= 119 kg ha^{-1} potassium, MF0= zero magnesium, MF1= 119 kg ha^{-1} magnesium.

Adding filter mud as natural wastes leads to change in pore size distribution due to its high organic matter content, which leads to an increase in fine capillary pores on the expense of quickly drainable pore. Consequently, increase the retained moisture in sandy soil is important to available moisture which was calculated as the difference between moisture content at field capacity (0.33 bar) and moisture content at wilting point (15.0 bar) and presented in Table 5 and Figure 4. The content of available moisture increased significantly with increasing the application rate of the natural amendment (FM) as shown in Table 5 and Figure 4, this finding could be explained on the basis of the effect of filter mud in combination with Mg and K on increasing of water holding pores and decreasing of the quickly drainable pores and also, due to the effect of organic materials in FM on the two limits of available water (FC and WP). This finding may be due to the high moisture capacity of filter mud addition compared with soil mineral particles sand and also, may be attributed to the role of organic matter for stable aggregates forming which improve soil moisture retention (Seddik et al., 2016). In addition, the effect of organic acids, which formed either during decomposition of organic amendments, may be helpful development of soil physical properties (Negim and Mustafa, 2016; Awwad et al., 2022).

Table 5. Individual effect of applied filter mud mixed with K and Mg fertilizers on soil moisture content at different suction pressures and available water (values are average of two growing seasons)**.**

Treatments		**Moisture content** (%, by weight) **at different suction pressures** (atm)						**AW**
		0.1	**0.33**	**0.66**	**1**	**3**	**15**	(%)
FM	**FM0**	6.66c	4.88c	3.22c	2.60c	2.34a	1.45c	5.21c
	FM1	11.26b	8.72b	4.95b	3.25b	2.39a	2.13b	9.14b
	FM2	12.37a	10.37a	5.96a	3.79a	2.60a	2.51a	9.87a
LSD $_{0.05}$ FM		**0.18**	**0.42**	**0.7**	**0.38**	**0.35**	**0.18**	**0.27**
PF	**PF0**	9.16b	7.96a	4.11a	3.19a	1.77c	1.90b	7.26b
	PF1	10.37a	7.83a	4.89a	3.17a	2.53b	2.04a	8.33a
	PF2	10.77a	8.17a	5.11a	3.28a	3.08a	2.04a	8.63a
LSD $_{0.05}$ PF		**0.49**	**ns**	**0.82**	**ns**	**0.22**	**0.11**	**0.5**
MF	**MF0**	9.88b	7.58b	4.60a	3.08b	2.26b	1.95b	7.93a
	MF1	10.32a	8.40a	4.82a	3.35a	2.67a	2.11a	8.21a
LSD $_{0.05}$ MF		**0.41**	**0.2**	**ns**	**0.27**	**0.26**	**0.12**	**ns**
Interaction:								
FM * PF		0.7	0.52	ns	ns	ns	ns	ns
FM * MF		ns	0.28	ns	ns	0.077	0.29	ns
PF * MF		ns	0.27	ns	ns	0.45	ns	ns
FM * PF * MF		ns	0.49	ns	ns	0.64	0.29	ns

FM= filter mud, **PF**= Potassium fertilization, **MF**= magnesium fertilization, **AW**= available water, mean values within each column followed by same letters are not significantly different at 5% level of probability (n = 3 for each individual treatment).

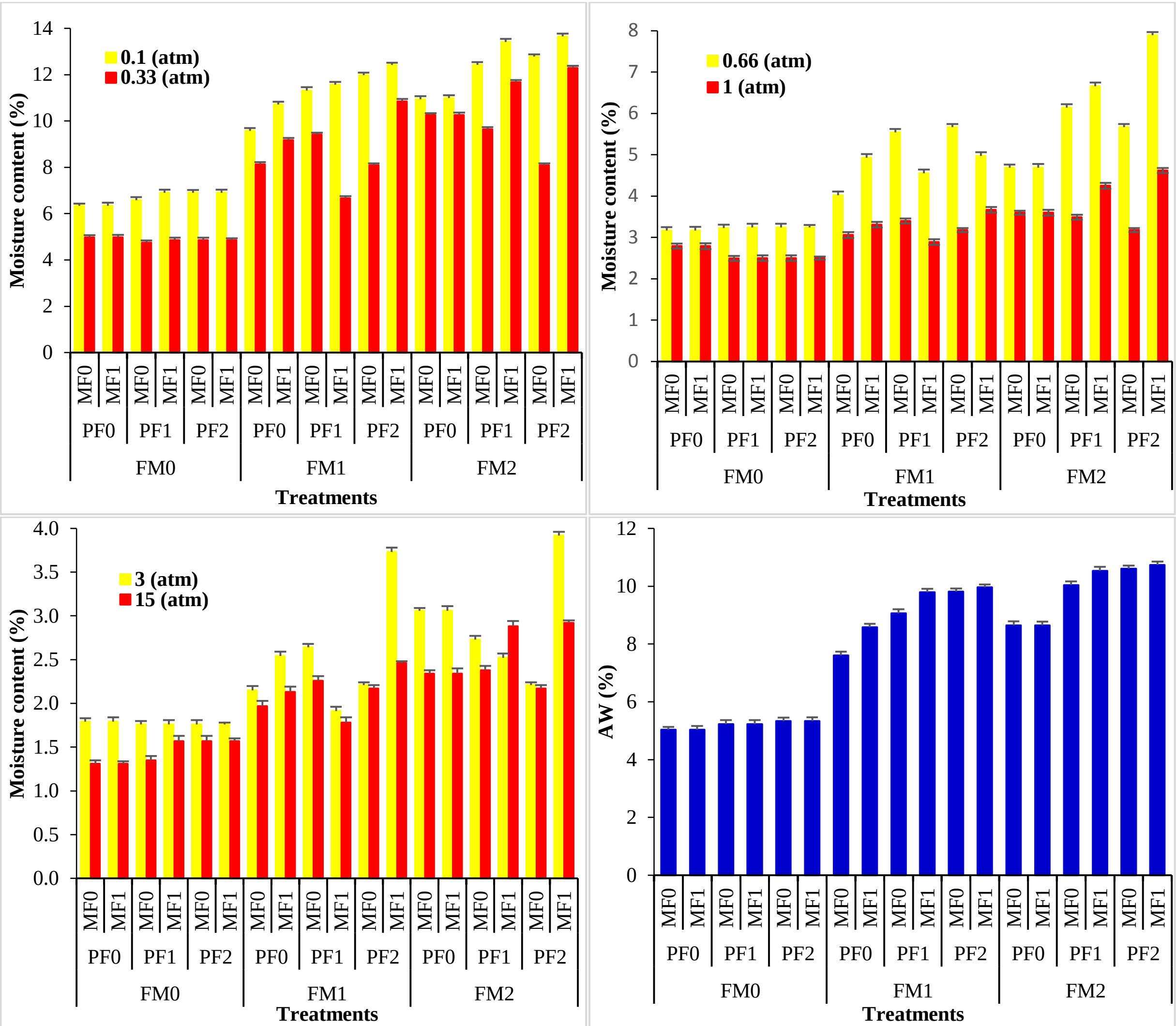

Fig. 4. The integrated effect of filter mud, potassium and magnesium fertilizers on soil moisture content at different suction pressures and available water (n=3, the error bar on the columns is the standard deviation). FM0 = zero filter mud, FM1= = 15 Mg ha^{-1} filter mud, FM2 = 20 Mg ha^{-1} filter mud, PF0 = zero potassium, PF1 = 95.2 kg ha^{-1} potassium, PF2= 119 kg ha^{-1} potassium, MF0= zero magnesium, MF1= 119 kg ha^{-1} magnesium.

3.5. Yield parameters of faba been

The obtained data in the Table 6 and Figure 5 showed that, an application of filter mud integrated with potassium and magnesium fertilizers, led to an increase in total yield (TY), seeds yield (SEY), and straw yield (SY). Results also emphasized that, the greatest yields were recorded with the plants received the treatment of FM2+PF2+MF1. The individual effect of filter mud on the seeds yield was significant but this effect was non-significant for TY and SY ($kgfed^{-1}$). Regarding, the individual increase effect of K and Mg fertilizers was significant for both TY and SEY, while it was non-significant for SY ($kgfed^{-1}$). In this respect, Ali et al. (2022) found that, addition of FM and its combination with chemical fertilizers led to a positive effect on soil fertility, potato growth, and its yield. Dry mass and water content of both tested plants (Daucus carota and Beta vulgaris) increased significantly by FM treatment as comparing with control plants. The studied plants grown in soil amended with FM levels showed highly significant increase in both chlorophylls content A and B than in control plants in both experimental plants (El-Tayeh, et al., 2019).

However, the beneficial effects of the combined treatments might be due to the stimulation integration between potassium sulfate fertilizers and FM where increasing soil fertility and enhancing the availability of some essential plant nutrients, which reflected on improving the vegetative growth of faba bean plants as well as increasing the hay and seed yields. Also, this simulative effect may be due to the role of potassium on production of active enzyme and enhanced translocation of assimilative and photosynthesis (El-Desuki et al., 2006; Gransee and Führs, 2013; Neuhaus, 2013; Awwad et al., 2022; Omara and Farrag, 2022).

Table 6. Individual effect of applied filter mud mixed with K and Mg fertilizers on the yield parameters of faba bean (values are average of two growing seasons).

Treatments		Yield (kg fed^{-1})		
		Seed yield	**Straw yield**	**Total yield**
FM	**FM0**	690.2c	1094.8a	1772.2a
	FM1	705.1b	1495.3a	2488.9a
	FM2	751.4a	1553.1a	2442.4a
LSD $_{0.05}$ FM		**14.32**	**ns**	**ns**
PF	**PF0**	586.6b	833.5a	1360.3b
	PF1	776.9a	1764.9a	2666.2a
	PF2	783.2a	1544.8a	2437.1a
LSD $_{0.05}$ PF		**31.63**	**ns**	**792.72**
MF	**MF0**	691.5b	1095.8a	1832.3b
	MF1	739.6a	1666.3a	2476.7a
LSD $_{0.05}$ MF		**27.52**	**ns**	**225.38**
FM * PF		45.16	ns	ns
FM * MF		39.47	ns	ns
PF * MF		41.2	ns	ns
FM * PF * MF		68.37	ns	ns

FM= filter mud, **PF**= Potassium fertilization, **MF**= magnesium fertilization, mean values within each column followed by same letters are not significantly different at 5% level of probability. ns = non-significant.

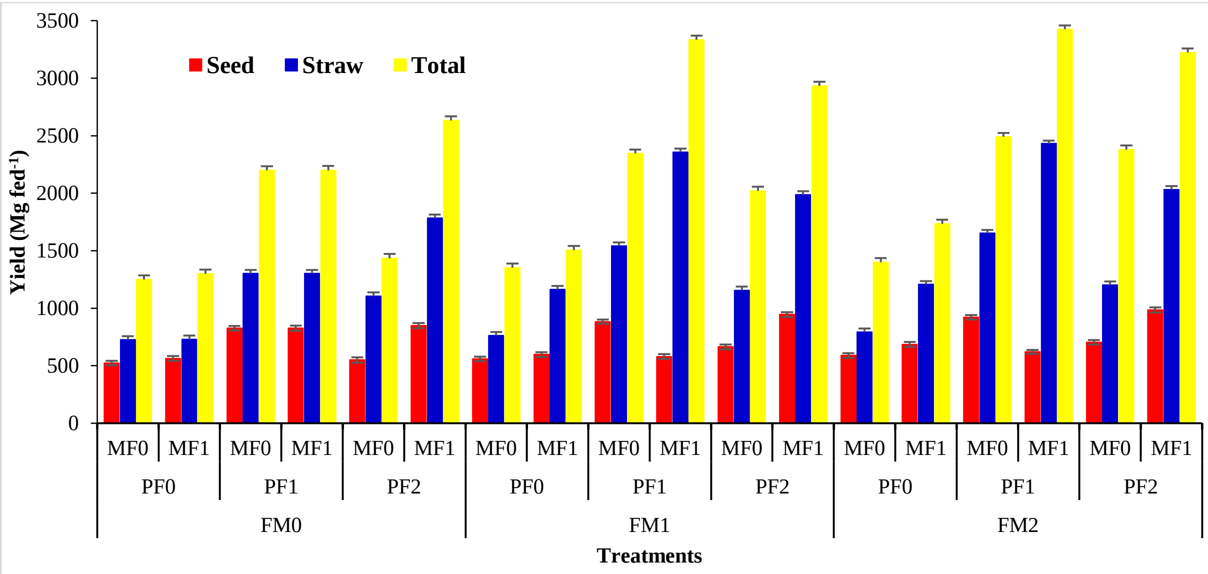

Fig. 5. The integrated effect of filter mud, potassium and magnesium fertilizers on straw and seed yields (n=3, the error bar on the columns is the standard deviation). FM0 = zero filter mud, FM1= = 15 Mg ha^{-1} filter mud, FM2 = 20 Mg ha^{-1} filter mud, PF0 = zero potassium, PF1 = 95.2 kg ha^{-1} potassium, PF2= 119 kg ha^{-1} potassium, MF0= zero magnesium, MF1= 119 kg ha^{-1} magnesium.

4. Conclusion

The effect of filter mud and chemical fertilizers of potassium and magnesium individually and in combination on sandy soil were evaluated under field experiment conditions. Filter mud at different application rates improved soil physicochemical properties, particularly the treatments of FM2 (20 Mgha^{-1}). The most noticed increases were the soil total porosity, fine capillary pores (FCP), water holding pores, available water, organic matter (OM), penetration resistance (PR) and soil available N, P, K and Mg. Addition of FM led to decrease in soil pH, bulk density, hydraulic conductivity and quickly drainable pores. Individually, application of chemical fertilizers of K and Mg did not have a significant effect on most of the examined soil physicochemical properties, with the exception of soil available macronutrients content. They had a slight efficacy, especially with the highest addition rates of them (119 $kgha^{-1}$) which were in soil OM, slowly drainable pores (SDP), water holding pores (WHP), FCP, and PR. Integrated chemical fertilizers of K and Mg with filter mud improved soil physicochemical properties, available macronutrients and soil moisture content which led to an increase the productivity of faba bean.

Ethic approval and consent to participate

This article does not contain any studies with human participates or animals performed by any of the authors.

Consent for publication

All authors declare their consent for publication.

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Authors contribution

Creating the work plan and writing the MS (W. M. Nada), and the contribution of the field and Lab work, writing the MS and statistical analysis (M. M. H. Hamad, E. G. Abo-Elela, and H. Mahrous).

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