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# Valorization of Cheese Whey as A Fertilizer: Effects on Maize Germination and Growth in Clay Loam and Calcareous Soil

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TWO POT experiments were conducted to valorize cheese whey functions in improving the chemical characteristics of a non-calcareous clay loam soil and a calcareous one (loamy sand). It also evaluates the influences of the fermented whey on maize seed germination and growth. Four different cheese whey levels: 0.0, 0.5, 0.75, and 1% on mass base were mixed with 12 kg soil then packed in plastic pots. The NPK recommended doses of maize were also considered as a reference treatment as well. The soil mixtures were incubated aerobically at soil field capacity for a month. Results revealed that as the whey level increased soil EC, organic matter, and macronutrient contents in soil while decreased soil pH decreased versus either to 0.0% whey or NPK treatments. In the second experiment, the germination index (GI) and final germination percentage (FGP) of wheat did not vary significantly among treatments; yet plant growth traits were boosted as the cheese whey level increased and also for the application of NPK compared to the 0.0 % whey level for both soil types. Ear weight was higher in the clay loam soil than in the calcareous one. For leaf numbers and shoot height as a function of time, there was a good agreement between predicted using polynomial 1st degree ($R^2$ ranged from 0.95 to 0.99). The response rates of both soil traits for leaf numbers and shoot height increased with increasing the whey level. The 1.0 % whey level gave high biomass weight in comparison to the NPK. It is concluded that 1.0% whey level could substitute the chemical fertilizers for growing maize for environmental and economic concerns.

**Keywords:** cheese whey; maize; germination; growth; clay loam soil; calcareous soil.

## 1. Introduction

Russia is the world's second-largest producer of urea, ammonia, and potash, as well as the fifth-largest producer of processed phosphates. As a result of the Russia-Ukraine conflict, prices for all fertilizers increased by an unprecedented amount (The Fertilizer Institute, 2022). Therefore, it's important to find alternatives for chemical fertilizers (Farid et al., 2023).

There are two main types of fertilizers: chemical and organic. The chemical fertilizers come from inorganic sources, which undergo chemical treatments and are relatively expensive. On the other hand, chemical NPK can help plants grow fast giving great yield (Khalifa, 2023; Khalil et al., 2023; Sarhan and Shehata, 2023) yet unbalanced addition of these fertilizers can lead to unintended negative consequences on the surroundings (water and air). The organic fertilizers come from organic sources such animal manure, plant wastes and food industrial wastes (Hussein et al., 2022). These organics did not disturb the environment and are considered cost-effective (Elshony et al., 2019; Tolba et al., 2021).

During food manufacturing, by-products are produced. Usually, such products have been regarded as a waste and dumped as sewage. Now, considering the environmental issues, managing these residues is a must. One of the friendly by-products is cheese whey that is produced in great quantities around the world. Cheese whey is the liquid by-product of cheese manufacture. Whey is a liquid form product that contains about 8%, 4-5% of easily decomposable organic compounds, mostly lactose and proteins

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(Kelling and Peterson, 1981). Nine kilograms of whey result for each produced kilogram of cheese (Robbins and Lehrsch, 1998). In the 1990s, Egypt's annual whey production has steadily increased by about 6%, reaching 1,452,500 metric tons in 2000 (Zhang et al., 2003). There are several kinds of cheese whey such as acid, sweet, and salty ones. While these kinds of cheese whey vary in character depending on the process of cheese production. Each kind of cheese whey has advantages and disadvantages based upon its components and its utilization area. Whey is a moderate acid with high chemical oxygen demand (COD), soluble salt, and plant nutrient contents compared to other wastewaters. Because of these characteristics, cheese whey has the potential to be used as an amendment or conditioner for many soils if the distance between the manufacturing plant and the use site is short. Cheese whey has the potential to enhance soil physical, chemical, and microbiological properties. Whey contains sufficient amounts of N, P, S, Ca, Na, and Mg, as well as proteins, for plant growth. The nitrogen found in the proteins could be converted to inorganic N that plants can use (Haroun and Ibrahim, 2003; Demir and Ozrenk, 2009; Tsakali et al., 2010). When applied to the surface of structurally weak, sodic soils, whey is known to improve aggregate stability (Lehrsch et al., 1994; Aboukila and Nilahyane, 2022). The soil scientists or environmentalists use the cheese whey as soil conditioners and plant nutrients supplies. Such use of whey in agricultural soils should be cautioned. Unfortunately, adding a great amount of whey, i.e., that is rich in sodium chloride, could deteriorate soil’s chemical and physical properties, reduce soil productivity, and degrade the environment (Robbins and Lehrsch, 1998).

Several studies found positive effects of cheese whey on plant nutrients levels in soil that this whey could boost plant germination and growth. Aboukila (2019) found that cheese whey rates of 10 and 20 g $kg^{-1}$ soil were effective in increasing seed corn germination and biomass yield. These rates gave 226, and 214% more yield compared to the control, respectively. Grosu et al. (2012) confirmed a positive effect of the whey application for the three studied species (wheat, soy, and broccoli) of plants. The maize is considered as the second strategy crop in Egypt for consumption as a food for people or animal. According to the World Data Atlas, the maize production of Egypt increased from 2,397 thousand tons in 1971 to 6,400 thousand tons in 2020 growing at an average annual rate of 2.22% (Egypt Maize production, 1971-2020, Knoema, 2023). Limited studies about using whey as a soil conditioner or as a bio-fertilizer are reported. Therefore, we intended in the present work to study the effect of cheese whey on clay loam and calcareous soil properties, and maize seed germination in both soils.

## 2. Material and Methods

### *2.1 Experimental soils*

Two types of soil were selected from El Beheira Governorate, North of Egypt for this study; the first one was a clay non-calcareous loam soil (*Typic Torrifluvents*) collected from the Damanhour region (31° 02' 23.8"N and 30° 26' 23.6"E). The second one was a calcareous (loamy sand) soil (*Typic Calciorthids)* collected from the Gianaclis region (30° 53' 37.23"N and 30° 07' 04.56"E). El Beheira Governorate has an arid climate, with a mean annual precipitation of 102 mm, and a mean annual temperature of 20.40̊ C (Climate-Data.org, 2017). Surface soil samples were collected (0-30 cm), air-dried, crushed, and sieved by a 2-mm sieve. Sub-samples were subjected to chemical and physical soil analyses. Table 1 shows the Initial characterizations of the studied soils.

### *2.2 Experimental cheese whey*

Mozzarella cheese whey, a by-product of the mozzarella cheese manufacture, was collected from Domtty cheese company, 6th October city, Giza Governorate, Egypt. Table 1 shows the main characteristics of cheese whey.

### *2.3 Experimental setup*

Two pots experiments were conducted. The aim of the first experiment was to study the effect of cheese whey on the soil properties, the second experiment was to study the effect of cheese whey on maize germination, growth, and yield.

### *2.4 Fundamental studies for cheese whey effects on the soil properties*

A pot experiment was conducted during the summer season of 2018 to represent the first experiment. Four reasonable whey levels (0.0, 0.5, 0.75, and 1% dry matter content) are used in the present experiment. These rates were chosen based on results obtained in the preliminary study (Aboukila et al., 2018a). The two soil types (clay loam and calcareous) were treated with cheese whey.

**Table 1. Initial characterizations of the studied soils and whey.**

| Analyte | Calcareous soil | Clay soil | Cheese whey |
|---|---|---|---|
| pH (1:2.5 w:w) | 8.10 | 8.37 | 3.80* |
| EC (dS $m^{-1}$, 1:2.5 w:w) | 0.47 | 1.55 | 5.26* |
| Available N (mg $kg^{-1}$) | 37.1 | 31.6 | 26250** |
| Available P (mg $kg^{-1}$) | 0.68 | 0.93 | 0.125** |
| Available K (mg $kg^{-1}$) | 120 | 230 | 0.305** |
| Total $CaCO_3$ (%) | 9.65 | 5.25 | ----- |
| Organic matter (%) | 0.79 | 1.68 | 3.10 |
| Dray matter (%) | ----- | ----- | 4.0 |
| Sand (%) | 88 | 45 | ----- |
| Silt (%) | 5 | 23 | ----- |
| Clay (%) | 7 | 32 | ----- |
| Texture | Loamy sand | Clay loam | ----- |
| Wilting point (%) | 7.0 | 17.9 | ----- |
| Field capacity (%) | 14.6 | 29.6 | ----- |
| $Ca^{+2}$ (cmolc $kg^{-1}$) | 1.27 | 3.88 | 15* |
| $Mg^{+2}$ (cmolc $kg^{-1}$) | 2.53 | 2.44 | 16* |
| $K^{+}$ (cmolc $kg^{-1}$) | 0.64 | 0.55 | 2.43* |
| $Na^{+}$ (cmolc $kg^{-1}$) | 0.47 | 8.00 | 1.3* |
| $CO_3^{-2}$ (cmolc $kg^{-1}$) | 0.00 | 0.73 | 0* |
| $HCO_3^{--}$ (cmolc $kg^{-1}$) | 1.20 | 3.37 | 0.4* |
| $Cl^{-}$ (cmolc $kg^{-1}$) | 2.67 | 5.67 | 29* |

* Measured directly in the whey,

** Total form of nutrient in whey (dry weight basis), the unit of P for cheese whey is %.

Additionally, NPK at recommended doses for maize were considered as a reference treatment. The NPK recommended dose of maize was 285 kg $ha^{-1}$ ammonium sulfate 20.5% N, 475 kg $ha^{-1}$ single super phosphate 15% $P_2O_5$, and 120 kg $ha^{-1}$ potassium sulphate 50% $K_2O$. All treatments were applied to 12 kg of each soil and placed in polyethylene pots. The pots were buried to the soil surface in an open field, with three replications for each treatment, using a randomized complete block design. To allow applied amendments to be decomposed, all pots were incubated aerobically under field conditions for one month. The soil moisture level of the amended soil was kept constant (near soil field capacity) during incubation by periodically weighing the pots and adding the lost water to offset evaporative loss. Following the incubation period, the soil was subjected to some chemical analyses.

### *2.5 Soil analyses*

Soil samples were air dried, and ground then passed through a 2 mm-sieve. Soil electrical conductivity (EC), pH, calcium carbonate equivalent (CCE), available N, P and K, soil organic matter, particle sizes distribution and cations and anions were measured according to Aboukila et al., (2018a). The hydraulic properties were calculated from knowledge of the particle sizes (Saxton et al., 1986).

### *2.6 Effect of cheese whey on maize seed germination and growth*

### *2.6.1 Seed germination analysis*

The genotype used in the experiment is Single Cross (S.C.) maize hybrid Pioneer (N11), were obtained from the National Research Centre, Cairo, Egypt. After incubation, 8 seeds of maize (*Zea mays* L.) were sown in each pot to attain the goals of the second experiment. Shoot sprouts were recorded daily for 15 days. The daily germination percentages of seeds were calculated.

### *2.6.2 Germination Index* (GI)

Germination Index (GI) was calculated as described by the Association of Official Seed Analysts guidelines (AOSA, 1993) as following:

GI = (Number of germinated seeds in the first count / Days of first count) + (Number of germinated seeds in the second count / Days of second count) + ……

\+ (Number of germinated seeds in the final count / Days of final count) (1) for the calculation of germination index (GI), most weight is set to the seeds germinated on the 1st day and less to the seed germinated later. The least weight would be for seeds germinated on the 15th day. Thus, the GI affirms both the seed germination speed and its percentage (Javari et al., 2018). A higher GI value indicates a higher rate and germination percentage. The final percentage of germination (FGP) was calculated by dividing the last number of germinated seeds in each pot by the total number of planted seeds, multiply by 100.

### *2.6.3 Growth and yield parameters analysis*

15 days after treatments inception and emergence of seeds, plants were thinned to a plant per pot. The growth of the maize lasted till the middle of October 2019. Various growth traits like stem height and leaf numbers were recorded each fifteen days till 75-day growth. At the end of experiment (after 120 days from sowing), the fresh shoot and yield of fresh ear weights were recorded. Figures were analyzed based upon the regression analysis. For characterizing a relation between such maize growth parameters (shoot height or leaf number) and time, the following series was utilized (Burden and Faris, 1985):

First-order polynomial function

$$F(x) = bt + a \quad (2)$$

Where F(t) is the series value at t (time) and a and b are series constants. The equation was fitted to the average values of any shoot height or leaf numbers to determine the series coefficients. Differentiating the equation with respect to time gives response of such a growth parameter to the change of time.

### *2.6.4 Irrigation scheduling*

The irrigation schedule was similar for both soils with different amounts. The amount of irrigation water was 2L pot$^{-1}$ for the calcareous soil and 3L pot$^{-1}$ for the clay loam soil. The amounts of irrigation water were slightly greater than the soil field capacity defined in Table (1) for both soils to mitigate the salt stresses. They differed according to the growing stage of maize. The irrigation amounts were added weekly within the first growth month, every five days within the second growth month, every 3 days within the third growth month and weekly within the fourth growth month. These irrigation schedules coincided with the growth stage.

### *2.7 Statistical analysis*

The differences between the means of the incubated soil parameters, growth parameters, and germination data were tested using analysis of variance (ANOVA). When significant, the means were compared using Fisher's protected least significant difference (LSD). All statistical analyses were performed using SAS software Version 13.1 (SAS Institute, 2013).

## 3. Results

### *3.1 Impact of cheese whey on soil properties*

Table (2) presents the chemical properties of the incubated soil using different levels of whey and NPK dose for the clay loam and calcareous soils in the first experiment. For the clay loam soil, the addition of whey reduced the soil-pH as the level of whey increased in comparison to either 0.0% whey-level or NPK. The soil-pH values of the NPK were similar to its values for zero whey level. Generally, the variations of pH values among the studied treatments were significant at 5% level. The 1% whey level possessed the lowest pH in both soils while the NPK and zero whey level had the highest pH values. The OM percentage behaved conversely to the soil-pH trend.

The soil electrical conductivity (EC) of soil increased as the level of whey increased. The EC of the zero level or NPK treatment were lower than that of the EC of the other whey levels. For the clay loam soil, the zero-whey level possessed 1.61 dS m$^{-1}$ while the 1% of whey had 2.16 dS m$^{-1}$ with a range of 0.55 dS m$^{-1}$ in soil water extract 1: 2.5. The corresponding values for the EC in soil paste were 5.32 and 7.00 dS m$^{-1}$ (Aboukila and Norton, 2017).

The available nitrogen (N), phosphorus (P) and potassium (K) were great for the whey levels in compared to the zero-whey level. These nutrients increased as the whey level increased in whey treated soils.

The properties (pH, EC, OM, available N, P, and K) of the whey amended calcareous soil behaved similarly to the clay loam soil (Table 2). The reduction of pH for the calcareous soil was noticeable in comparison to the reduction of pH for the clay loam soil. The pH ranged between 8.09 for zero whey level to 7.69 for 1% whey level, respectively. The electrical conductivities (EC) in soil: water extract (1:2.5) were 0.43 and 1.55 dS m$^{-1}$ for zero and 1.0 % whey, respectively.

**Table 2. The chemical properties of the incubated soils with different levels of whey and NPK application.**

| Soil type | Whey levels | pH | EC (dS $m^{-1}$) | OM (%) | N (mg $kg^{-1}$) | P (mg $kg^{-1}$) | K (mg $kg^{-1}$) |
|---|---|---|---|---|---|---|---|
| Clay loam | 0.0% | 8.40 a* | 1.61 c | 1.70 cd | 31.1 d | 0.82 d | 210 d |
| | 0.50% | 8.37 a | 1.75 bc | 1.92 c | 54.1 b | 1.23 c | 304 c |
| | 0.75% | 8.29 b | 1.78 b | 2.20 b | 59.6 b | 1.83 b | 384 b |
| | 1% | 8.05 c | 2.16 a | 2.48 a | 81.5 a | 2.34 a | 424 a |
| | NPK | 8.41 a | 1.66 bc | 1.56 d | 45.8 c | 1.12 cd | 243 d |
| Calcareous | 0.0% | 8.09 a | 0.43 b | 0.78 b | 36.8 d | 0.70 c | 112 b |
| | 0.50% | 8.01 b | 0.80 b | 0.96 ab | 67.6 bc | 1.57 b | 124 b |
| | 0.75% | 7.75 c | 1.31 a | 1.06 ab | 79.0 ab | 1.97 ab | 151 b |
| | 1% | 7.69 c | 1.55 a | 1.42 a | 87.6 a | 2.30 a | 204 ab |
| | NPK | 7.95 b | 0.42 b | 0.70 b | 55.6 c | 0.50 c | 373 a |

* Within columns, values followed by different lowercase letters are significantly different at α = 0.05.

The concentration of N and P in the whey amended calcareous soils was greater than their corresponding concentrations in the clay loam soil. While the concentration of K in the whey amended clay loam soil was great in comparison to the calcareous soil. The concentrations of K in the whey treatments behaved similarly to the previous trend of N and P in the clay loam soil. However, the concentration of K in the whey treatments was lower than its content in the treatment of NPK in the calcareous soil.

### 3.2 Effect of cheese whey on maize seed germination and growth

### 3.2.1 Maize seed germination

Table (3) shows effects of whey amendments and NPK on final germination parameters (FGP). The values of FGP were 83, 83, 92, 92 and 83 % in the clay loam soil amended with 0.0, 0.5, 0.75 and 1%, whey, and NPK, respectively. The corresponding values for the calcareous soil were 75, 83, 92, 88, and 92%. The zero-whey level in the calcareous soil showed the lowest FGP of 75 % among all treatments in both soils. In spite of that there were no significant variations among treatments in these two parameters.

The germination index (GI), that measures the speed of germination, was calculated using Eq. 1. The GI values for the present study were shown in Table (3). The values of GI in the clay loam soil were 1.26, 1.14, 1.17, 1.15, and 1.08 for the 0.0, 0.5, 0.75, and 1.0 % whey levels and NPK, respectively. This germination index behaved similarly for FGP discussed earlier for maize seeds. The differences in GI values between the treatments were not significant at the level of 5% significance. The corresponding GI values were 0.83, 0.88, 1.01, 0.94 and 1.12 for the calcareous soils. The GI values in the calcareous soil were less than their values in the clay loam soil, but the differences in GI values between both soils are small.

### 3.2.2 Maize growth and yield

Table (4) showed the leaf numbers of maize grown in both soils after harvesting (120 day). The 0.0 whey level possessed the lowest leaf numbers in both soils while 1.0% whey level and NPK showed the greatest leaf numbers. The differences between the 0.0 whey level in leaf numbers and most of the other treatments were significant at 5%.

The number of leaves did not vary significantly among treatments, except for the application of 0% whey. This treatment led to significant reductions in leaf number in the two soils under investigation.

Effects of whey levels and NPK on maize shoot height were shown in Table (4). For the clay loam soil, the 0.0 and 0.5% levels had the lowest values while the other three treatments possessed the highest values. The differences were significant at the 5% level.

**Table 3. Germination parameters (FGP & GI) of maize at studied soils as influenced by whey levels and NPK treatments.**

| Whey levels or NPK | FGP (%) | | GI | |
|---|---|---|---|---|
| | Clay loam | Calcareous | Clay loam | Calcareous |
| 0.00% | 83.33 a* | 75.00 a | 1.26 a | 0.83 a |
| 0.50% | 83.33 a | 83.33 a | 1.14 a | 0.88 a |
| 0.75% | 91.67 a | 91.67 a | 1.17 a | 1.01 a |
| 1.00% | 91.67 a | 87.50 a | 1.15 a | 0.94 a |
| NPK | 83.33 a | 91.67 a | 1.08 a | 1.12 a |

* Within columns, values followed by different lowercase letters are significantly different at α = 0.05.

**Table 4. Maize growth parameters in studied soils as influenced by whey and NPK treatments.**

| Treatment | Leaf No. | | Shoot height (m) | | Shoot weight (kg) | | Ear weight (kg) | |
|---|---|---|---|---|---|---|---|---|
| | Clay loam | Calc.** | Clay loam | Calc. | Clay loam | Calc. | Clay loam | Calc. |
| 0.00% | 13.0 b* | 13.0 b | 2.6 c | 2.7 c | 1.6 a | 1.2 b | 0.71 d | 0.54 d |
| 0.50% | 13.7 ab | 14.3 a | 2.7 b | 2.8 bc | 1.7 a | 1.2 b | 0.77 c | 0.64 c |
| 0.75% | 14.3 ab | 14.7 a | 2.9 a | 2.9 b | 1.7 a | 1.5 a | 0.82 b | 0.73 b |
| 1.00% | 15.3 a | 15.0 a | 2.9 a | 3.0 a | 1.8 a | 1.6 a | 0.94 a | 0.84 a |
| NPK | 15.3 a | 15.0 a | 2.9 a | 2.9 b | 1.8 a | 1.6 a | 0.90 a | 0.83 a |

* Within columns, values followed by different lowercase letters are significantly different at α = 0.05.
** Calcareous soil.

The shoot heights range in the calcareous soils was 2.7 (0.0 whey level) to 3.0 m (1% whey level). The differences in height were significant as well. The shoot height in the clay loam soil was slightly shorter than in the calcareous soil.

Table (4) showed the fresh shoot weights of maize grown in clay loam and calcareous soil after harvesting. The weights were 1.6, 1.7, 1.7, 1.8 and 1.8 kg pot$^{-1}$ for 0.0, 0.5, 0.75 and 1.0 % whey level, and NPK dose, respectively. The additive organic whey or chemical NPK fertilizers increased the fresh weight of maize compared to the zero-whey level. The fresh weight followed the order, 0.0<0.5=0.75<1% whey=NPK chemical dose. The corresponding shoot fresh weights in the calcareous soils were 1.2, 1.2, 1.5, 1.6 and 1.6 kg pot$^{-1}$. Like the clay loam soil, the 0.0 and 0.5 % whey levels possessed the lowest values of shoot weights while, the 1% and NPK gave the highest weight.

The maize growth in the calcareous soil using the five treatments showed similar fresh weight behavior as in the clay loam soil. However, the fresh weights of maize in the calcareous soil were low in comparison to their values in the clay loam soil. It seems that significant reductions occurred in shoot wights of plants grown on a calcareous soil, when amended with 0 or 0. 5% whey.

The fresh weights of maize ears are shown in Table (4). The clay loam soil gave greater ear weight in all treatments than the calcareous soil did. Generally, the highest increases were attained for both 1% whey and the NPK treatment with no significant variations between these two treatments in the two soils of study. On the other hand, the least values were recorded for the treatment that did not receive any of these two additives.

Growth of maize was monitored as a function of time via two parameters: stem height and leaf numbers. These parameters were described using 1st order polynomial function. Generally, such a polynomial is a good tool to describe the growth parameters quantitatively. In the present study, the leaf numbers of maize were described using (Eq. 2) at different times. The leaf number values were presented in Figure (1) as well. The $R^2$ values of all treatments ranged from 0.95- 0.99 and from 0.98- 0.99 for the clay loam and calcareous soils, respectively. It is clear that the 1st polynomial model described the leaf number variations well. As time increased, the leaf number increased linearly for all treatments.

The effect of time on shoot maize height was described using 1st polynomial (Eq.2) at different time for both soils used in the present study. The shoot heights values were shown in Figure (2) for both soils. As time increased the shoot height increased linearly. The polynomial described well the shoot height variations for whey levels and NPK treatments. The $R^2$ were 0.98 to 0.99 for all treatments for both soils.

The first derivative of the 1st polynomial (Eq.2) for the leaf number was calculated and presented in Figure (3). The derivate represents quantitatively the leaf number response to the additive whey levels and NPK dose in both soils used. For the clay loam soil, the derivatives values were 0.155, 0.162, 0.173, 0.186 and 0.194 day$^{-1}$ for whey levels of 0.0, 0.50, 0.75, 1.0% and NPK treatments, respectively. It is interesting that the response rate of leaf numbers increased as the whey level increased. The NPK and 1% whey possessed the greatest response while 0.0 whey level gave the lowest. So, additive whey might be useful in fertilization management strategy of maize. The corresponding leaf responses in the calcareous soil were 0.158, 0.176, 0.176, 0.182 and 0.182 day$^{-1}$. The response rate of leaf numbers behaved in the calcareous soil similarly to the response rate in the clay loam soil.

The first derivative of the 1st polynomial (Eq.2) for the shoot height was obtained and shown in Figure (4). The derivate represents the shoot height response to the additive whey levels and NPK dose in both soils used. As stated above for leaf rate responses, these derivates are quantitatively described the response of shoot height to the treatment's application. For the clay loam soil, the derivatives values were 0.036, 0.038, 0.041, 0.042 and 0.041 m day$^{-1}$ for the whey levels 0.0, 0.50, 0.75, 1.0% and NPK treatments, respectively. The average response rate was 0.0389 m day$^{-1}$. So, additive whey might be useful enhancing the maize growth. The corresponding shoot height in the calcareous soil was 0.038, 0.0.039, 0.043, 0.045 and 0.0.043 m day$^{-1}$ with an average of 0.042 m day$^{-1}$. The response rate of shoot height increased as the application whey levels increased and addition of NPK in the calcareous soil similarly to the response rate in the clay loam soil.

## 4. Discussion

Increasing the whey level resulted in an increase in the soil organic matter. The decomposition of soil OM leads to reductions in soil acidity. This result agrees with the result reported in several studies (Aboukila et al., 2018a and Aboukila et al., 2018b among others). Robbins and Lehrsch (1992) and Mekki et al. (2006) reported that increasing the rate of acid whey application decreased soil-pH.

In the present study, increases of EC as a result of whey amendments are not severe and it might be reasonable of plant growth such as moderately salt tolerant maize. This increase in soil salinity results inherently from the salt of the whey. The EC of the whey levels differed significantly in comparison with either 0.0 whey levels or NPK treatment. Whey is very salty because of the salts found in milk (Robbins and Lehrsch, 1998). The EC range in soil paste was 1.78-6.40 dS m$^{-1}$ according to Aboukila and Abdelaty (2017). Yields are slightly affected or not affected at low salt concentrations (Maggio et al., 2001). The yields decreased as the concentrations increase, because most plants are significantly hampered or even killed by high salt concentrations (100-200 mM NaCl). Maas and Hoffman (1977) stated that wheat (*Triticum aestivum*) produced a lower yield where the salinity reached 100 mM NaCl. Grosu et al (2012) studied the effect of using whey as fertilizer on growth and germination of three species of plants: wheat (*Triticum aestivum* L.), soybean (*Glicine max (L) Merr*), and broccoli (*Brassica oleracea* L., *var botrytis, subvar. cymosa*). Their findings indicated that whey addition during cultivation had a positive effect on the three plant species.

The source of N, P and K in whey is easily decomposable organic compounds, mostly lactose and proteins after whey fermentation (Demir and Ozrenk, 2009; Tsakali et al., 2010). Whey typically contains 40-50 g kg$^{-1}$ of readily decomposable organic compounds and 8% solids (Kelling and Peterson, 1981). These nutrients are present in sufficient quantities to allow acid whey to be used to complement or replace the application of inorganic fertilizer or manure. It is obvious from the

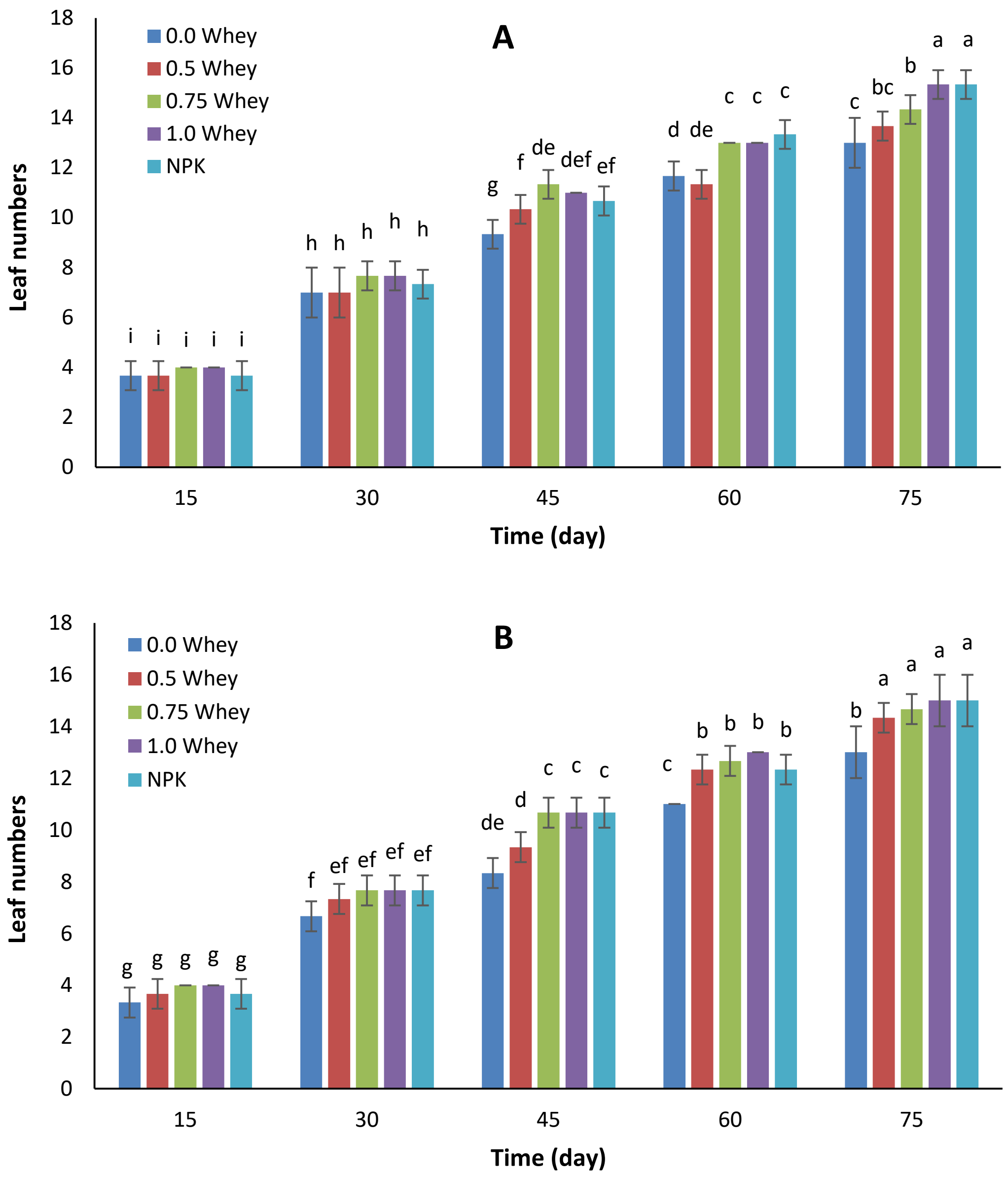

**Fig. 1. Leaf numbers as a function of time for clay loam (a) and calcareous soil (b). Within columns, values followed by different letters are significantly different at α = 0.05.**

EC and nutrient concentrations resulted from whey levels used that the whey is highly recommended as a source of plant nutrient especially NPK. The reduction in soil pH raised nutrient availability, especially the micronutrients in the calcareous soil (Aboukila et al. 2018b). This finding is promising to reclaim calcareous soil using whey. The high content of K in the clay loam soil might be inherent. It is worth noting that the contents of N, and P for all of whey treatments for both soils were greater than their corresponding concentrations for the treatment of NPK as a recommend dose for maize and zero whey level.

Generally, it is recommended to use the whey at 0.5 % as a complete fertilizer dose for maize in both soils. So, amending such a soil using 0.5% whey can be enough to boost maize growth. Using the whey as plant nutrients enrichment source has advantage over a chemical source because the whey supplies the plant with such nutrient with low release rate during the growth period. Additionally, using whey as a source of nutrients reduces the leaching of nutrients (i.e., nitrate) that contaminate the water resource (i.e., groundwater). Similar results in Michigan USA, over an 18-year period, annual applications of 8.4 cm of whey increased the surface soil potassium and phosphorus concentrations to abundant levels (Peterson et al. 1979).

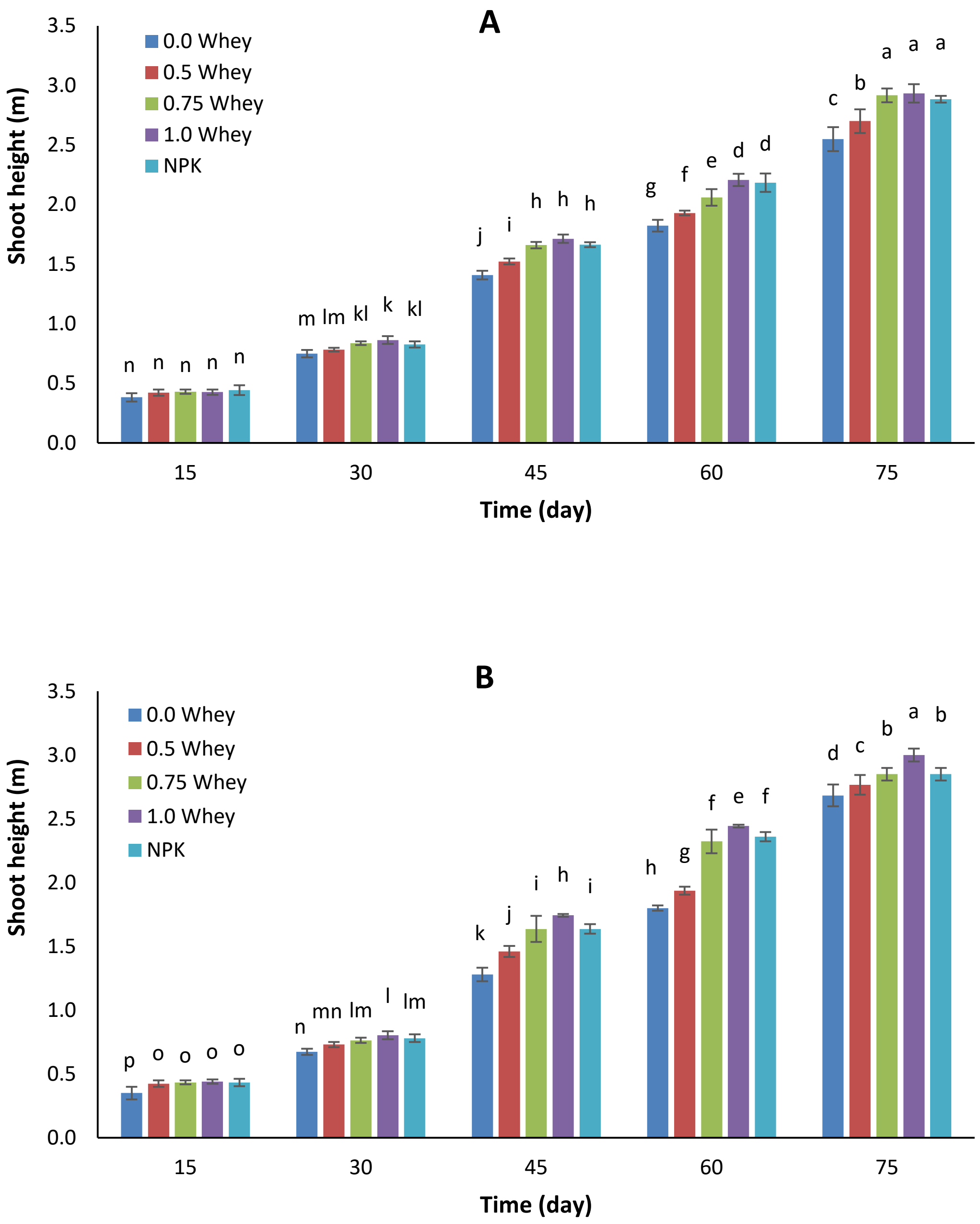

**Fig. 2. Shoot height of maize as a function of time for the treatments used in clay loam (a) calcareous soils (b). Within columns, values followed by different letters are significantly different at α = 0.05.**

Seed vigor is a substantial quality parameter that needs to assess germination and viability tests to seed sight into the performance of a seed in the field or in storage. The final germination percentage (FGP) and germination index (GI) are the germination parameters that were evaluated in the present study to explain seed vigor.

The lowest FGP value in the zero-whey level in the calcareous soil might be due to the low aeration of the crust layer of the calcareous in comparison to the other treatments. The presence of organic matter resulted from the whey boosts the aeration and available water that are required for seed germination. Generally, the FGP did not differ significantly among all treatments in both soils. Therefore, the additive whey to the soil did not deteriorate the properties of soil and did not affect the germination percentage negatively. These results were reverent to the low salt concentration in the whey additive treatments. The whey used in the recent study contains a low concentration of soluble salt (i.e., EC of 5.26 dS $m^{-1}$). The amended whey soil or treated NPK soil possessed a great FGP, and they were more vigorous than untreated soils. The low values of FGP of maize seeds for the zero-whey level were due to both low soil water holding capacity and germination accelerating nutrients. Generally, the additive organic sources promoted the germination of maize seeds. The enhancement of germination was relevant to the organic matter application rate, soil water holding capacity and plant nutrients which were presented earlier. It is worth noting that whey or NPK is preferred over 0.0 % whey application for encouraging seed germination of plants in both soils. Similarly, the germination percentage or the germination rate did not increase for either lettuce or tomato seeds as a function of humic acid concentration (Piccolo et al., 1993).

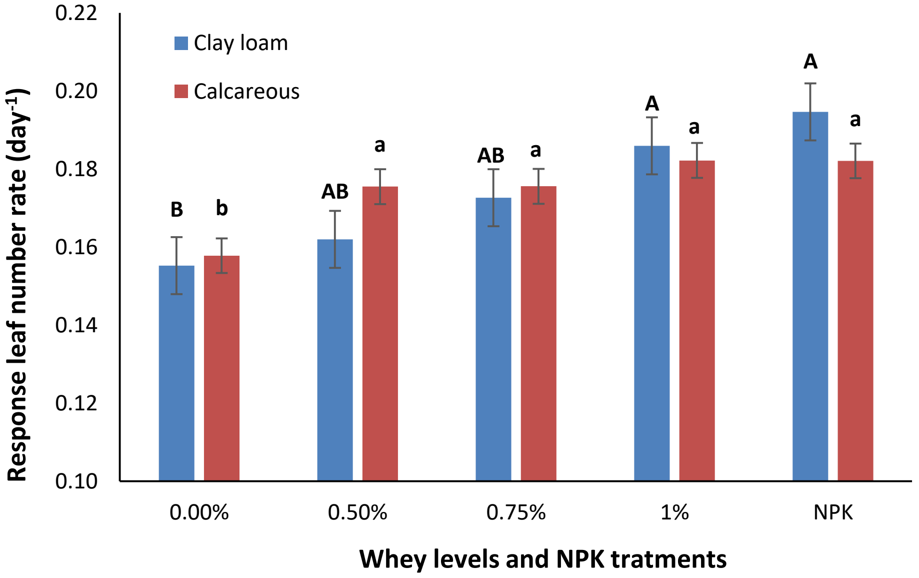

**Fig. 3. Response rate of maize leaf number for whey levels and NPK. Within columns, values followed by different letters are significantly different at α = 0.05.**

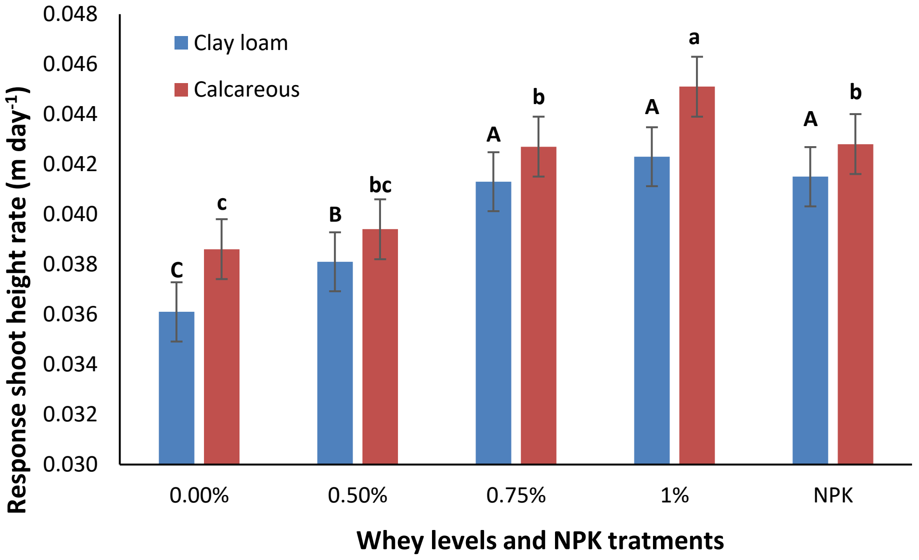

**Fig. 4. Response rate of maize shoot height for whey levels and NPK. Within columns, values followed by different letters are significantly different at α = 0.05.**

The differences in GI values between the treatments were not significant in the clay loam soil. Therefore, the soil environmental properties for the germination were similar in all treatments and were able to support the seeds by similar amount of nutrients or water or heat that needed by maize seeds. The small differences in GI in both soils are explained by similarity in the environmental germination factor between the two soils and the treatment used.

Application of whey and readily NPK boosted the leaf numbers in both soils. The differences in leaf numbers for both soils were not noticeable. Similarly, whey additions up to 32 in. over 4 years period significantly increased the maize yield quantity and quality (Peterson et al., 1979). Aboukila (2019) reported that an application of cheese whey could serve as a good soil amendment to enhance soil nutrient status and thereby increase maize growth.

The additive whey at a rate higher than 0.5% or NPK boosted the maize shoot height in both soils. The positive response in maize height is due to readily available nutrients such as N, P and K that are released from the whey material or NPK fertilizer. The 0.0 % whey level showed low plant height because of plant nutrient lack (Table 2). Similar conclusions were reported by Hafez et al. (2015) and Aboukila (2019). Organic input is usually considered as an alternative to mineral fertilizer. For example, Mugendi et al. (1999) and Agele (2000) found that soil application of Leucaena and Calliandra green biomass with or without fertilizer enhanced soil N by 1-8% over a 4-year period. When biomass was not applied during the same period, the soil N decreased by 2-4%. The applied whey to soil might enhance the microorganisms that increase the plant nutrients availability. Due to its properties, whey is useful not only for plant nutrition but also for soil microflora. It is stated that whey is rich in nutrients and some carbon compounds particularly lactose, which microorganisms use as an energy source (Demir and Ozrenk, 2009).

The superiority of whey 1% and NPK source over other treatments, in enhancing fresh shoot weights of maize, was relevant to the availability of soil water and nutrients to maize plants. The fresh plant weight behaved similarly to the plant height discussed earlier. The low fresh weight can be attributed to the deficiency of plant nutrients in the 0.0 whey level compared to the other treatments. The low values of fresh weights in the calcareous soils are due to the lack of nutrient availability. The clay loam soil might supply maize with more quantity of nutrients than the calcareous soil does. Generally, for calcareous soils, despite high applications of P fertilizer for many years, P deficiency in cereals is common (Holloway et al., 2001).

It is concluded that 1.0% whey could substitute the chemical fertilizer for growing maize for environmental and economic concerns. The additive organic sources increased the fresh weight of maize in comparison to the control treatments. Aboukila et al. (2018b) found that the spent grain applied at 2% possessed the greatest fresh weight followed by the mixed spent grain and compost. They explained that this superiority of spent grain source over other treatments was relevant to the availability of soil water and nutrients to maize plants.

The whey and NPK enhanced the leaf numbers which assures the positive effect of nutrient on the leaf numbers. Rajkovich et al. (2012) reported that animal manure biochar enhanced biomass yields up to 43%, and maize stover biochar up to 30%, whereas food waste biochar reduced biomass up to 92% in comparison to controls that received similar fertilization. Also, they reported that post-treatment of biochar may provide practical opportunities to mitigate potential adverse effects on crop growth as shown here for Na.

The additive whey or NPK created enhancing environmental growth factor (i.e., pH, nutrients availability, soil organic matter, temperature, soil water holding capacity, the generation of cation exchange capacity (CEC) to reduce nutrient leaching among others) for maize both soils. So, improving in these factors boosted the growth of maize. Rajkovich et al. (2012) reported that at 0.5% and 2% biochar, the level of P, Mg, and K absorbed in the maize was positively correlated with biomass production, which also showed up in a positive correlation with EC and pH.

The increase in the response rate of leaf numbers as the whey level increase is due to the suitability growth factors such as the nutrient availability and soil water holding capacity. The clay loam soil possessed slightly high rates in comparison to the rates in the calcareous soil. These differences in the rates among the two soils could be due to the high availability of phosphorous and micronutrients in the clay loam soil compared to the calcareous soils. Taalab et al. (2019) reported that when calcareous soils are fertilized with phosphorus, a series of fixation reactions take place, reducing P solubility and, eventually, availability to crops. Precipitation of various calcium phosphate minerals, as well as surface adsorption of P on both lime and clay surfaces, are involved in phosphorus fixation.

Generally, it is noticeable that the response rate of shoot height increased as the whey level increased as leaf number rates. The 1.0 % whey level and NPK gave the greatest response while zero whey level gave the lowest in both soils. The increases in both rates as the whey level increase are due to the increase of the nutrient and soil water availability. The response shoot height rates in the calcareous soil were slightly greater than its values in the clay soil.

## 5. Conclusion

The addition of cheese whey to clay loam and calcareous soil increased soil organic matter, available N, P, and K content while decreased soil pH as the whey level increased in both soils. The 0.75 and 1 % whey levels were better than the NPK treatment in these studied traits for both soil types. The plant growth was improved by the application of cheese whey. The additive whey levels neither enhance nor inhibit the germination of maize seeds relative to 0.0 whey level or NPK dose for both soil types. The growth traits (shoot heights, leaf numbers, and shoot and ear weights) were boosted as the cheese whey level increased and application of NPK compared to the 0.0 % whey level for both soil types. The growth traits at 1.0 % cheese whey were approximately equal to its values using the fully recommend NPK dose for both soil types. In the agricultural practices, the cheese whey at 1 % level can provide the maize crop by its NPK requirements. Therefore, it is recommended using the cheese whey in organic fertilization strategies in future agricultural practices. It is concluded that using cheese whey waste in agricultural production has the potential to improve soil fertility, provide a favourable environment for plants, economic and environmental means of disposal.

## Conflicts of interest

There are no conflicts to declare.

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