Journal Homepage
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Anbar Journal of Agricultural Sciences
(University of Anbar – College of Agriculture)

Effect of Adding Different Levels of Potassium Humate and Olive Mill Wastewater on The Physical and Hydro-Dynamic Properties of Subsurface Soil Layers and Potato Plant Production

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Article info

Received: 2025-02-06
Accepted: 2025-04-18
Published: 2025-12-31

DOI-Crossref:
10.32649/ajas.2025.189067

Cite as:
Ibrahim, J., Zainah, R., and Baddour, R. (2025). Effect of Adding Different Levels of Potassium Humate and Olive Mill Wastewater on The Physical and Hydro-Dynamic Properties of Subsurface Soil Layers and Potato Plant Production. Anbar Journal of Agricultural Sciences, 23(2): 979-995.

Abstract

The research was conducted in fall 2019 on silty clay soil at the Center of Scientific Agricultural Research in Latakia. It involved nine treatments comprising additions of olive mill wastewater at 0, 2, 4 $L.m^{-2}$ and potassium humate at 0, 10, 20 $kg.ha^{-1}$. The results showed a significant decrease in bulk density at 0.26 $g.cm^{-3}$ from the highest rates of each treatment compared to the control at 1.4 $g.cm^{-3}$. Increasing the treatment levels improved soil porosity compared to the control, while the *a* and *b* values of the constants also increased. This is considered a good indicator of better water availability to the plant for the olive mill wastewater treatments. Potassium humate was added at the same moisture tension value. The average production of potato tubers at the highest treatment levels was significantly above that for other treatments, increasing by 80%. This was followed by the 64.45% and 63.43% production increase from the olive mill wastewater and potassium humate treatments of 4 $L.m^{-2}$ and 10 kg. ha^{-1} and 2 $L.m^{-2}$ and 20 $kg.ha^{-1}$, respectively.

Keywords: Olive mill wastewater, Potassium humate, Potato, Bulk density, Production, Subsurface soil layer.

Anbar J. Agric. Sci., Vol. (23) No. (2), 2025. ISSN: 1992-7479 E-ISSN: 2617-6211

تأثير إضافة مستويات مختلفة من هيومات البوتاسيوم ومياه معاصر الزيتون العادمة (ماء الجفت) في بعض الخواص الفيزيائية والهيدروديناميكية لطبقة التربة تحت السطحية وفي إنتاج نبات البطاطا

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الخلاصة

نفِّذ البحث في العروة الخريفية على تربة طينية غرينية في مركز البحوث العلمية الزراعية في اللاذقية (محطة ستخيرس) عام 2019 حيث تضمنت الدراسة تسعة معاملات (تمت إضافة ماء الجفت بمعدل 0، 2، 4 ل.م$^{-2}$، وتمت إضافة هيومات البوتاسيوم بمعدل 0، 10، 20 كغ. هكتار$^{-1}$)، أظهرت النتائج انخفاضا معنويا في قيمة الكثافة الظاهرية مقارنة بمعاملة المقارنة حيث أن زيادة مستوى إضافة هيومات البوتاسيوم وماء الجفت عزز انخفاض الكثافة الظاهرية للمعاملات المدروسة والتي بلغت أقل قيمة لها 1.14 غ.سم$^{-3}$ في معاملة ماء الجفت وهيومات البوتاسيوم معا بالمعدل الأعلى لكل منهما مقارنة بمعاملة المقارنة 1.40 غ.سم$^{-3}$، كما حسن زيادة مستوى إضافة هيومات البوتاسيوم وماء الجفت حجم المجموعات المسامية مقارنة بمعاملة المقارنة. لوحظ ارتفاعا في قيمة كل من الثابتين a وb مع زيادة مستوى الإضافة وهذا يعتبر مؤشرا جيدا على إتاحة الماء للنبات بشكل أكبر بالنسبة للمعاملات المضاف لها ماء جفت وهيومات البوتاسيوم عند نفس قيمة الشد الرطوبي. تفوق متوسط إنتاج درنات البطاطا في معاملة ماء الجفت وهيومات البوتاسيوم معا بالمعدل الأعلى لكل منهما معنويا على باقي المعاملات حيث زاد بمقدار 80%، تلاها المعاملتان ماء الجفت بمعدل 4 ل. م$^{-2}$ وهيومات البوتاسيوم بمعدل 10 كغ. هكتار$^{-1}$ معا والمعاملة ماء الجفت بمعدل 2 ل. م$^{-2}$ وهيومات البوتاسيوم بمعدل 20 كغ. هكتار$^{-1}$ معا حيث زاد 64.45 % و63.43 % على التوالي.

كلمات مفتاحية: ماء الجفت، هيومات البوتاسيوم، بطاطا، كثافة ظاهرية، الإنتاج، طبقة التربة تحت السطحية.

Introduction

Most soil studies in the Syrian Arab Republic focus on surface soil layers, but population increases and the intensification of agricultural production have led to the emergence of the problem of soil compaction in the subsurface soil layer. A study on subsurface soil layers in some locations on the Syrian coast under current investment conditions revealed that 81.81% of the studied sites had exceeded the permissible limits of compaction and required urgent reclamation (5) to improve their physical properties. The elimination of horizontal stresses necessitate mechanical disintegration and the continuous addition of organic materials both synthetic, such as inexpensive potassium humate, and natural, such as wastewater from olive oil mills due to its inherent elements. This is to achieve food security and meet agricultural requirements, and to enable their use in eliminating various environmental problems, especially those concerning crops that are widely consumed with potatoes being at the forefront.

Potatoes (*Solanum tuberosum*) belong to the nightshade family (Solanaceae) and are considered sensitive to the physical environment and soil stress, obtaining their moisture needs from the first 30-40 cm of soil. Therefore, attention must be paid to this layer. The chemical composition of the tubers varies according to prevailing climatic conditions, soil type, the variety cultivated, applied agricultural practices, and storage conditions. However, in general, they contain 77.5% water and 22.5% dry matter, of which 70% are sugars, with starch the predominant element. Proteins constitute 1-2% of the dry matter, and they also contain minerals, fats, and vitamins (10).

In Syria, potatoes are planted in spring (mid-January to mid-February) and autumn (mid-July to mid-August) in the warmer areas such as the Syrian coast, and in summer (between March and April) in the colder or high-altitude areas such as in Salamiya. It is known that the soil in arid and semi-arid areas has low organic matter content and fertility and is significantly exposed to degradation, pollution, and desertification on a large scale. Organic waste from various natural sources is widely used to increase organic matter in the soil and enhance crop productivity, such as olive mill wastewater, which contains relatively high amounts of organic matter that can be used as a potential material (14).

Olive mill wastewater does present environmental issues, but due to its high nutrient content, its direct use in the agricultural fields of Mediterranean countries is one of the options for disposing of it as it has positive effects on soil structure from its high organic matter content (3). It is a cheap source of organic and inorganic materials that can be obtained for its economic importance or its potential to be transformed into products for use in agriculture, biotechnology, and food industries. There are approximately 750 million olive trees worldwide, 98% of which are in the Mediterranean region where more than 97 % of the oil is produced. The type of olive mill wastewater varies according to soil characteristics, the use of fertilizers and pesticides, cultivated area, maturity stage, harvest time, prevailing climate, and weather conditions, as well as the method of oil extraction (26).

The waste water from olive oil production contains high levels of salts, organic materials, suspended particles, and toxic chemicals (especially phenols), which can negatively affect the physical, chemical, and biological properties of soil, and make it toxic to plants. It can also positively affect plant growth when applied after processing due to its high metal and organic material content (22). It was also shown by (20) that diluted olive mill wastewater at a 75:50% ratio reduced plant toxicity and increased nitrogen, phosphorus, and potassium in the soil. It also increases soil salinity which should be taken into consideration with continuous application. Diluted olive mill wastewater at a ratio of 25% eliminated plant toxicity and enhanced plant growth. In a study (16) under rainy conditions, the application of 60 m^3. ha^{-1} olive mill wastewater significantly improved wheat growth without observing an effect on wheat yield parameters such as dry weight, straw yield, harvest index, and soil properties, where the index improved between 20.1% to 79.4%. Adding olive mill wastewater to loamy soil at a rate of 100 $m^3.ha^{-1}$ led to a significant decrease in bulk density by 0.1 $g.cm^{-3}$, and the total porosity and pores containing available water increased by 3.63% and 2.24%, respectively, compared to the control (8).

There is a possibility of soil compaction during potato cultivation, which will limit root spread. Using a scale representing the relationship between root spread rate and soil resistance to penetration, it was found that in two-thirds of the studied fields, soil resistance to penetration was greater than or equal to 3 megapascals, where the root growth rate was less than 2 mm/day within the upper 0.55 m of the soil profile (23). Experiments often show a significant decrease in productivity due to artificial soil compaction (25).

Humic acids have a positive effect on the availability and absorption of nutrients by plants, as they facilitate the availability and transfer of nutrients. Additionally, the group of amino acids, especially trace elements, can enhance the absorption of negatively charged phosphate ions and improve their availability to plants (12). Humates, usually derived from leonardite, are the most common type of humic material, and are commercial products prepared from leonardite, which contains 60% humic acids. Commercial humates consist of humic and fulvic acids, and some materials can be a mixture of humates found in leonardite mines (24).

Humic acid provides an economically effective solution to environmental issues as it reduces the toxicity of mineral fertilization and limits soil erosion. It increases plant productivity and enhances their ability to absorb nutrients and vitamins, increasing resistance to diseases. Crops treated with humic substances have higher nutritional value. The application of humic substances also improves soil structure and increases crop yield. This is particularly important in drought conditions as it helps the soil retain water (11). Adding potassium humates at a rate of 2% by weight led to an improvement in the structure of sandy loam soil as the percentage of macroaggrigates with a diameter greater than 2 mm significantly exceeded the other studied treatments (19).

Different humic acid products showed varied responses to agricultural systems in terms of quality indicators such as source, concentration, treatment, productivity, and quality, and based on soil index, cation exchange, and the effect on fertilizer use efficiency. Humates also increase phosphorus availability to plants by complexing ions in the soil. The regular use of high-quality products in different years led to an increase in potato production from stable yields of 11.4% to a maximum of 22.3% (21).

The best effect for increasing potato yield and its components was obtained by fertilizing them with potassium oxide at 100 $kg.feddan^{-1}$ and treating the plant with humic acid at 2 $kg.feddan^{-1}$ (18).

Materials and Methods

This research was conducted in 2019 at the Agricultural Scientific Research Center in Lattakia (Sit-khires Research Station) on clayey-silty soil using a randomized block design comprising nine treatments with three replicates. The experimental plot area sizes were 3 * 3 = 9 m².

The nine treatments were as follows:

W0H0: Comparison treatment without any addition.

W0H1: Adding only potassium humate at 10 kg.ha^{-1} to the subsurface soil layer.

W0H2: Adding only potassium humate at 20 kg.ha^{-1} to the subsurface soil layer.

W1H0: Adding only olive mill wastewater at 2 L.m^{-2} to the subsurface soil layer.

W1H1: Adding olive mill wastewater at 2 L.m^{-2} and potassium humate at 10 kg.ha^{-1} to the subsurface soil layer.

W1H2: Adding olive mill wastewater at 2 L.m^{-2} and potassium humate at 20 kg.ha^{-1} to the subsurface soil layer.

W2H0: Adding only olive mill wastewater at 4 L.m^{-2} to the subsurface soil layer.

W2H1: Adding olive mill wastewater at 4 L.m^{-2} and potassium humate at 10 kg.ha^{-1} to the subsurface soil layer.

W2H2: Adding olive mill wastewater at 4 L.m^{-2} and potassium humate at 20 kg.ha^{-1} to the subsurface soil layer.

Materials were added to the clayey silt soil samples (disturbed - undisturbed) taken at depths of 0-20 cm and 20-50 cm before planting at soil moisture levels of 75-80% field capacity to determine their physical and chemical properties. The results are shown in Table 1.

Table 1: Physical and chemical properties of the studied soil before planting.

Soil property	Soil depth (cm)	
	0-20	**20-50**
Clay %	45.89	**47.36**
Silt %	50.51	**47.33**
Sand %	3.6	**5.31**
Soil type	uT(clayey silt)	**uT(clayey silt)**
Organic matter %	1.27	**0.99**
Total calcium carbonate %	43.7	**43.2**
Effective calcium carbonate %	23	**25**
Cation exchange capacity μ.m\100 g.soil	37.7	**35.5**
Permanent wilting point % by weight	18	**18**
Field capacity % by volume	36	**37.33**
Bulk density g. cm^{-3}	1.18	**1.4**
Particle density g. cm^{-3}	2.6	**2.63**
Shrinkage limit % by weight	16	**16.4**

Tables 2 and 3 show the composition of both added olive mill wastewater and potassium humate.

Table 2: Characteristics of olive mill wastewater extracted from modern factories using the three-phase centrifugation method.

Characteristics	Unit of Measurement	Value
pH	-	**5.9-4.5**
Organic matter	%	**15**
Dry matter	g. L^{-1}	**161-10**
Chemical oxygen demand	g. L^{-1}	**200-15**
Biochemical oxygen demand	g. L^{-1}	**50-30**
Suspended solids	g. L^{-1}	**9-6**
Oil	g. L^{-1}	**29.8-0.4**
Total polyphenols	g. L^{-1}	**7.1-0.4**
Organic nitrogen	g. L^{-1}	**0.14-0.97**
Total phosphorus	mg. L^{-1}	**495-42**
Ash	g. L^{-1}	**12.5-0.4**
Potassium	g. L^{-1}	**2500-630**
Calcium	mg. L^{-1}	**200-47**
Iron	mg. L^{-1}	**31.5-8.8**
Sodium	mg. L^{-1}	**124-18**
Magnesium	mg. L^{-1}	**180-60**
Zinc	mg. L^{-1}	**1.4-4.5**
Copper	mg. L^{-1}	**3.4-1.1**
Manganese	mg. L^{-1}	**5.2-0.9**
Nickel	mg. L^{-1}	**0.3-1.5**
Cobalt	mg. L^{-1}	**0.5-0.1**
Lead	mg. L^{-1}	**0.7-0.4**

Table 3: Chemical composition of commercial potassium humate.

Potassium humate	80 - 85 %
Potassium (as K2O dry matter)	**10 - 12 %**
Total organic nitrogen	**1.0 %**
Dry matter	**85 - 90 %**
Iron (Fe)	**1.0 %**
Others	**2.0 %**
Particle size of insoluble constituents	**<100 µm**
Solubility in water	**100 %**
Product type	**Water soluble granules**

As for the method of adding olive mill wastewater and potassium humate, it was done using a mechanical dismantler connected with a tube and a pump to inject the humate into the subsurface soil layer up to a depth of 50 cm (Figure 1).

Figure 1: Mechanical dismantler with pumping tube fixed at its end to tillage depth.

The humate was added after being dissolved by a pump placed on a tank and the materials injected at a depth of 50 cm and 70 cm between the dismantling lines. The pump was calibrated to first inject the liquid olive mill wastewater followed by the potassium humate after it was dissolved in water. The pump injected the olive mill wastewater according to the specified addition rates based on the flow of the sprayer over a time unit ($L.s^{-1}$) and on the concentration of the prepared humate solution ($g.L^{-1}$) before addition. Thus, olive mill wastewater was added simultaneously and disassembly carried out at the shrinkage limit. The humate was dissolved in water for pumping into the subsurface soil layer according to the flow ($L.s^{-1}$), speed of the tractor ($m.s^{-1}$), and the line length according to the following equation:

Quantity of water required to be mixed with humate (L) = [Sprayer flow rate ($L.s^{-1}$) / Tractor speed ($m.s^{-1}$)] × Line length (m)

The land was prepared for cultivation by adding mineral fertilizers according to the recommendations of the Ministry of Agriculture and Agrarian Reform of Syria (4). Phosphorus, potassium, and a third of the nitrogen were added before planting, followed by surface plowing to mix them with the soil. The land was marked out in 70 cm-spaced lines and the tubers planted 25 cm apart. The necessary plant maintenance operations were then carried out, including weeding, preparation, irrigation, and fertilization. The second and final thirds of the nitrogen fertilizer were added about a month after germination and at the onset of tuber formation, respectively. Spraying was also carried out to prevent late blight.

Spunta potatoes which are a Dutch variety with a medium maturity delay were obtained from the seed multiplication organization in Latakia and planted in fall 2020. The tubers are elongated, oval, and with medium dry matter content. They produce well in autumn and are resistant to late blight disease, early blight, black leg, and drought. Irrigation was done at 80% of the field capacity after determining soil moisture content. Following that, undisturbed soil samples were taken from the subsurface soil layer to determine their physical and hydrodynamic properties, as follows:

Bulk density of the subsurface soil layer: using known volume metal cylinders of 100 cm^3 with a height of 4 cm and a cross-sectional area of 25 cm^2.

Distribution of the pore system in the subsurface soil layer: a membrane pressure device was used to determine the volume of the pore groups according to the following relationships: Pm = 4 σ W/d, Pm: pressure (Pascal), σ W: surface tension of water (Newton/meter), d: pore diameter (meter).

Then, the volume of the pore groups was determined as follows:

$PV\%>50\mu m = PV\% - Wvol.pF_{1.8}$

$PV\%>10\mu m = PV\% - Wvol.pF_{2.5}$

$PV\%(10\text{-}50)\ \mu m = Wvol.pF_{1.8} - Wvol.pF_{2.5}$

$PV\%(0.2\text{-}10)\ \mu m = Wvol.pF_{2.5} - Wvol.pF_{4.2}$

$PV\%<0.2\ \mu m = Wvol.pF_{4.2}$

where, $Wvol.pF_{1.8}$ is the volumetric moisture at the end of the pressure equivalent to $pF_{1.8}$.

The total porosity volume of the soil was determined as follows:

$PV\% = (1 - \varrho d / \varrho s)*100$

where, (ϱ d) is the bulk density and (ϱ s) is the true density of the soil ($g.cm^{-3}$).

Moisture retention curves and the hydrodynamic constants: Determined based on a soil sample using the membrane pressure device by applying the following pressure:

($pF_{1.8}$, $pF_{2.5}$, pF_3, $pF_{3.5}$, $pF_{4.2}$) and the content calculated.

The corresponding moisture tension for each moisture tension logarithm from one was found, and the relationship between moisture content (θ) and the logarithm of moisture tension (ψ) was established, where (lg ψ = pF).

A logarithmic relationship was reached that was transformed into an exponential equation of the form $\psi = a.\ \theta^b$, according to (9), where ψ = moisture tension, θ = moisture content, (a, b) = experimental constants.

Production per unit area ($kg.dunum^{-1}$) = average plant production × plant density in the unit area.

Statistical analysis: The GenStat program was used to evaluate the results at a confidence level and least significant difference of 5%.

Results and Discussion

Bulk Density: As Table 4 shows, bulk density significantly decreased at higher levels of potassium humate and olive mill wastewater. The second concentration of olive mill wastewater (W2H0) resulted in a significant decrease in bulk density compared to the humate (W0H2). As for the interaction effect, bulk density was lowest at 1.14 $g.cm^{-3}$ for the W2H2 treatment, a decrease of 0.26 $g.cm^{-3}$ compared to the control. This was followed by the W2H1 treatment, which decreased by 0.25 $g.cm^{-3}$, and the W2H0 and W1H2 treatments which both decreased by 0.24 $g.cm^{-3}$ compared to the control.

This is attributed to the increase in the organic matter content in the subsurface soil layer from the additional inputs. This is consistent with (1), who indicated that addition of potassium humate to sandy soil at a rate of 1 $kg.feddan^{-1}$ led to a decrease in bulk density and a significant increase in total porosity compared to the control, thus improving soil structure. There was also a gradual decrease in both bulk and particle density of the soil from the olive mill wastewater addition, which was explained by the increase in organic matter content in the soil (17).

Table 4: Average bulk density of the studied treatments in the 20-50 cm subsurface soil layer.

Treatments	Average bulk density (g. cm^3)
W0H0	**1.40^{f}**
W0H1	**1.24^{e}**
W0H2	**1.22^{d}**
W1H0	**1.21^{cd}**
W1H1	**1.18^{bc}**
W1H2	**1.16^{ab}**
W2H0	**1.16^{ab}**
W2H1	**1.15^{ab}**
W2H2	**1.14^{a}**
LSDα0.05	**0.026**
CV%	**1.6**

Note: a, b, c refer to the presence of significant differences between the treatments at the 5% significance level for the studied properties.

Pore System Distribution: Table 5 shows the significant increase in total porosity arising from the humate and olive mill wastewater application compared to the control. There was also an increase in the percentage of other pore groups due to the higher levels of humate and olive mill wastewater compared to the control, and a significant decrease in the percentage for pores smaller than 0.2 microns, which are those containing water not beneficial to the plant.

Treatment W2H2 showed a significant increase in total porosity volume, number of macropores larger than 10 microns, and pores containing available water by 8.94%, 6.56%, and 5.63%, respectively. Additionally, pores containing non-absorbable water decreased by 3.26% compared to the control.

The higher levels of humates and olive mill wastewater decreases bulk density which improves the soil structure by increasing porosity due to the organic matter content of olive mill wastewater, which directly contributes to the formation of about 65% of the dry matter (6). Alternatively, the application of organic matter after applying olive mill wastewater increased small pores and reduced large pores (7). Moreover, humic acid fertilizer improves the physical properties of the soil and increases porosity (1).

Table 5: Total porosity volume and its distribution in the 20-50 cm subsurface soil layer treatments.

Treatments	Pv %	Pv>50 %	Pv>10%	Pv(0.2-10)%	Pv<0.2%
W0H0	46.69[c]	9.00c	10.15[d]	11.41[d]	**25.14[d]**
W0H1	48.39[b]	16.97 [a]	12.82[c]	12.82[cd]	**22.75[c]**
W0H2	50.63[ab]	16.65 [ab]	14.03[bc]	14.03[bc]	**22.57[bc]**
W1H0	53.76[ab]	14.33 [b]	17.76 [a]	14.04[bc]	**21.96 [ab]**
W1H1	54.61 [ab]	15.62 [ab]	17.67 [a]	15.00 [abc]	**21.94 [ab]**
W1H2	55.21[a]	15.21[b]	17.32 [a]	16.20 [ab]	**21.69 [a]**
W2H0	55.38 [a]	18.21 [a]	18.95 [a]	15.09 [abc]	**21.34 [a]**
W2H1	55.72 [a]	14.77 [b]	17.93 [a]	16.24 [ab]	**21.56 [a]**
W2H2	55.63 [a]	14.13 [b]	16.71 [ab]	17.04 [a]	**21.88 [ab]**
LSDα0.05	2.32	2.56	3.1	2.09	**0.7**
Cv%	2.5	9.9	11.2	8.3	**1.8**

Note: a, b, c refer to the presence of significant differences between the treatments at the 5% significance level for the studied properties.

Moisture Tension Curves: Figures 2 to 10 show that with increasing moisture tension, the moisture content of the soil decreases, and the wilting point and field capacity can be determined through the curve, and thus the percentage of available water. The olive mill wastewater treatment showed an increase in the soil's ability to retain water (13 and 15) possibly due to the high organic matter content of the wastewater.

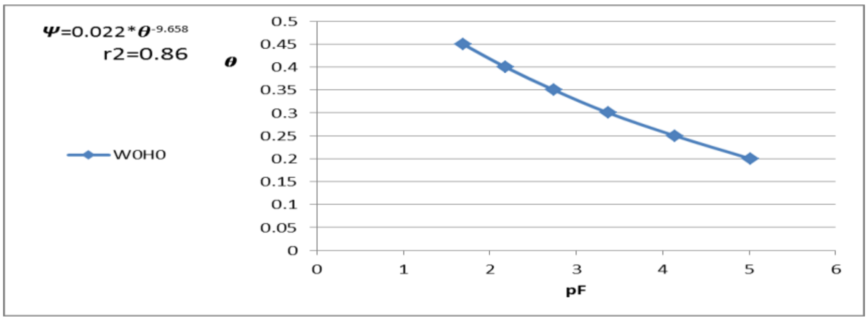

Figure 2: Moisture-tension curve of the W0H0 treatment in the 20-50 cm subsurface soil layer.

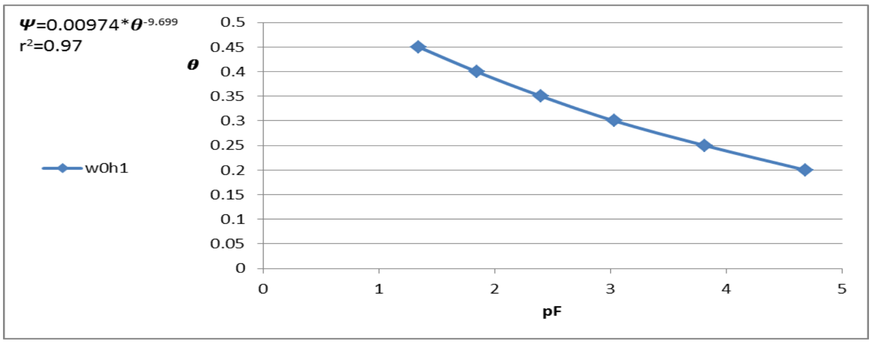

Figure 3: Moisture-tension curve of the W0H1 treatment in the 20-50 cm subsurface soil layer.

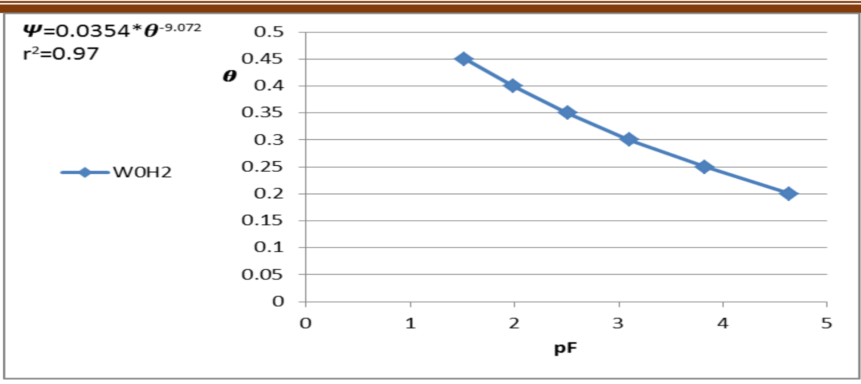

Figure 4: Moisture-tension curve of the W0H2 treatment in the 20-50 cm subsurface soil layer.

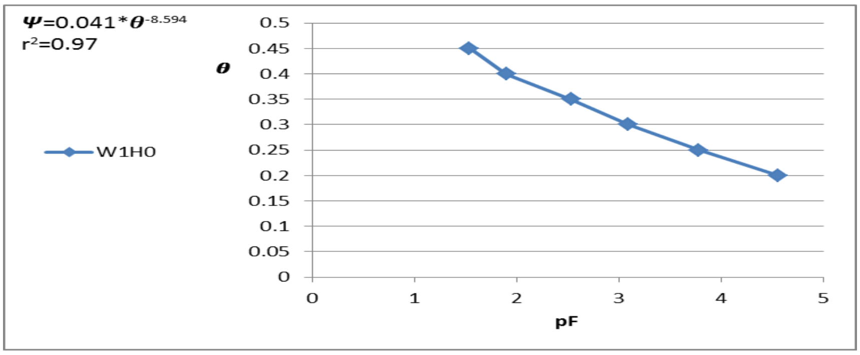

Figure 5: Moisture-tension curve of the W1H0 treatment in the 20-50 cm subsurface soil layer.

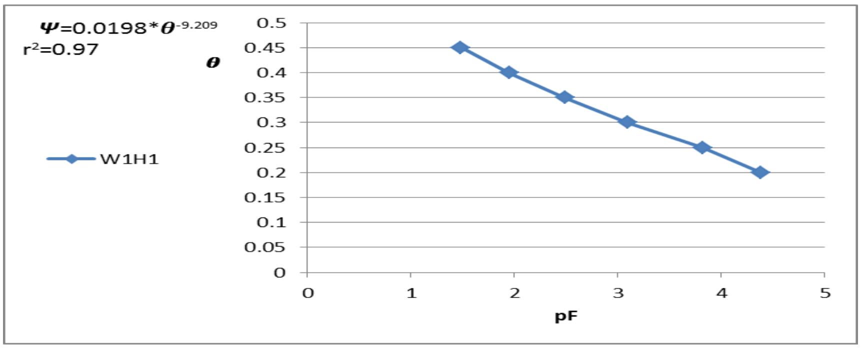

Figure 6: Moisture-tension curve of the W1H1 treatment in the 20-50 cm subsurface soil layer.

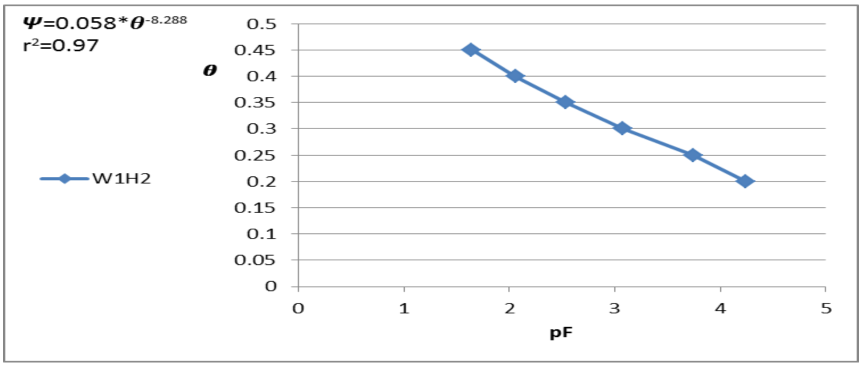

Figure 7: Moisture-tension curve of the W1H2 treatment in the 20-50 cm subsurface soil layer.

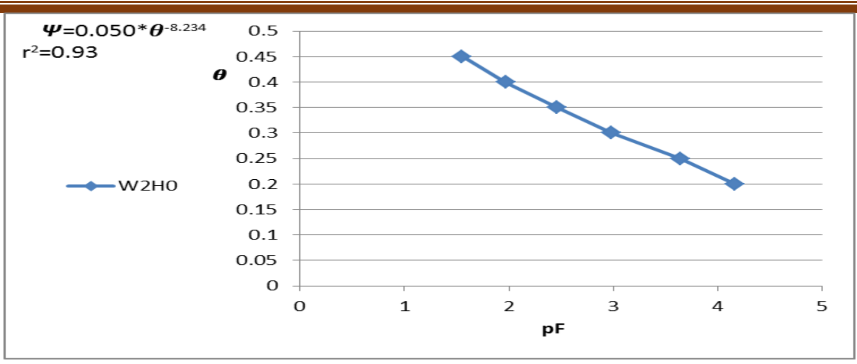

Figure 8: Moisture-tension curve of the W2H0 treatment in the 20-50 cm subsurface soil layer.

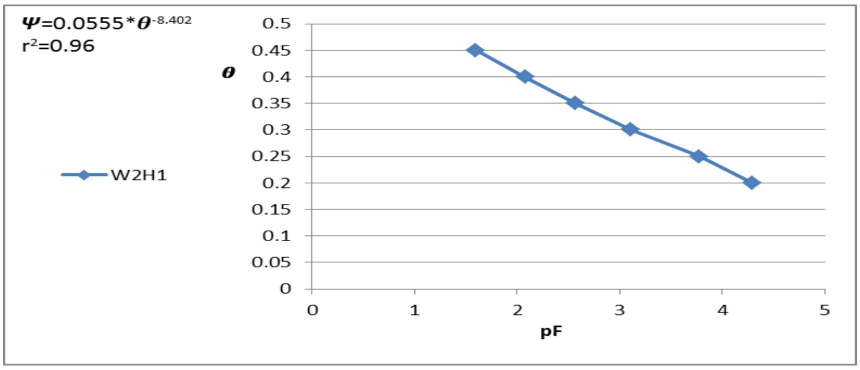

Figure 9: Moisture-tension curve of the W2H1 treatment in the 20-50 cm subsurface soil layer.

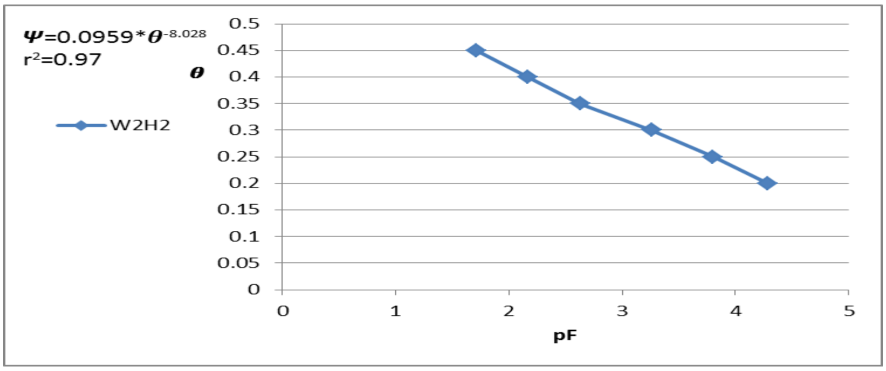

Figure 10: Moisture-tension curve of the W2H2 treatment in the 20-50 cm subsurface soil layer.

As Table 6 shows, the values for the *a* and *b* constants increased at higher olive mill wastewater and humate levels, the former by 0.0737 and the latter by 1.63 in the W2H2 treatment compared to the control. This is a good indicator of greater water availability for the plant at the same moisture tension value. These constants enter the experimental calculations for the amount of water rising by capillarity from the groundwater level or from the subsurface irrigation network.

Table 6: Relationship between moisture content, moisture tension, and average constant values for the studied treatments in the 20-50 cm subsurface soil layer.

Treatment	Moisture tension curve equation	Coefficient of determination r^2	Constant	
			a	b
W0H0	$\Psi = 0.022.\ \theta^{-9.658}$	0.86	0.022	**-9.658**
W0H1	$\Psi = 0.00974.\ \theta^{-9.699}$	0.97	0.00974	**-9.699**
W0H2	$\Psi = 0.0354.\ \theta^{-9.072}$	0.97	0.035	**-9.072**
W1H0	$\Psi = 0.041.\ \theta^{-8.594}$	0.97	0.041	**-8.594**
W1H1	$\Psi = 0.0198.\ \theta^{-9.209}$	0.97	0.0198	**-9.209**
W1H2	$\Psi = 0.058.\ \theta^{-8.288}$	0.97	0.058	**-8.288**
W2H0	$\Psi = 0.050.\ \theta^{-8.234}$	0.93	0.050	**-8.234**
W2H1	$\Psi = 0.0555.\ \theta^{-8.402}$	0.96	0.0555	**-8.402**
W2H2	$\Psi = 0.0957.\ \theta^{-8.028}$	0.97	0.0957	**-8.028**

Note: The coefficient of determination had a positive value indicating the strength of the relationship between moisture tension and content between the studied factors, and whether the relationship is direct or inverse.

Production: The average production of the W2H2 treatment significantly exceeded the other treatments by 80% compared to the control (Table 7). The W2H1 and W1H2 treatments showed an average production difference of 64.6% and 63.5%, respectively over the control. This is attributed to the richness of olive mill wastewater in mineral elements and their availability to the plant, in addition to the role of organic matter in improving the soil's physical properties (Tables 4 and 5, and the graphical representations of the moisture tension curves) thereby increasing root growth and effectiveness.

This agrees with (2) where the treatment with humic acid derived from leonardite had a significant 66.4% effect of increasing potato tuber production compared to the control, and that humic substances of organic origin can improve soil properties, stimulate plant growth, and enhance nutrient absorption. (11) also indicated that the application of organic acids improves soil structure, increases crop yield and quality, and overall productivity, as it affects plant growth both directly and indirectly by improving the physical, chemical, and biological conditions of the soil. Olive mill wastewater also improves the productivity of some important crops and enhances soil fertility (6).

Table 7: Average potato plant production for the studied treatments.

Treatment	Average production	
	%	Kg/donum
W0H0	100[e]	**1862[e]**
W0H1	120.3[d]	**2238[d]**
W0H2	144.3[c]	**2686[c]**
W1H0	117.1[d]	**2178[d]**
W1H1	144.1[c]	**2682[c]**
W1H2	163.5[b]	**3043[b]**
W2H0	146.4[c]	**2761[c]**
W2H1	164.6[b]	**3062[b]**
W2H2	180[a]	**3347[a]**
LSDα0.05	5.98	**98.2**

Note: a, b, c refer to the presence of significant differences between the treatments at the 5% significance level for the studied properties.

Conclusions

The addition of potassium humates and olive mill wastewater led to a decrease in the bulk density of the studied treatments, which reached its lowest value at 1.14 $g.cm^{-3}$ in the W2H2 treatment compared to the W0H0 control treatment (1.40 $g.cm^{-3}$). Higher levels of potassium humate and olive mill wastewater improved the size of the pore groups compared to the control treatment, with a significant increase in total porosity seen in the W2H2 treatment. Air pore sizes exceeding 10 microns and those containing available water amounted to 8.94%, 6.56%, and 5.63%, respectively. Also, the size of pores containing dead water decreased by 3.26% compared to the control. However, no significant differences were observed in porosity rates among the treatments.

An increase was also noted in the values of both the *a* and *b* constants by 0.0737 and 1.63, respectively, in the W2H2 treatment. This is considered a good indicator of greater water availability for the plant for the treatments supplemented with olive mill wastewater and potassium humates at the same moisture tension value.

The average potato tuber yield for the W2H2 treatment significantly exceeded the others, by 80%, followed by the W2H1 and W1H2 treatments at 64.6% and 63.5%, respectively. This increase is attributed to the synergistic role of both the potassium humate and olive mill wastewater in improving the soil's physical properties, such as reducing bulk density and increasing both porosity and water available to the plant. Additionally, it improved the fertility properties of the soil, such as increasing organic and mineral content and providing nutrients to the plant at the same moisture tension value.

Further research is recommended in this area using different concentrations and types of crops and soils to determine the optimum treatments required that will contribute positively to the physical and productive properties of the soil.

Supplementary Materials:

No Supplementary Materials.

Author Contributions:

Rasha Baddour: review and editing. The authors have read and approved the published version.

Funding:

This research received no external funding.

Institutional Review Board Statement:

The study was conducted according to the plan drawn up by the supervisor and what was approved by the Scientific Committee in the Scientific Department.

Informed Consent Statement:

Not applicable.

Data Availability Statement:

Data available upon request.

Conflicts of Interest:

The authors declare no conflict of interest.

Acknowledgments:

The researchers thank the supervisors for the assistance provided throughout the research period. Our gratitude also to the Chairman and the faculty members of the Soil and water science Department.

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