

The Impact of Subsurface Tillage Techniques and Irrigation Methods on Soil Dynamics, Growth, and Potato Crop Yield

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This study was conducted in the field of the College of Agriculture and Forestry/ University of Mosul during the spring agricultural season of 2023 to examine the effect of three irrigation systems (drip, sprinkler, and surface irrigation) and the use of a subsoil plow at depths of 25-35 cm and 35-45 cm on the potato crop. The split-plot design was used once in a Randomized Complete Block Design (RCBD) with three replications. Data were then recorded and statistically analyzed. The results were as follows: The drip irrigation system significantly outperformed in the leaf area of the plant and the yield per plant. The sprinkler irrigation system significantly outperformed in irrigation costs, while the surface irrigation significantly outperformed in pump operating time. The 35-45 cm tillage depth significantly outperformed in plant height, leaf area per plant, yield per plant, and marketable tuber yield, with an increase of 17.32%, 12.56%, 25.14%, and 12.63% respectively. The 25-35 cm tillage depth recorded the lowest significant values in operating costs and pump operating time, at 18.02% and 12.88% respectively. The interaction between drip irrigation and 35-45 cm tillage depth recorded the highest significant values in plant height, leaf area per plant, yield per plant, and marketable tuber yield, while the interaction between sprinkler irrigation and 25-35 cm tillage depth recorded the highest values in operating costs and pump operating time.

Keywords: Subsurface Tillage, Irrigation Systems, Water Consumption.

1. Introduction

The potato crop is one of the most important vegetable crops worldwide due to its economic significance in achieving food security for humans. Its tubers contain proteins, carbohydrates, amino acids, calories, and nutrients (Elsevier et al., 2016). However, climate change and water scarcity in recent years have led to a reduction in agricultural land globally, posing a significant threat to human food security (Training et al., 2022). This has led many researchers to focus

on finding a balance between increasing crop production to meet the growing population and maintaining crop quality while utilizing water in the most efficient manner. The goal is to increase productivity per unit area with minimal water consumption.

Selecting the appropriate irrigation system in terms of installation costs and compatibility with the type of plant, soil, and surrounding climate is crucial. Surface irrigation is one of the oldest irrigation methods used worldwide due to its ease of use and lower installation costs compared to other irrigation methods. Many studies have recommended transitioning from surface irrigation to sprinkler irrigation due to its significant benefits in water use efficiency, reducing soil erosion, enhancing soil nutrient content, and improving soil physical properties in fields prone to water erosion and nutrient deposition resulting from surface irrigation (Ippolito et al., 2017).

Drip irrigation is one of the most recent irrigation systems, demonstrating its ability to save water and energy used in pump operation and increase crop yields. It delivers water directly to plants in precise amounts, maintaining soil structure and reducing nutrient leaching, as well as minimizing fertilizer depletion (Narayanamoorthy et al., 2018). Additionally, it significantly improves moisture distribution around the plant, reducing water use due to decreased evaporation and direct delivery to the root zone (Reyes et al., 2016). This method is more efficient in saving water at the top of ridges when planting potatoes compared to sprinkler irrigation, as it promotes plant growth by providing water directly to the root zone while preserving soil structure, unlike sprinkler irrigation, which can cause soil compaction due to water droplets hitting the soil surface, increasing soil bulk density in the topsoil layer and reducing soil water absorption at the ridge tops.

Drip irrigation has proven highly effective in increasing water use efficiency compared to surface irrigation by reducing soil water evaporation and providing sufficient water for plant growth. This results in increased plant height, leaf area, number of tubers per plant, yield per plant, and marketable yield compared to surface irrigation (Akram et al., 2020). In addition to selecting the appropriate irrigation method to maintain soil physical properties and provide suitable moisture for plants, using deep subsurface plowing to break up compacted soil layers at greater depths improves soil physical properties, enhances soil aeration, increases water drainage, and maintains optimal soil moisture. This reduces soil compaction, improves root nutrient absorption, increases root elongation, and enhances soil nutrient availability through different soil bacterial communities (Costa et al., 2017).

Deep plowing can reduce soil bulk density by 8.88% and increase soil porosity by 13.04% in the 20-40 cm soil layer, while reducing soil pressure by 56.96% in the 0-40 cm soil layer. Deep plowing improves moisture movement in deeper soil layers, reducing water consumption and increasing root depth, leading to better nutrient absorption from the soil and higher crop yields (Qiang et al., 2022). Soil compaction in the root zone, especially in upper soil layers, hinders root growth and reduces root density, resulting in lower leaf emergence rates and decreased vegetative growth, ultimately reducing overall crop yield. Regulating irrigation amounts can alleviate soil pressure, increasing water and nutrient use efficiency from the soil (Stalham et al., 2007).

Soil compaction can also cause root accumulation in small cavities in the topsoil layer, reducing nutrient absorption from the soil (Copas et al., 2009). Deep plowing (30-120 cm) at

least once is highly beneficial in breaking up deep soil layers, improving soil aeration and water drainage, facilitating deeper root penetration, and increasing nutrient absorption from the soil, ultimately enhancing plant productivity (Burger et al., 2024). This research aims to identify the best irrigation method for potato crops and the optimal plowing depth to improve vegetative growth traits, increase tuber yield per unit area, and reduce irrigation system operating costs.

The aim of the current study is to evaluate the yield and production costs of potato crops with three tillage depths and three irrigation methods.

2. Materials and Methods:

The study on materials and methods was conducted in the spring season of 2023 in the vegetable field belonging to the College of Agriculture and Forestry at the University of Mosul, located north of Mosul and 5 km away from the city center. The field soil is characterized as clayey loam, from which samples were taken from the soil surface and at a depth of 30 cm. These samples were analyzed in the central laboratory of the College of Agriculture and Forestry at the University of Mosul, as detailed in Table (1).

Table (1): shows the physical properties of soil and soil contents.

PH	7.1
EC(mS/cm)	1.80
Field Capacity	19.98%
Sand	25.05
Clay	37.95
Silt	37

Planting of potatoes of the local variety Lucinda, grade A, which were purchased from a farmer and stored in refrigerated warehouses at a temperature of 4-5 °C for six months. The produced potatoes of the same variety, grade E, were planted using a special planter for potato planting on January 20, 2023. The distance between rows was 0.75 m, between potatoes was 0.25 m, and at a depth of 0.15 m, with the furrow depth reaching 0.26 m. Irrigation schedules for the field were determined by measuring soil moisture using a soil moisture meter at a depth of 30 cm. The ideal moisture level was set at 70% of the soil field capacity (Elzner et al., 2018).

The study included two factors:

1. Irrigation Systems, which consisted of three irrigation systems:

a. Drip Irrigation: Drip irrigation pipes were installed on top of the ridge after planting the potatoes, with a spacing of 25 cm between drippers. Dripper discharge was calculated by placing a graduated cylinder of known volume under the dripper, measuring the time required to fill the cylinder, and calculating the amount of water discharged. The discharge rate was measured at the beginning and end of the drip line to achieve a 5% difference in dripper discharge, with a valve installed at the beginning of each line to stop irrigation once the appropriate moisture level is reached.

b. Sprinkler Irrigation: Sprinklers were installed in two lines with a total of 18 nozzles, 9 per line, to achieve water overlap between the lines. The outer side of the sprinkler lines was

neglected. Discharge from each sprinkler was measured by calculating the amount of water discharged from the nozzle over a specified time period using plastic hoses in the nozzle and a 15-liter basin to measure the discharge rate of the first and last sprinklers to balance the system.

c. Furrow Irrigation: The field was divided into four sections based on plowing depths, with each section irrigated directly using water drainage tubes. Pump discharge was measured by timing the filling of a known-volume container with water discharged from the tube.

2. Plowing Depths: The land was plowed using a subsoiling tillage in two treatments The distance between the plowing lines was 1 meter

a. Plowing at a depth of 25-35 cm.

b. Plowing at a depth of 35-45 cm.

Then the disc plow is used at a depth of 20 cm to turn the soil, and the land is leveled before the planting process.

Study treatments: The study comprised 6 treatments (2x3), combining irrigation systems and plowing depths in a one-time split-plot design within a complete randomized block design with three replications. Irrigation systems were assigned to main plots and plowing depths to subplots. The potatoes were harvested at the end of the season on July 1, 2023, and the following traits were recorded:

1. Plant height (cm.plant⁻¹): Measured by taking the lengths of aerial stems from the soil surface to the tip of the stem, extracting the average plant height from five plants per experimental unit from the central row.

2. Leaf area per plant (cm².plant⁻¹): Three plants from each treatment were sampled, their leaves were collected, and leaf weight was measured. Ten leaf discs with a diameter of 1 cm were then taken from each plant using a cork borer, with 30 discs taken for the three plants. The discs and leaves were dried in an electric oven at 68-70°C for 72 hours until a constant weight was achieved. Leaf area per plant was calculated based on the dry weight of the discs and leaves using a proportionate method.

$$\text{Leaf area (cm}^2\text{)} = \frac{\text{The paper area of the disks (30 disks)} \times \text{the dry weight of the leaves (3 plants)}}{\text{The dry weight of the disks (20 disks)}}$$

3. Pump runtime to reach the ideal soil moisture at a depth of 30 cm:

Drip Irrigation System:

1. The number of emitters per hectare was calculated as follows:
2. The distance between emitters in the same line is 0.25 m.
3. The distance between rows is 0.75 m.
4. The number of emitters per hectare is 53,333 emitters.
5. The discharge rate of each emitter is 4.59 L.hr⁻¹.

Emitter discharge per hectare = number of emitters per hectare × discharge rate of each emitter.

$$\text{Operating hours (hr/ ha)} = \frac{\text{Pump discharge (L/ hr)}}{\text{Emitter discharge (L/ ha)}}$$

Sprinkler Irrigation System:

The distance between each sprinkler is 6 m.

The number of sprinklers per hectare is 277.4 sprinklers.

The flow rate of a single sprinkler is 14.5 liters .minute.

Sprinkler discharge.ha⁻¹ = discharge rate of each sprinkler × number of sprinklers.ha⁻¹.

$$\text{Operating hours (hr/ ha)} = \frac{\text{Pump discharge (L/ hr)}}{\text{Sprinkler discharge (L/ ha)}}$$

Flood Irrigation System:

Based on the pump runtime calculated by determining the area of the experimental unit which measured 367.5 square meters." and the time required to irrigate the experimental unit as follows:

$$\begin{aligned} \text{Operating hours (hr/ ha)} &= \frac{\text{Area of one hectare}}{\text{Area of the experimental unit}} \\ &\times \text{Time required to irrigate the experimental unit} \end{aligned}$$

Operating Costs of Irrigation Systems:

Operating costs of irrigation systems = operating hours/ hectare × fuel purchase price (\$) × fuel consumption (L/ hr) × number of irrigations during the season.

Marketing Yield of Tubers (ton.ha⁻¹):

Calculated for the same plant, excluding damaged tubers and tubers weighing less than 25 gm as follows:

$$\text{Marketing yield of tubers (Ton/ ha)} = \frac{\text{Marketing yield / plant} \times \text{number of plants/ ha}}{1,000,000}$$

Single Plant Yield (grams per plant):

$$\text{Single plant yield (gm)} = \frac{\text{Total weight of five plants from each experimental unit}}{5}$$

Statistical analysis: After recording the data, it was processed using the SAS program (2000), and the values calculated were found to be below the 0.05 probability level (Al-Rawi, 2000).

3. Results and Discussion:

The results of Table (2) indicate no significant difference in plant height attribute among the

irrigation systems, with drip irrigation system significantly outperforming in the leaf area attribute of the plant, reaching 1439.1 cm² per plant. This differed significantly from the other two systems, with the lowest leaf area per plant at 1096.6 cm² per plant observed in the furrow irrigation system. The reason for this is that drip irrigation method delivers water directly and in controlled amounts to the root zone, ensuring the soil receives the necessary ideal moisture for root growth by preventing soil saturation and safeguarding plant roots from rotting. This is achieved by maintaining optimal moisture levels for the plants for longer periods. Additionally, drip irrigation prevents nutrient leaching from the soil and reduces weed growth by providing water directly to the root zone, minimizing competition for nutrients. This is in contrast to flood irrigation and sprinkler irrigation systems, which leach nutrients from the soil, increase salt accumulation, and raise the soil's apparent density, hindering root penetration and reducing nutrient supply to the stem, such as phosphorus, nitrogen, and calcium. Furthermore, it reduces the plant's photosynthesis process. These findings are consistent with the study by Akram et al. (2020).

Table (2): The effect of irrigation systems on potato vegetative properties

Treats Irrigation System	Plant Height (cm)	Leaf Area (cm ² plant ⁻¹)
Drip	96.41 a	1439.1 a
Furrow	85.16 a	985.1 b
Sprinkler	89.00 a	1096.6 b

Table (3) results indicate a significant difference in the operating costs of irrigation systems, with the sprinkler irrigation system giving the highest value at 102.00 (\$/ha⁻¹), a significant difference compared to the other two systems, with the lowest value at 76. (\$/ha⁻¹) in the drip irrigation system. The results also show a significant decrease in pump runtime to reach the ideal soil moisture at a depth of 30 cm in the drip irrigation system, reaching 15.03 (hr/ha⁻¹). This can be explained by the evaporation that occurs when using sprinklers due to the high-water pressure and the water exiting the nozzle in a mist form, leading to evaporation before the water reaches the soil. Consequently, a larger amount of water is needed to reach the plant's full saturation stage. Additionally, sprinkler irrigation reduces soil pore size due to the pressure of water droplets on the soil surface, causing the soil to retain less water. This leads to an increase in pump runtime and the number of irrigations per season. These findings are in line with the studies by Reyes et al. (2016), and Narayanamoorthy et al. (2018).

Table (3): The effect of irrigation systems on mechanical properties

Irrigation System	Operating Costs (\$/ha ⁻¹)	Pump Operation Time to Reach 30 cm Irrigation Depth (hr/ha ⁻¹)
Drip	76.50 b	15.30 b
Furrow	83.75 b	22.02 a
Sprinkler	102.00 a	20.41 a

The results in Table (4) indicate that the drip irrigation system outperformed in the yield per single plant, reaching 912.50 gm significantly differed from the sprinkler irrigation system, which yielded higher values at 733.25 gm. The reason for this is attributed to the direct and precise delivery of water to the plant root zone, providing the necessary optimal moisture for

tuber growth for the longest possible period, unlike surface irrigation and sprinkler irrigation, which can cause water stress to the plant due to either moisture deficiency or excess, leading to poor soil aeration, leaching of nutrients, increased soil bulk density hindering shoot growth on tubers, and restricting the uptake of available nutrients in the soil. It is noted that drip irrigation yielded the highest significant value in marketable tuber yield, reaching 47.72 (ton.ha⁻¹), differing significantly from the sprinkler irrigation system, which yielded lower values at 40.57 tons per hectare. This aligns with the findings of Akram et al. (2020).

Table (4): The effect of irrigation systems on potato crop properties.

Irrigation System	Plant Yield (gm Plant ⁻¹)	Marketable Yield of tubers (ton.ha ⁻¹)
Drip	912.50 a	47.72 a
Furrow	810.40 ab	42.19 ab
Sprinkler	773.25 b	40.57 b

The results in Table (5) indicate a significant difference in plant height between plowing depths, where the depth of 35-45 cm yielded the highest significant value in plant height at 97.38 cm, while the plant height at the depth of 25-35 cm was 83.00 cm. It is observed that plowing depth of 35-45 cm led to a significant increase in leaf area, reaching 1304.65 cm².Plant⁻¹, differing significantly from the plowing depth of 25-35 cm, which resulted in a smaller leaf area of 1042.55 cm² for Plant⁻¹. The reason for this can be attributed to the breaking up of compacted soil layers and reducing soil pressure in the root zone extension area, where soil pressure can restrict root movement, decrease soil water drainage, leading to root rot and poor nutrient uptake, ultimately reducing plant height due to limited nutrient resources from the roots and decreased photosynthesis process, resulting in a smaller leaf area. This aligns with the findings of Burger et al. (2024) and Costa et al. (2017).

Table (5): The effect of plowing depths by subsoil plow on potato vegetative properties.

Treats Subsoil Plow Depths	Plant Height (cm)	Leaf Area (cm ² plant ⁻¹)
(25 - 35) cm	83.00 b	1042.55 b
(35 - 45) cm	97.38 a	1304.65 a

The results in Table (6) indicate a significant decrease in irrigation system operation costs and pump operation time at a plowing depth of 35-45 cm, with values of \$80.16 per hectare and 18.08 hours per hectare, respectively, showing a significant difference from the depth of 25-35 cm, which yielded higher values in these two aspects at \$94.66 per hectare and 20.41 hours per hectare, respectively. The reason for this can be attributed to the increased breakdown of deep soil layers with greater plowing depth, leading to larger soil pores, increased soil water absorption rate, faster water penetration to the plant root zone, achieving optimal soil moisture levels that plants can utilize efficiently without water wastage during irrigation. This can improve soil structure, create water channels in the soil, and enhance soil water retention capacity. These findings align with those of Burger et al. (2024) and Stalham et al. (2007).

Table (6): The effect of plowing depths by subsoil plow on mechanical properties.

Subsoil Plow Depths	Operating Costs (\$/ha)	Pump Operation Time to Reach 30 cm Irrigation Depth (hr/ha)
(25 - 35) cm	94.66 a	20.41 a
(35 - 45) cm	80.16 b	18.08 b

The results in Table (7) indicate a significant superiority in both the yield per single plant and the marketable tuber yield at a plowing depth of 35-45 cm, reaching 881.23 grams per plant and 46.08 tons per hectare, respectively. This is compared to the plowing depth of 25-35 cm, which yielded lower values in both the yield per single plant and the marketable tuber yield at 782.87 grams per plant and 40.91 tons per hectare, respectively. The reason for this is that deep plowing works to increase the breakdown of deep soil layers, enlarge soil pores, allowing roots to explore a larger soil volume, absorb nutrients, improve water and air movement in the soil, providing optimal moisture for plant growth, increasing shoot growth, the number of tubers per plant, tuber size, and the quality of potato tubers. These findings align with those of Qiang et al. (2022) and Burger et al. (2024).

Table (7): The effect of plowing depths by subsoil plow on potato crop properties.

Subsoil Plow Depths	Plant Yield (gm)	Marketable Yield of tubers (ton.ha ⁻¹)
(25 - 35) cm	782.87 b	40.91 b
(35 - 45) cm	881.23 a	46.08 a

The results of Table (8) indicate the interaction between irrigation systems and tillage depths on the vegetative growth characteristics of potato crops. It is noted that the treatment of the interaction between drip irrigation system and tillage depth of 35-45 cm excelled in plant height and leaf area of the plant, reaching 104.16 cm and 1670.00 cm².plant⁻¹ respectively, showing significant differences with some other treatments. The lowest values in this interaction were 77.50 cm and 928.50 cm².plant⁻¹ in plant height and leaf area respectively.

Table (8) The effect of interaction between irrigation systems and deferent plowing depths by subsoil plow on potato vegetative properties.

Irrigation System	Subsoil Plow Depths	Plant Height (cm)	Leaf Area (cm ² plant ⁻¹)
Drip	(25-35)cm	88.66 bc	1208.25 b
	(35-45)cm	104.16 a	1670.00 a
Furrow	(25-35)cm	77.50 c	928.50 c
	(35-45)cm	92.83 ab	1041.70 c
Sprinkler	(25-35)cm	82.83 bc	990.90 c
	(35-45)cm	95.16 ab	1202.25 b

The results of Table (9) in the interaction between irrigation systems and tillage depths indicate a significant decrease in the operating costs of irrigation systems and pump operation time when the drip irrigation system interacts with a tillage depth of 35-45 cm, amounting to 68.000 dollars per hectare and 13.60 hectares per hour respectively, with a significant difference among all treatments of this interaction. The lowest values were 113.50 dollars per hectare and 22.67 hours per hectare for the operating costs of irrigation systems and pump operation time, respectively, in the treatment of the interaction of sprinkler irrigation with a tillage depth of 25-35 cm.

Table (9): The effect of interaction between irrigation systems and deferent plowing depths by subsoil plow on mechanical properties.

Irrigation System	Subsoil Plow Depths	Operating Costs (\$ ha)	Pump Operation Time to Reach 30 cm Irrigation Depth (hr.ha ⁻¹)
Drip	(25 - 35) cm	85.00 d	17.01 e
	(35 - 45) cm	68.00 f	13.60 f
Furrow	(25 - 35) cm	85.50 c	21.54 c
	(35 - 45) cm	82.00 e	22.50 b
Sprinkler	(25 - 35) cm	113.50 a	22.67 a
	(35 - 45) cm	90.50 b	18.14 d

The results of Table (10) indicate the interaction between irrigation systems and tillage depths, showing that the interaction of the drip irrigation system with a tillage depth of 35-45 cm yielded the highest significant values in single plant yield and marketable tuber yield, reaching 969.00 grams per plant and 50.75 tons per hectare respectively. There was a significant difference among some treatments, with the lowest values being 732.60 grams and 38.44 tons per hectare for single plant yield and marketable tuber yield, respectively, in the treatment of sprinkler irrigation with a tillage depth of 25-35 cm.

Table (10): The effect of interaction between irrigation systems and deferent plowing depths by subsoil plow on potato Yield.

Irrigation System	Subsoil Plow Depths	Plant Yield (gm)	Marketable Yield of tubers (ton .ha ⁻¹)
Drip	(25 - 35) cm	856.00 ab	44.69 ab
	(35 - 45) cm	969.00 a	50.75 a
Furrow	(25 - 35) cm	760.00 b	39.60 b
	(35 - 45) cm	860.80 ab	44.78 ab
Sprinkler	(25 - 35) cm	732.60 b	38.44 b
	(35 - 45) cm	813.90 ab	42.69 ab

4. Conclusions:

From this study, we conclude that using subsoil plowing at a tillage depth of 35-45 cm along with drip irrigation system was the most effective in improving vegetative growth, increasing the marketable yield of potato crops, reducing pump operation time to reach optimal soil moisture, and decreasing operating costs of the irrigation system compared to irrigation methods and tillage depth of 25-35 cm used in the experiment.

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References

1. Stalham, M., Allen, E., Rosenfeld, A., and Herry, F. (2007). Effects of soil compaction in potato (*Solanum tuberosum*) crops. *The Journal of Agricultural Science*, 145(4), 295-312.

2. Copas, M. E., Bussan, A. J., Drilias, M. J., and Wolkowski, R. P. (2009). Potato yield and

- quality response to subsoil tillage and compaction. *Agronomy Journal*, 101(1), 82-90.
3. Tian, J., Chen, J., Ye, X., and Chen, S. (2016). Health benefits of the potato affected by domestic cooking: A review. *Food Chemistry*, 202, 165-175.
 4. Reyes-Cabrera, J., Zotarelli, L., Dukes, M. D., Rowland, D. L., and Sargent, S. A. (2016). Soil moisture distribution under drip irrigation and seepage for potato production. *Agricultural Water Management*, 169, 183-192.
 5. Ippolito, J. A., Bjorneberg, D., Stott, D., and Karlen, D. (2017). Soil quality improvement through conversion to sprinkler irrigation. *Soil Science Society of America Journal*, 81(6), 1505-1516.
 6. Costa, C. F., Melo, P. C., Guerra, H. P., and Ragassi, C. F. (2017). Soil properties and agronomic attributes of potato grown under deep tillage in succession of grass species. *Horticultura Brasileira*, 35, 75-81.
 7. Narayanamoorthy, A., Bhattarai, M., and Jothi, P. (2018). An assessment of the economic impact of drip irrigation in vegetable production in India. *Agricultural Economics Research Review*, 31(1), 105-112.
 8. Elzner, P., Jůzl, M., and Kasal, P. (2018). Effect of different drip irrigation regimes on tuber and starch yield of potatoes. *Plant, Soil and Environment*, 64(11), 546.
 9. Akram, M. M., Asif, M., Rasheed, S., and Rafique, M. A. (2020). Effect of drip and furrow irrigation on yield, water productivity and economics of potato (*Solanum tuberosum* L.) grown under semiarid conditions. *Science Letters*, 8(2), 48-54.
 10. D'Amelia, V., Sarais, G., Fais, G., Dessì, D., Giannini, V., Garramone, R., ... and Melito, S. (2022). Biochemical characterization and effects of cooking methods on main phytochemicals of red and purple potato tubers, a natural functional food. *Foods*, 11(3), 384.
 11. Qiang, X., Sun, J., and Ning, H. (2022). Impact of subsoiling on cultivated horizon construction and grain yield of winter wheat in the north China plain. *Agriculture*, 12(2), 236.
 12. Ogundeji, A. A. (2022). Adaptation to climate change and impact on smallholder farmers' food security in South Africa. *Agriculture*, 12(5), 589.
 13. Burger, D., Bauke, S., Schneider, F., Kappenberg, A., and Gocke, M. (2024). Root-derived carbon stocks in formerly deep-ploughed soils—A biomarker-based approach. *Organic Geochemistry*, 104756.