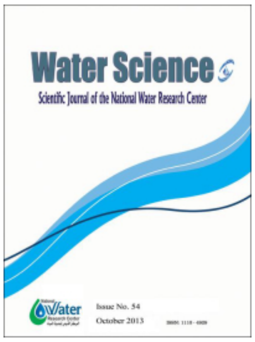


Water Science

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/twas20

Water productivity of barley crop under laser land leveling technique and minimum tillage

N. E. Mansour, Ayman El-Sayed, D. M. Sabra, S. M. A. Nassar, B. A. Bakry, R. E. Abdelraouf & R. Ragab

To cite this article: N. E. Mansour, Ayman El-Sayed, D. M. Sabra, S. M. A. Nassar, B. A. Bakry, R. E. Abdelraouf & R. Ragab (2023) Water productivity of barley crop under laser land leveling technique and minimum tillage, Water Science, 37:1, 458-471, DOI: 10.1080/23570008.2023.2290936

To link to this article: https://doi.org/10.1080/23570008.2023.2290936

Published online: 06 Dec 2023.

WATER SCIENCE
2023, VOL. 37, NO. 1, 458–471
https://doi.org/10.1080/23570008.2023.2290936

Water productivity of barley crop under laser land leveling technique and minimum tillage

N. E. Mansour[a], Ayman El-Sayed [b], D. M. Sabra[c], S. M. A. Nassar[d], B. A. Bakry[c], R. E. Abdelraouf[e] and R. Ragab[f]

[a]Agricultural and Natural Resources Engineering, Department of Agricultural Engineering Faculty, Damanhour University, Damanhour, Egypt; [b]National Water Research Center, Drainage Research Institute, El-Qanater, El-Khayreya, Egypt; [c]Department of Field Crops Research, Agricultural and Biological Research Institute, National Research Centre, Dokki, Cairo, Egypt; [d]Plant Genetic Resources Dept, Desert Research Center, El-Matarya, Cairo, Egypt; [e]Water Relation and Field Irrigation Department Agricultural and Biological Research Institute, National Research Centre, Damanhour, Egypt; [f]UK Centre for Ecology and Hydrology, UKCEH, UK

ABSTRACT

Laser land leveling is an important method that helps to improve the spatial distribution of irrigation water and fertilizers applications, subsequently reduce water, nutrient, and energy inputs to agriculture and contributes to increasing productivity. Thus, the aim of the study was to improve the productivity of the barley crop grown in sandy lands under conditions of water scarcity and the negative impact of climate change in Egypt by using laser leveling and the minimum tillage method. Two experiments were conducted during the 2020/2021 and 2021/2022 seasons at the Nubariya farm, Buhaira Governorate, Egypt to study the effects of laser leveling and minimum tillage (zero – tillage, 10 cm, 20 cm, and 30 cm) affecting the distribution of soil moisture, water stress, effectiveness of water application, yield characteristics, water productivity, and some quality parameters of the barley crop. The statistical analysis' findings revealed a considerable influence of both laser soil leveling and minimum depth of plowing on productivity, water productivity and quality properties of barley crop. Laser leveling with a plowing depth of 10 cm gave the most favorable values of the soil moisture content at the root-zone as well as better grain yield and water productivity in addition to improve the quality properties of barley. The grain yield has improved by 12.65% and 10.41%, while water productivity has increased by 12.75% and 10.06% during the seasons 2020/2021 and 2021/2022, respectively. This increase is likely the result of improving soil moisture distribution and increasing irrigation application efficiency, which resulted in less water stress in the root zone and subsequently increased yield, water productivity and quality properties of barley during the two growing seasons. Generally, the application of laser land leveling as eco-friendly practice will help in sustaining barley productivity in Egypt particularly in the sandy soil regions. According to this study, laser-assisted precision field leveling has the potential to improve grain yield and crop establishment, water productivity and barley quality properties in addition to achievement of the highest net income for farmers.

ARTICLE HISTORY
Received 8 July 2023
Revised 25 November 2023
Accepted 29 November 2023

KEYWORDS
Laser soil leveling; tillage depths; water stress; water application efficiency; barley

Introduction

There is substantial stress and demand on the agriculture sector to reduce its fresh water consumption for irrigation in arid and semi-arid nations with rapid population increase and scarce fresh water resources (Abdelraouf, El-Shawadfy, Ghoname, & Ragab, 2020a). The importance and necessity of reducing irrigation water consumption through the development and improvement of new and innovative technologies is underscored by the fact that water scarcity and shortage are one of the most significant and critical issues affecting crop cultivation and production in Egypt (Abdelraouf, Refaie, & Hegab, 2013; El-Metwally et al., 2015). Due to the Arab Republic of Egypt's limited water supplies and infrequent rainfall, the water productivity of crops is very essential (Hozayn, Abd El-Wahed, Abd El-Monem, Abdelraouf, & Ebtihal, 2018). Application of contemporary irrigation techniques and related technology is crucial for arid and semi-arid areas (Abdelraouf, Abou-Hussein, Abd-Alla, & Abdallah, 2012; El-Habbasha, Okasha, Abdelraouf, & Mohammed, 2014).

A significant grain of cereal crops, barley (Hordeum vulgare, L.) is farmed all over the world in temperate climates. After maize, wheat, and rice, it is considered to be the fourth most significant cereal crop in the world (FAO, 2016). According to (Lakshmi, Shephalika, & Banisetti), barley is one of the crops that can withstand harsh environmental circumstances the best. The primary uses of barley are as a food source, animal feed, and a primary ingredient in the creation of beer (Pour-Aboughadareh, Naghavi, & Khalili, 2013).

Sandy soils predominate in most newly reclaimed areas of Egypt. These soils have very low soil fertility as

CONTACT Ayman El-Sayed aymanawad1@yahoo.com National Water Research Center, Drainage Research Institute, P.O. Box 13621/5, El-Qanater El-Khayreya, Egypt

well as poor capacity for retaining nutrients and water. However, the use of the proper mineral fertilization management might help in making its cultivation possible and profitable (Safina, 2010).

Laser land leveling (LLL) is a method that helps to produce even land surfaces, reducing the spatial surface heterogeneity and micro-topography. Subsequently, leading to a more uniform land surfaces for a more uniform water and fertilizers distribution across the field. The outcome is a reduction in water, nutrient, and energy input and enhancing farmers income as a result of the reduction in costs and improving in crop productivity (Shahani, Kaiwen, & Memon, 2016). The utilization of irrigation water is inefficient when fields are uneven. For the efficient use of limited irrigation water, proper field leveling is necessary. The main issues for producing high-quality seeds include poor irrigation water quality, uneven terrain, and declining soil health. In order to produce enough high-quality seeds, it is crucial to use precise land leveling techniques and control irrigation water usage effectively. By removing unneeded depressions and higher contours, land leveling promotes uniformity and the efficient use of precious water resources (Katiyar, Uttam, & Devendra, 2021; Naresh et al., 2012). Poor farm design and uneven fields have been observed to be the cause of 30% of water losses (Asif, Ahmed, Gafool, & Aslam, 2003).

Traditional techniques of leveling land are more time-consuming, labor-intensive, and expensive. One of the best tools for precisely leveling and smoothing the surface of agricultural land is a laser land leveler. With laser leveling, the blade is automatically raised and lowered in response to the land's microtopography using a laser guidance system. In addition to lowering leveling costs, laser land leveling also ensures the correct level of precision and lessens the amount of work required for planting and managing crops.

With a sufficient decrease in water use, laser leveling could shorten the duration of irrigation by up to 20–25% (Shahani, Kaiwen, & Memon, 2016). According to Bhatt and Sharma (2009), this method could save between 25 and 30 percent of irrigation water without having a negative impact on crop productivity. It boosts water use efficiency, lowers weeds, improves production, and makes crops mature more uniformly. Less water is also required for field preparation. When used for different crops and cropping patterns, laser land leveling has led to water savings of up to 15–30% (Abdelraouf, Mehana, Sabreen, & Bakry, 2014).

Traditional mechanical plowing has an impact on the physical characteristics of the soil, which are crucial for supplying nutrients to the plant and regulating soil air and moisture regimes (Kouwenhoven, Perdok, Boer, & Oomen, 2002). Increased soil organic matter is a hallmark of soil condition changes brought on by crop residue deposition on the surface under traditional conservation tillage (López-Fando & Pardo, 2009). The availability of nutrients increases as the top soil surface layer's organic matter content gradually rises (Fernández, Fernández, Cervera, & Torres, 2007). According to Mohamed (2017), tillage practises have an impact on physical soil attributes such as bulk density and moisture content, and it is required to alter the environment to produce the best circumstances for improving crop yield. Additionally, it has been demonstrated that using conservation tillage, such as direct planting, which reduces plowing depth and frequency, reduces energy use and enhances soil water retention (Evans, Stevens, & Iversen, 2010).

One such tested technique that is very helpful in preserving irrigation water and increasing crop output is land leveling with a laser leveler. In light of this, this study was conducted with the aim of evaluating the influence of a laser soil leveling technique with little tillage on increasing barley productivity in semi-arid climate regions like Egypt and areas with sandy soil.

Materials and methods

The research location and irrigation system

The field tests were carried out at the experimental at the El-Nubaria farm, in the Al-Buhayrah governorate, north of Egypt, during the two barley growing seasons 2020–2021 and 2021–2022 (Figure 1). The farm is located at 30° 30'1.4"'N, 30° 9' 10.9"' E, and has a mean elevation of +21 m. The ground water level in the study area is approximately 6 meters. The experimental area experiences warm winters and hot, dry summers due to its semi-arid climate. The local weather station at El-Nubaria Farm provided the information on maximum and minimum temperatures, relative humidity, and wind speed (Table 1).

The sprinkler irrigation system components

The irrigation system used was a fixed sprinkler system. The irrigation system consisted of a centrifugal pump with a 45 m^3/h discharge rate, a screen filter and a backflow prevention device, a pressure regulator, pressure gauges, control valves, and a flow meter. The water was transported from the source to the primary control sites in the field through the main line, a 110 mm-diameter PVC pipe. PVC pipes with a 75 mm OD made up the sub-main lines that joined the main line. The sub-main line, control valves, and discharge gauges were connected to manifold lines composed of polyethylene (PE) pipes with a 63 mm outside diameter. The sprinkler had a 3/4" diameter,

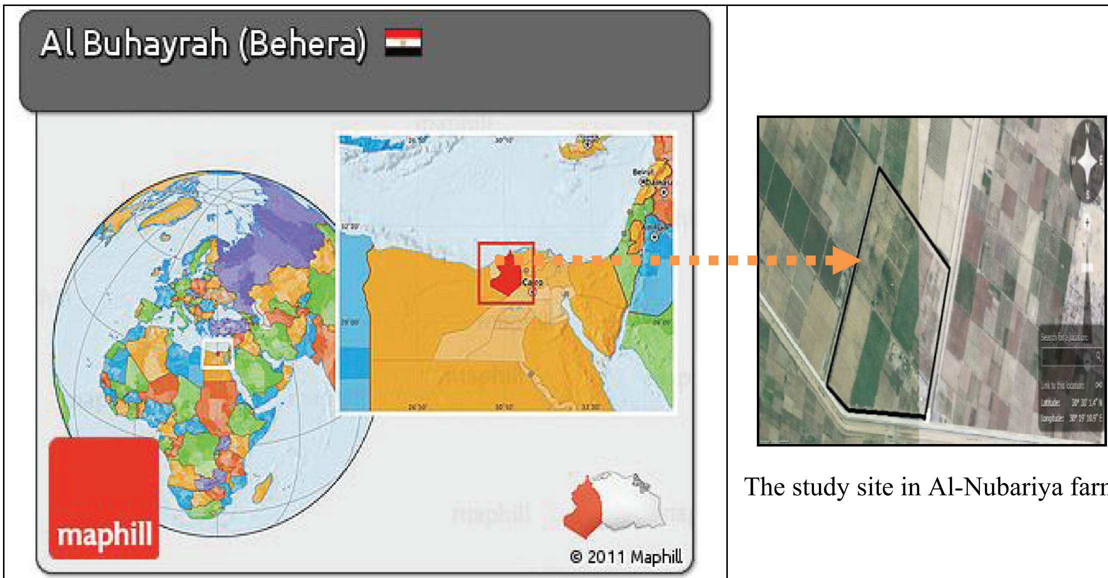


Figure 1. The research location in Egypt's al buhayrah governorate.

Table 1. Part of the climate data of the study site (monthly average of two seasons 2020/2021 and 2021/2022).

Month	Tmax	Tmin	RH	Wind	Rain 2020/2021	Rain 2021/2022
November	25.25	12.28	59.38	3.43	2.50	3.10
December	21.86	11.42	65.61	3.57	5.70	6.60
January	18.69	6.98	66.01	3.48	19.60	20.40
February	22.12	7.39	61.58	3.65	16.40	19.40
March	25.18	11.27	52.64	4.28	7.44	8.00
April	28.52	12.63	45.59	4.39	0.00	0.00

Tmax: maximum air temperature (°C), Tmin: minimum air temperature (°C), Wind: wind speed (m/s), RH: average relative humidity (%), Rain: average precipitation (mm/day).

a 1.18 m^3/h discharge rate, a 12 m wetted radius, and a 250 kPa working pressure.

The soil's physical and chemical composition, as well as the irrigation water's

The pH of the soil is 7.7, the salinity is 1.67 dS m^{-1} reported as electric conductivity (EC), and the organic matter content in the top 30 cm of the soil is 0.41%. The soil texture is sandy (85.4% sand, 9.5% silt, and 5.1% clay). The amounts of extractable Fe, Mn, and Zn were 2.99, 1.75, and 0.67 mg/kg soil, respectively, while the amounts of available soil N, P, and K were 17.2, 4.3, and 25 mg/kg soil, respectively. Table 2 displays the chemical properties of irrigation water.

Experimental design

A split-plot design with three replications was used for the experimental design and treatments.

Table 2. The chemical characteristics of the irrigation water.

	Cations and anions (mg/l)									
	Anions				Cations				EC	
SAR	SO_4^-	Cl^-	HCO_3^-	$CO3^-$	K^+	Na^+	Mg^{++}	Ca^{++}	(dSm^{-1})	pH
2.7	1.45	1.72	1.11	0.73	0.32	2.6	0.66	1.43	0.42	7.15

EC = Electrical Conductivity SAR = Sodium Adsorption Ratio.

Laser land leveling | Adjustment the depths of tillage

Figure 2. The equipment's used in the laser leveling process and the tillage.

Soil leveling methods (Laser soil leveling, "LL," and without soil leveling, "WL") were used in the main plots, while tillage depths (zero tillage, 0 cm depth, "D0," 10 cm depth, "D10," 20 cm depth, "D20," and 30 cm depth, "D30") were used in the sub main plots. Figure 2 shows the equipment used in the laser leveling process and plowing.

Experimental unit area

An area in the research farm in the Nubaria region was allocated to the experiment for growing barley under the sprinkler irrigation system. The total area allocated for the implementation of the experimental design was 5760 m^2. The area was divided into two parts to allow for the two land leveling methods to be implemented. The main unit of irrigation treatment amounted to 2880 m^2. This main unit was divided into four experimental subunits for minimum tillage depths, where the sub-main units were 720 m^2. This unit was divided into three replicates, where the area of each replica was 240 m^2. The crop was barley (Giza 123 variety) irrigated by sprinkler irrigation system and the irrigation was scheduled every three days.

Barley irrigation requirements

According to Allen, Pereira, Raes, and Smith (1998), the crop coefficient (Kc) and Penman-Monteith equation were used to compute the daily irrigation water requirements. The volume of irrigation water applied for seasons 2020/2021 and 2021/2022 was calculated using Equation 1 and amounted to 2620 m^3 ha^{-1}/season for 2020/2021 and 2600 m^3 ha^{-1}/season for 2021/2022. Barley was sown on the 20th of November and the harvested on 15th of April in both seasons.

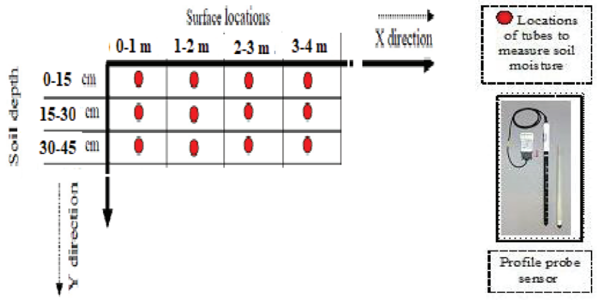
$$IRg = [ET_O \text{ x } Kc]/Ei - R + LR \quad (1)$$

Where Kc = crop factor (Allen, Pereira, Raes, & Smith, 1998), Ei = irrigation efficiency (assumed 80%), R, mm rainfall and ET_O = reference evapotranspiration, mm/day (estimated from the Central Laboratory for Climate – Agricultural Research Centre Egyptian Ministry of Agriculture at El-Nubaria farm and according to Penman-Montei; The amount of water needed for salt leaching was determined as the ratio of irrigation water salinity to drainage water salinity, or LR, mm. There was a three-day interval between irrigations. The Table 3 contains all the details of estimating and calculating the volumes of irrigation water added during the two growing seasons.

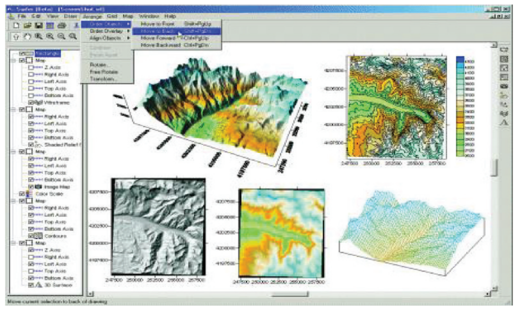
Table 3. Details of estimating and calculating the volumes of irrigation water added during the two growing seasons.

	2020/2021				2021/2022			
	Init. stage	Dev. stage	Mid. stage	late stage	Init. stage	Dev. stage	Mid. stage	late stage
$ET_{O,}$ mm/day	4.65	1.71	1.51	2.11	4.63	1.72	1.55	2.14
Kc (FAO 56)	0.33	0.74	1.15	0.72	0.33	0.74	1.15	0.72
Ei,%	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
R, mm/day	0.08	0.19	0.60	0.25	0.10	0.22	0.66	0.27
LR, mm/day	0.21	0.16	0.18	0.18	0.20	0.15	0.17	0.18
IRg, mm/day	2.05	1.55	1.75	1.83	2.01	1.52	1.74	1.84
Days of each age stage (FAO 56)	22	33	57	36	22	33	57	36
IRg, mm/stage	45.10	51.15	99.75	65.88	44.22	50.16	99.18	66.24
IRg, mm/season	262				260			
IRg, m^3/ha/season	2620				2600			
$IRg = [ET_O \text{ x } Kc]/Ei - R + LR$								
Irrigation water added at each tillage level (m^3/ha/season)	2620				2600			

ETo: reference evapotranspiration, Kc: crop coefficient, Ei: irrigation efficiency, R: Rainfall, LR: the ratio of irrigation water salinity to drainage water salinity, IRg: Gross Irrigation Requirement.



Soil moisture content measuring sites



Surfer 13 Golden software program

Figure 3. Contouring map of moisture levels for all treatments under study.

Evaluation parameters

Contouring maps of soil moisture distribution

Two hours after watering, soil moisture content was measured using a profile probe instrument to determine the distribution of soil moisture and at different locations. The locations were measured at 0 (Sprinkler holder)-100, 100–200, 200–300 and 300–400 cm on the horizontal "X" direction and at soil depths of 0 (soil surface)-15, 15–30 and 30–45 cm on the horizontal "Y" direction. By using Surfer 13 Golden software program, the contouring map for soil moisture levels of all treatments can be obtained as shown in Figure 3.

Water stress in the root zone

Before every watering during the growing season, soil moisture in the root zone was assessed. Maximum available total water is determined as the difference between the soil moisture content at field capacity and wilting point. Water stress (WS) is calculated as a ratio of the current water availability (difference between current soil moisture and wilting point soil moisture) and maximum water availability (Abdelraouf *et al.*, 2020a; 2020b).

Irrigation application efficiency

The ratio of actual water retained in the root zone to irrigation water applied to the field is known as irrigation application efficiency (IAE). Equation 2 was used to calculate the IAE:

$$\mathrm{IAE} = (\mathrm{Ds}/\mathrm{Da})\ \mathrm{x}\ 100 \qquad (2)$$

Where IAE is the water application efficiency, %, Da is the depth of applied water (mm), and Ds is the depth of retained water in the root zone (mm).

Ds is calculated by equation 3

$$\mathrm{Ds} = (\theta 1 - \theta 2)\ \mathrm{x}\ \mathrm{d}\ \mathrm{x}\ \rho \qquad (3)$$

Where d is the depth of the soil layer (in millimeters), θ1 is the average soil moisture content in the root zone following irrigation, θ2 is the average soil moisture content in the root zone prior to irrigation, and is the bulk soil density (in grammes per cubic centimeter). IAE is measured at peak of irrigation requirement for barley.

Yield component of barley

At harvest, ten plants from each plot from the two middle rows were randomly selected to measure plant height (cm), spike length (cm), and the number of spikes/m^2.

Grain yield of barley

Grain, straw, and yield were measured from a random section of each plot measuring 5 m by 4 m, and the results were converted to yield per hectare. The harvest index was determined as the grain yield to total dry matter yield ratio.

Water productivity of barley "WP $_{Barley}$"

James (1988) computed the water productivity of barley as follows:

$$\mathrm{WP}_{\mathrm{Barley}} = \mathrm{Ey}/\mathrm{IRg} \qquad (4)$$

In this equation, WP Barley is water productivity (kg Barley m-3 water), Ey is the economic/marketable yield (kg $_{\mathrm{Barley}}$/ha), and IRg is the amount of irrigation water applied ($m^3{}_{\mathrm{water}}$/ha/season).

Quality of barley

Some of quality traits of grain barley were estimated (content of protein, carbohydrates and fibers per 100 gm of grain barley). The analysis of the samples' total nitrogen (TN) content, which was ascertained using a standardized procedure (such as Kjeldahl's method), was used to determine the protein concentration. Equation (5) was used to calculate the total crude protein (TCP) by multiplying the TN content of grains by 6.25.

$$\text{Proteins content, \%} = \text{N-content x } 6.25 \qquad (5)$$

Economic evaluation

Net income was determined according to Rizk (2007) as:

Net income; "NI" – Total income – Total costs (6)

Statistical analysis

According to Snedecor and Cochran (1982), combined data analysis for the two examined growing seasons was performed, and the values of least significant differences (L.S.D. at 5% level) were determined to compare the means of the various treatments.

Results and discussion

Contouring maps of soil moisture distribution

Due to increased resistivity and lower water potential, moisture content is the primary factor that determines how susceptible soil is to compaction (Dekemati, Simon, Vinogradov, & Birkás, 2019). The soil compaction has a negative impact on seed germination and roots development.

Figure 4 shows the effective and positive effect of laser leveling on the moisture distribution compared to the moisture distribution in the case of no leveling. The figure shows the extent of the effect of plowing depth on the moisture distribution within the rooted area. The best soil moisture distribution was achieved with laser leveling, accompanied by the least water stress and was associated with the plowing depth of 10 cm, as well as zero plowing, compared to the rest of the other plowing depths. The increased plowing depth led to poor moisture distribution associated with increased water stress.

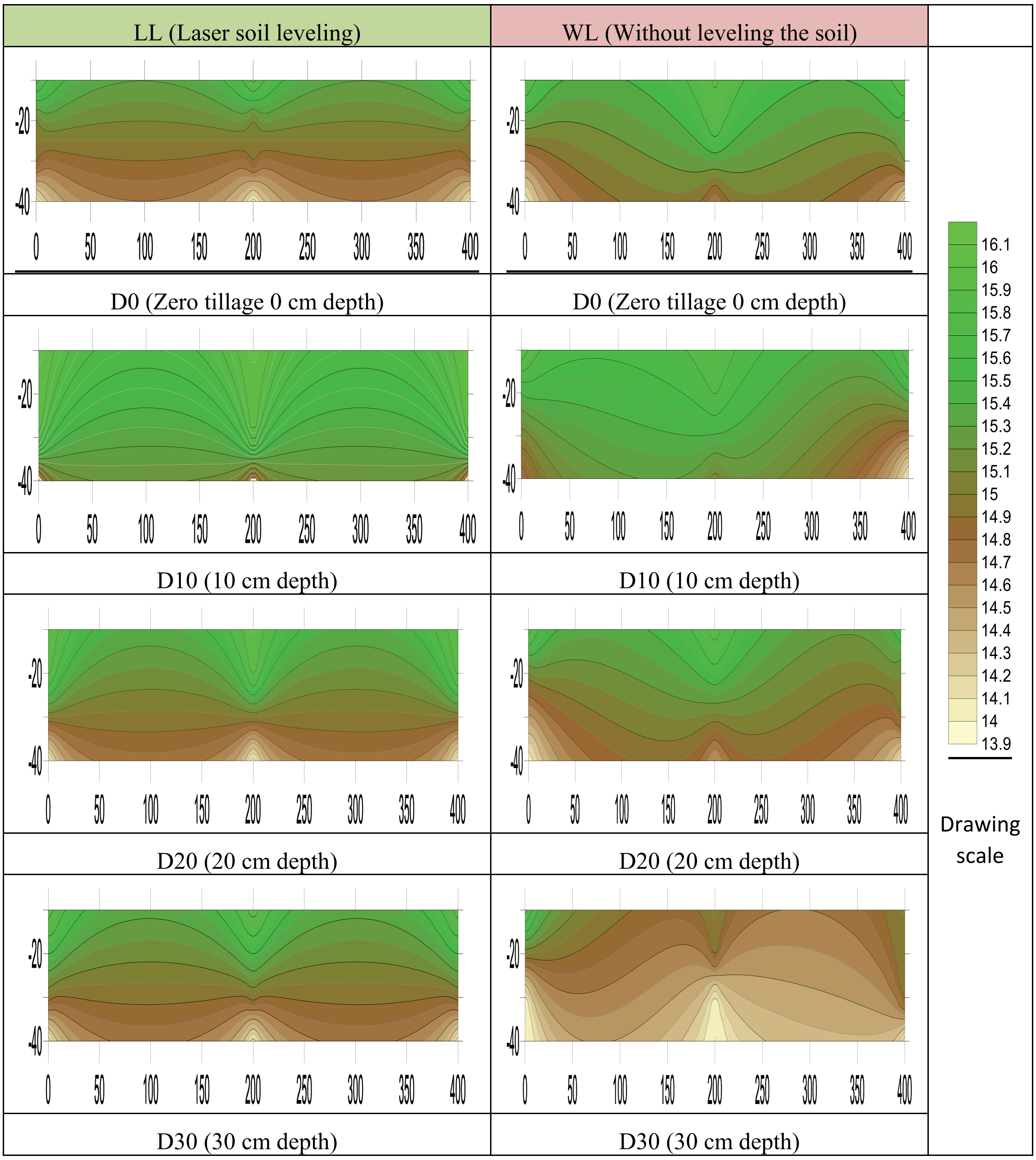


Figure 4. Contouring maps of soil moisture distribution with laser leveling methods and tillage depths. [(laser soil leveling "LL" and without leveling the soil "WL"), (zero tillage = 0 cm depth "D0," 10 cm depth "D10," 20 cm depth "D20" and 30 cm depth "D30")], [the locations were measured at 0 (sprinkler holder)-100, 100–200, 200–300 and 300–400 cm on the horizontal "X" direction and at soil depths of 0 (soil surface)-15, 15–30 and 30–45 cm on the horizontal "Y" direction.].

The best moisture distribution was achieved with laser leveling and at a plowing depth of 10 cm. This was because the lowest depth of plowing resulted in limiting deep percolation beyond the root zone, subsequently leading to an increase in the horizontal water movement compared to the vertical water movement. This was reflected positively on the volume of wet soil within the root zone, and in the reduction of water stress within the root zone. These results agree with the concepts reported previously by Molden, Murray-Rust, Sakthivadivel, and Makin (2003).

Shah et al. (2017) claim that a decrease in total soil porosity causes an increase in soil moisture content. As pore space shrinks due to compaction, water cannot travel freely through the soil profile and cannot percolate through the root zone to deeper soil layers (Dexter, 2004).

Water stress inside the root zone

In agriculture, several attempts were made to substitute the energy-intensive plowing with more simplified less energy-consuming tillage practice (Orzech, Orzech, & Załuski, 2020).

There was a clear significant effect of laser leveling and the depth of plowing on the water stress that the roots of the growing barley were exposed to. The moisture content values were measured for all treatments under study before each irrigation from the beginning of the growing season until the last irrigation, and all values were collected. The average for each treatment was then calculated.

Figure 5 demonstrates that the values of moisture content when leveling the soil with laser are higher than the values of no leveling treatment. The values of moisture content at a plowing depth of 10 cm are slightly higher than the values of no plowing treatment, while the difference in moisture content values becomes less significant with increasing plowing depth.

The highest values of soil moisture, which were accompanied by the lowest water stress experienced by the roots, were obtained from laser leveling with a plowing depth of 10 cm.

Intensive tillage, according to Shah et al. (2017), causes higher soil compaction, which inhibits plant development, root water uptake, and soil productivity. In the early phases of plant growth, conventional tillage reduces soil bulk density and enhances soil porosity. According to Małecka, Blecharczyk, Sawinska, Piechota, and Waniorek (2012), using a stubble cultivator in place of a traditional plow considerably enhanced the moisture content of soil at depths of 0–10 cm and 10–20 cm. Numerous researchers claim that switching from conventional to zero tillage enhanced soil moisture content while lowering topsoil's capillary water capacity (Boydaş & Turgut, 2007).

Irrigation application efficiency

When studying the effect of laser soil leveling and the depth of plowing on the efficiency of the applied irrigation water to the soil, it was found that there is a significant effect on the values of the irrigation application efficiency.

Figure 6 shows that the values of irrigation application efficiency with laser leveling were higher than the values obtained with no leveling. Figure 6 also shows that with the depth of plowing, the irrigation application efficiency values were at their highest when the plowing depth was 10 cm, followed by low values when there was no tillage.

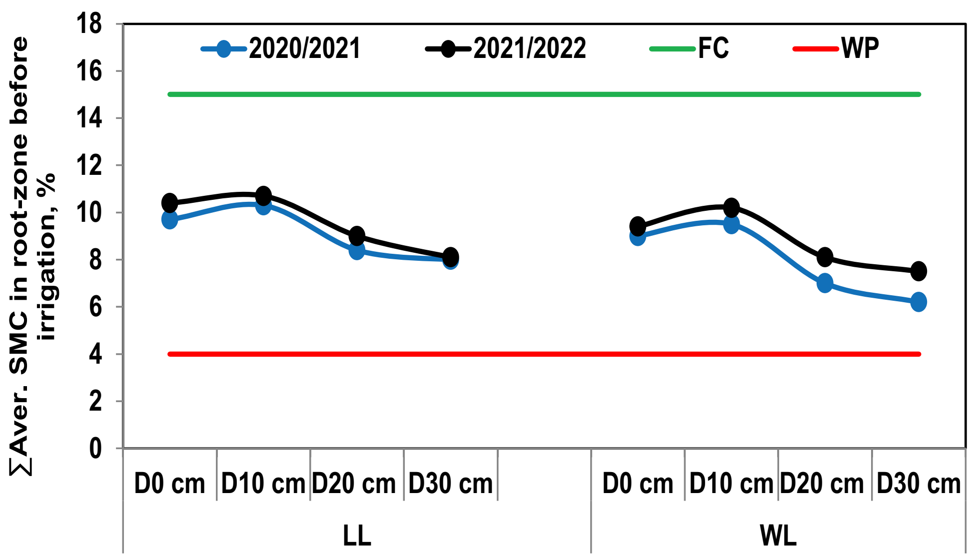


Figure 5. Effect of soil leveling methods and tillage depths on the water stress (average of soil moisture content "SMC" in root zone before irrigation) of barley roots. [(laser soil leveling "LL" and without leveling the soil "WL"), (zero tillage = 0 cm depth "D0," 10 cm depth "D10," 20 cm depth "D20" and 30 cm depth "D30")].

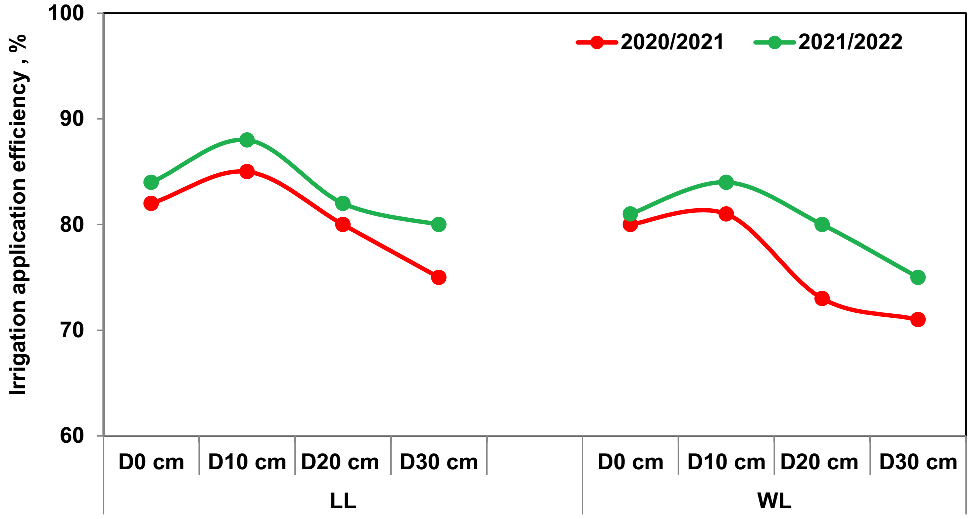


Figure 6. Effect of soil leveling methods and tillage depths on the irrigation application efficiency. [(laser soil leveling “LL” and without leveling the soil “WL”), (zero tillage = 0 cm depth “D0,” 10 cm depth “D10,” 20 cm depth “D20” and 30 cm depth “D30”)].

From Figure 6 it is clear that the highest values of the irrigation application efficiency were obtained when the soil was leveled by laser with depth of plowing of 10 cm. This treatment led to an increase in the horizontal water movement relative to the vertical water movement, which subsequently led to an increase in the volume of wet soil of the root zone. These conditions have led to an increase in the values of the irrigation application efficiency of this treatment compared to the other treatments.

Yield and yield components of barley

The yield and yield components of barley were strongly impacted by the laser leveling and plowing (Table 4 and Figure 7). The maximum plant height was recorded in the laser-leveled field, with the lowest depth of plowing at 10 cm, compared to the minimum in the unleveled field. A small yet noticeable difference was noted for both spike length and number of spikes/m^2 in the case of laser leveling with a plowing depth of 10 cm.

Laser land leveling with a plowing depth of 10 cm produced maximum grain yield values of 4.39 and 4.56 t ha^{-1} in the 2020/21 and 2021/22 growing seasons, respectively, compared with the other plowing depths as the increased plowing depth led to a poor moisture distribution, which is associated with increased water stress. Significantly higher grain yield over a laser leveled field with a plowing depth of 10 cm might be attributed to better development of yield components like a higher number of spikes/m^2, high spike length,

Table 4. Effect of tillage depths and soil leveling techniques on the components of barley yield.

		Plant height, cm		Spike length, cm		No. of spikes/m^2	
Soil leveling methods	Tillage depth, cm	2020/21	2021/22	2020/21	2021/22	2020/21	2021/22
Effect of soil leveling methods on the yield components of barley							
LL		86.59	87.42	10.95	10.74	363.43	367.55
WL		82.95	84.10	10.67	10.53	358.48	357.48
LSD at 5%		1.91	2.04	0.34	0.42	3.00	3.40
Effect of tillage depths on the yield components of barley							
	D0	86.34	87.37	11.02	11.07	366.13	368.63
	D10	87.99	88.29	11.38	11.01	369.19	370.82
	D20	84.10	84.97	10.80	10.45	356.39	358.03
	D30	80.65	82.41	10.05	10.02	352.11	352.59
LSD at 5%		1.01	1.13	0.26	0.27	2.10	2.20
Effect of soil leveling methods and tillage depths on the yield components of barley							
LL	D0	87.88	88.86	11.20	11.07	368.63	372.00
	D10	89.02	89.24	11.46	11.26	372.50	374.97
	D20	86.14	87.25	10.84	10.53	357.10	364.93
	D30	83.30	84.31	10.30	10.11	355.47	358.30
WL	D0	84.79	85.87	10.84	11.07	363.63	365.25
	D10	86.90	87.03	11.09	10.75	365.87	366.67
	D20	82.05	82.68	10.76	10.37	355.67	351.12
	D30	78.00	80.51	9.80	9.93	348.74	346.88
LSD at 5%		1.79	2.00	0.31	N.S	2.80	N.S

[(Laser soil leveling “LL” and without leveling the soil “WL”), (zero tillage = 0 cm depth “D0,” 10 cm depth “D10,” 20 cm depth “D20” and 30 cm depth “D30”)].

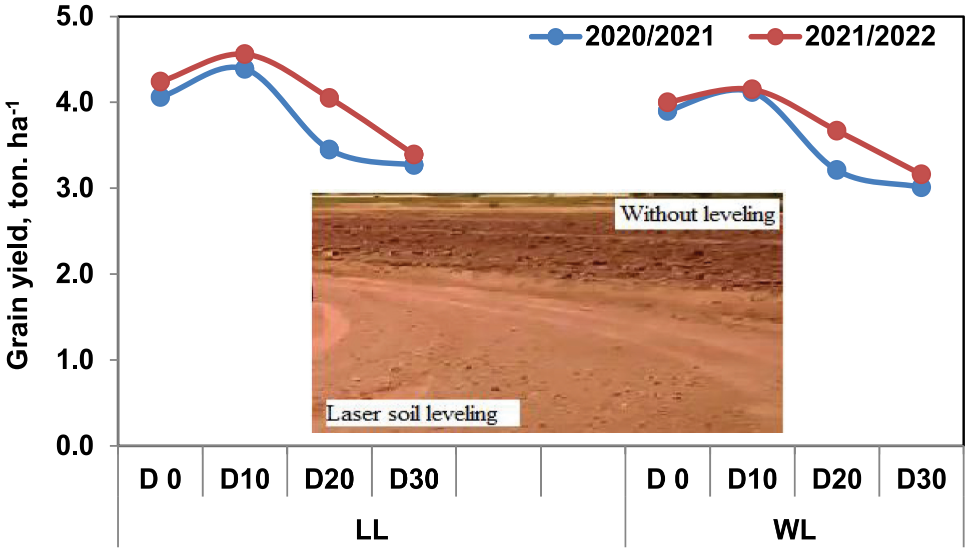


Figure 7. Effect of soil leveling methods and tillage depths on the grain yield of barley crop. [(laser soil leveling "LL" and without leveling the soil "WL"), (zero tillage = 0 cm depth "D0," 10 cm depth "D10," 20 cm depth "D20" and 30 cm depth "D30")].

and more dry matter yield due to the more efficient use of inputs, and uniform availability of soil moisture in the root zone of the crop.

The reason for lower grain yield in either an unleveled field or a long plowing depth of more than 10 cm might be the uneven distribution of water and fertilizers/nutrient availability over the field, which drastically reduced the yield and yield components in lower and elevated spots.

The results of the statistical analysis showed that there is a significant effect of both laser soil leveling and minimum depth of plowing on grain yield. Laser leveling with a plowing depth of 10 cm gave the most favorable values of the soil moisture content at the root-zone as well as better grain yield. The grain yield has improved by 12.65% and 10.41% during the seasons 2020/2021 and 2021/2022, respectively. This increase is likely to be the result of improving soil moisture distribution and increasing irrigation application efficiency, which led to a decrease in water stress within the root-zone and subsequently increased yield, water productivity and quality properties of barley during the two growing seasons.

Water productivity of barley

Land leveling and plowing depth techniques had a significant impact on the water productivity of the

Table 5. Effect of soil leveling methods and tillage depths on the total dry matter, straw, grain yield and water productivity of barley.

Soil leveling methods	Tillage depth, (cm)	Total dry matter yield, ton/ha 2020/21	Total dry matter yield, ton/ha 2021/22	Straw yield, ton/ha 2020/21	Straw yield, ton/ha 2021/22	Grain yield, ton/ha 2020/21	Grain yield, ton/ha 2021/22	Water productivity, kg/m^3 2020/21	Water productivity, kg/m^3 2021/22
Effect of soil leveling methods on the total dry matter, straw, grain yield and water productivity of barley									
LL		12.31	12.48	8.52	8.42	3.79	4.06	1.45	1.56
WL		11.85	12.23	8.29	8.38	3.56	3.85	1.36	1.48
LSD at 5%		0.23	0.23	0.27	0.27	0.06	0.06	0.06	0.06
Effect of tillage depths on the total dry matter, straw, grain yield and water productivity of barley									
	D 0	12.30	12.56	8.32	8.37	3.98	4.19	1.52	1.61
	D10	12.49	12.76	8.23	8.26	4.26	4.51	1.63	1.73
	D20	11.88	12.27	8.55	8.42	3.33	3.86	1.28	1.49
	D30	11.67	11.82	8.53	8.55	3.14	3.28	1.2	1.26
LSD at 5%		0.18	0.18	0.19	0.19	0.05	0.05	0.05	0.03
Effect of soil leveling methods and tillage depths on the total dry matter, straw, grain yield and water productivity of barley									
LL	D 0	12.37	12.64	8.31	8.39	4.06	4.24	1.55	1.63
	D10	12.57	12.72	8.18	8.16	4.39	4.56	1.68	1.75
	D20	12.33	12.40	8.88	8.35	3.45	4.05	1.32	1.56
	D30	11.98	12.14	8.71	8.76	3.27	3.39	1.25	1.30
WL	D 0	12.23	12.47	8.32	8.34	3.90	4.00	1.49	1.59
	D10	12.40	12.80	8.28	8.35	4.12	4.15	1.57	1.71
	D20	11.42	12.14	8.21	8.48	3.21	3.67	1.23	1.41
	D30	11.35	11.49	8.34	8.33	3.01	3.16	1.15	1.22
LSD at 5%		0.30	0.30	0.33	0.32	0.08	0.08		

[(Laser soil leveling "LL" and without leveling the soil "WL"), (zero tillage = 0 cm depth "D0," 10 cm depth "D10," 20 cm depth "D20" and 30 cm depth "D30")].

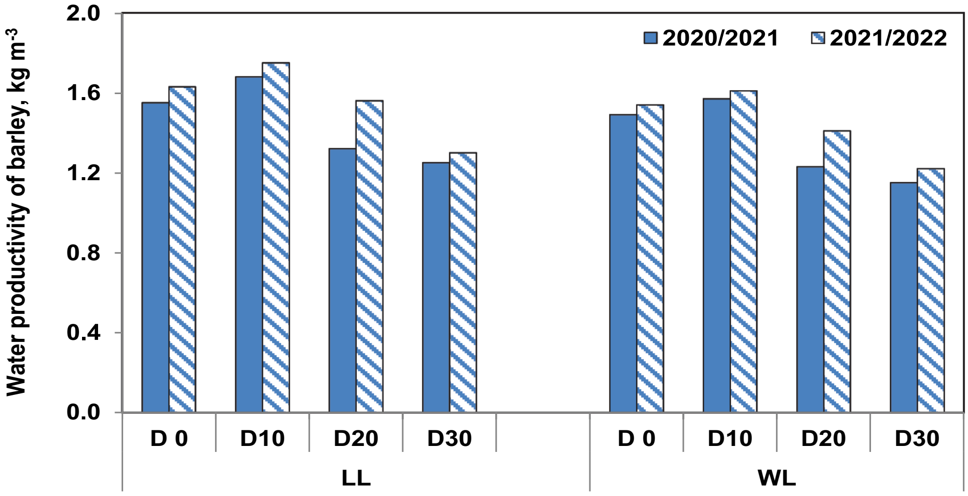


Figure 8. Effect of soil leveling methods and tillage depths on the water productivity of barley crop. [(laser soil leveling "LL" and without leveling the soil "WL"), (zero tillage = 0 cm depth "D0," 10 cm depth "D10," 20 cm depth "D20" and 30 cm depth "D30")].

barley crop (Table 5 and Figure 8, 9). When compared to the unleveled field, laser leveling resulted in higher water productivity of the barley crop, whereas laser leveling gave estimated values of water productivity of 1.45 and 1.56 kg/m^3, compared to without leveling, which gave values of 1.36 and 1.48 kg/m^3 in the 2020/21 and 2021/22 growing seasons, respectively.

In case of the plowing depth, the highest values were found in the case of the 10 cm plowing depth compared to the other plowing depths. The estimated values in the case of 10 cm plowing depth were 1.63 and 1.73 kg/m^3 in the 2020/21 and 2021/22 growing seasons, respectively.

Regarding the laser leveling and non-leveling with different plowing depths, the highest values were recorded in the laser leveling with a 10 cm plowing depth, where the values were 1.68 and 1.75 kg/m^3 in the 2020/21 and 2021/22 growing seasons, respectively.

Thus, in the light of this study, it is imperative to recommend that laser land leveling should be popularized among the farmers as it not only increases water use efficiency and yield but also ensures better germination, better utilization of water and nutrients inputs.

The findings revealed that there were variations in the productivity of the water, as illustrated in Figure 8 and Table 5. Increased water application to uneven fields was associated with lower water productivity and lower grain yield. The crop's vulnerability to water stress or deficit, a feature of uneven field surfaces, was also demonstrated by the decline in water productivity in unleveled fields. The ineffective utilization of the water applied was the cause of lower WP in unleveled fields. According to the findings, laser land leveling increases crop yields by making better use of water resources, is more cost-effective, and uses less water overall.

Figure 9 shows that the highest percentages of rationalization in irrigation water were achieved when using the laser soil leveling technique with the

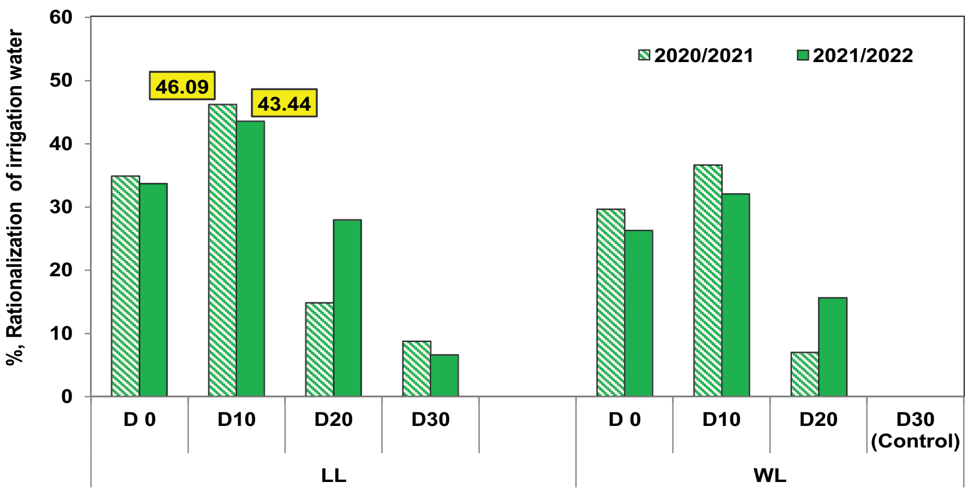


Figure 9. Effect of soil leveling methods and tillage depths on %, rationalization of irrigation water. [(laser soil leveling "LL" and without leveling the soil "WL"), (zero tillage = 0 cm depth "D0," 10 cm depth "D10," 20 cm depth "D20" and 30 cm depth "D30")].

minimum depth of plowing (10 cm depth), as these percentages were 46.09 % and 43.44 % during the two seasons of 2020/2021 and 2021/2022, respectively. This confirms the importance of laser leveling with plowing at a minimum depth. These findings are consistent with those of (Abdelraouf & Abuarab, 2012; Eid & Negm, 2019, Abdelraouf et al. 2020b; Jat, Chandna, Gupta, Sharma, & Gill, 2006; Sabra, Reda, El-Shawy, El-Refaee, & Abdelraouf, 2023) who reported that the use of laser land leveling under different crops has led to water savings of 15% to 30%.

These findings demonstrated that Precision Land Levelling (PLL) boosted the effectiveness of irrigation application by distributing water evenly and increasing water potential, which led to uniform seed germination, improved crop growth, and a greater agricultural yield.

Quality of barley

Figure 10 and the results presented in Table 6 show the significant effect of laser leveling and the shallow plowing depth on the quality characteristics of the barley crop, such as protein content, carbohydrates, and fibers. The results of the quality properties of the barley under study improved with the laser soil leveling compared to the non-leveling. The results of the quality values were greater when plowing at a depth of 10 cm when compared to the deeper plowing depths of 20 and 30 cm and when not tilling, and these results were achieved for the two growing seasons of barley.

Perhaps the positive effect of laser leveling and plowing at a depth of 10 cm is due to the same reasons

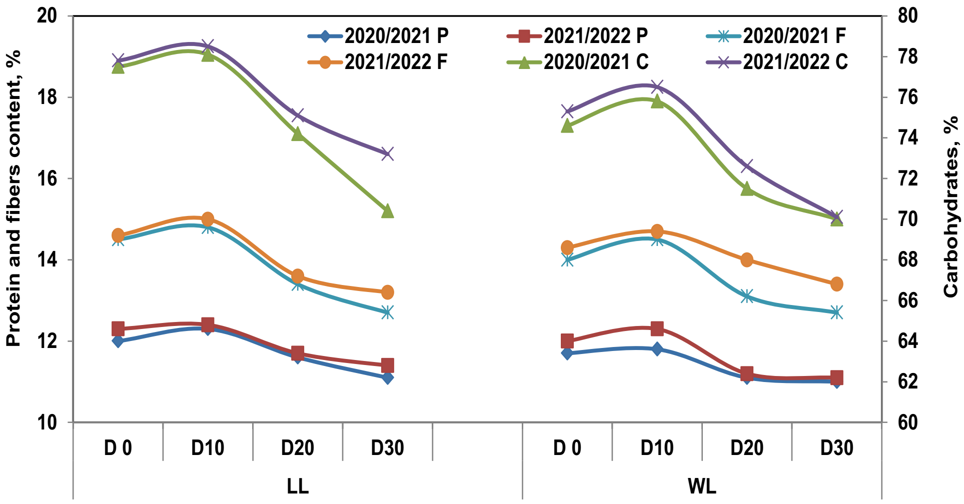


Figure 10. Effect of soil leveling methods and tillage depths on some quality traits of barley. [(laser soil leveling "LL" and without leveling the soil "WL"), (zero tillage = 0 cm depth "D0," 10 cm depth "D10," 20 cm depth "D20" and 30 cm depth "D30")], [P: protein content; F: fibers content; C: carbohydrates content].

Table 6. Effect of soil leveling methods and tillage depths on some barley quality.

		Protein content, %		Carbohydrates, %		Fibers, %	
Soil leveling methods	Tillage depth, cm	2020/21	2021/22	2020/21	2021/22	2020/21	2021/22
Effect of soil leveling methods on some barley quality							
LL		11.8	12.0	75.1	76.2	13.9	14.4
WL		11.4	11.5	73.0	73.6	13.6	14.1
LSD at 5%		0.21	0.22	1.14	1.15	0.31	0.25
Effect of tillage depths on some barley quality							
	D 0	11.8	12.0	76.1	76.5	14.3	14.5
	D10	12.1	12.3	77.0	77.5	14.7	14.9
	D20	11.4	11.5	72.9	73.9	13.3	13.8
	D30	11.1	11.3	70.2	71.7	12.7	13.4
LSD at 5%		0.20	0.21	1.12	1.13	0.33	0.34
Effect of soil leveling methods and tillage depths on some barley quality							
LL	D 0	12.0	12.3	77.5	77.8	14.5	14.6
	D10	12.3	12.4	78.1	78.5	14.8	15.0
	D20	11.6	11.7	74.2	75.1	13.4	13.6
	D30	11.1	11.4	70.4	73.2	12.7	13,2
WL	D 0	11.6	11.7	74.6	75.1	14.0	14.3
	D10	11.8	12.1	75.8	76.5	14.5	14.7
	D20	11.1	11.2	71.5	72.6	13.1	14.0
	D30	11.0	11.1	70.0	70.1	12.7	13.4
LSD at 5%		0.19	0.21	1.15	1.21	N.S	N.S

[(Laser soil leveling "LL" and without leveling the soil "WL"), (zero tillage = 0 cm depth "D0," 10 cm depth "D10," 20 cm depth "D20" and 30 cm depth "D30")], LSD at 5%: When comparing the means of various treatments with the same number of replications, the least significant difference is taken into account.

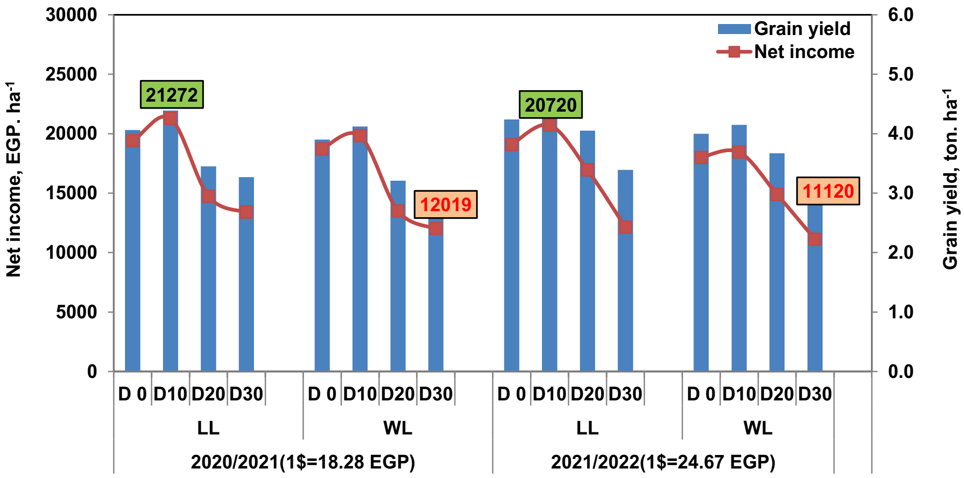


Figure 11. The relationship between total income, total costs and net income.

Table 7. Economic evaluation of laser soil leveling and plowing processes and net income calculation.

Dates of planting seasons	Soil leveling methods	Tillage depth, cm	Grain yield, ton/ha	Price per ton, EGP	Total income, EGP/ha	Costs of plowing and leveling, EGP/ha	Total other costs, EGP/ha	Total costs, EGP/ha	Net income, EGP/ha
2020/2021	LL	D 0	4.06	6850	27811	400	8000	8400	19411
		D10	4.39	6850	30072	800	8000	8800	21272
		D20	3.45	6850	23633	900	8000	8900	14733
		D30	3.27	6850	22400	1000	8000	9000	13400
	WL	D 0	3.90	6850	26715	0	8000	8000	18715
		D10	4.12	6850	28222	400	8000	8400	19822
		D20	3.21	6850	21989	500	8000	8500	13489
		D30	3.01	6850	20619	600	8000	8600	12019
2021/2022	LL	D 0	4.24	7000	29680	600	10000	10600	19080
		D10	4.56	7000	31920	1200	10000	11200	20720
		D20	4.05	7000	28350	1400	10000	11400	16950
		D30	3.39	7000	23730	1600	10000	11600	12130
	WL	D 0	4.00	7000	28000	0	10000	10000	18000
		D10	4.15	7000	29050	600	10000	10600	18450
		D20	3.67	7000	25690	800	10000	10800	14890
		D30	3.16	7000	22120	1000	10000	11000	11120

[(Laser soil leveling "LL" and without leveling the soil "WL"), (zero tillage = 0 cm depth "D0," 10 cm depth "D10," 20 cm depth "D20" and 30 cm depth "D30")], LSD at 5%: When comparing the means of various treatments with the same number of replications, the least significant difference is taken into account., 2021 (1$ = 18.28 EGP); 2022 (1$ = 24.67 EGP).

that led to an increase in the crop productivity of barley. Levelling has made it possible to plant more land, which has led to higher yields (Gajri, Ghuman, & Singh, 2002).

Economic evaluation

Figure 11 and the results presented in Table 7 show the economic evaluation and the positive effect of applying laser leveling techniques and plowing at the 10 cm depth. The positive impact on grain yield resulted in better net income for the farmers.

The highest values of net farm income when using laser leveling and soil plowing at a depth of 10 cm were 21,272 and 20,720 EGP (Egyptian pounds, 1US$ = 20 EGP approx.) per hectare, while the lowest net income values when not using laser leveling and plowing at 30 cm were 12,019 and 11120 EGP per hectare during the two growing seasons 2020/2021 and 2021/2022, respectively.

Conclusion

Although the volume of irrigation water added to all treatments under study is equal, the performance of laser leveling proved to have improved the distribution of water within the root zone, which led to increasing irrigation efficiency which resulted in a decrease in the plant water stress when compared to non-leveling.

There was also positive effect of plowing at 10 cm depth, compared to deeper depths. Deep plowing resulted in increased water stress, which caused a decrease in the rate of water and nutrients uptake.

Perhaps the reason for the negative impact of no-tillage is due to soil compaction, which led to a decrease in germination rate and the rate of irrigation water infiltration into the soil. Poor infiltration could lead to water stress in the root zone and losses by evaporation from soil surface.

Laser leveling with a plowing depth of 10 cm gave the most favorable values of the moisture content and water availability in the root zone as well as the grain yield and water productivity in addition to improving the barley quality properties.

Generally, utilizing laser land leveling as eco-friendly practice will help in sustaining barley productivity in Egypt particularly in the sandy soil regions. This study showed that the laser-assisted precision land leveling has shown its positive impact such as better crop establishment, enhanced the grain yield, water productivity, barley quality properties and achieving better net income for farmers.

Disclosure statement

No potential conflict of interest was reported by the author(s).

ORCID

Ayman El-Sayed http://orcid.org/0000-0002-4315-3627

References

Abdelraouf, R. E., Abou-Hussein, S. D., Abd-Alla, A. M., & Abdallah, E. F. (2012). Effect of short irrigation cycles on soil moisture distribution in root zone, fertilizers use efficiency and productivity of potato in new reclaimed lands. *Journal of Applied Sciences Research*, *8*(7), 3823–3833.

Abdelraouf, R. E., & Abuarab, M. E. (2012). Effect of irrigation frequency under hand move lateral and solid set sprinkler irrigation on water use efficiency and yield of wheat. *Journal of Applied Sciences Research*, *8*(11), 5445–5458.

Abdelraouf, R. E., El-Shawadfy, M. A., Fadl, A. H., & Bakr, B. M. M. (2020b). Effect of deficit irrigation strategies and organic mulching on yield, productivity of irrigation water and fruit quality of navel orange under arid regions conditions. *Plant Archives*, *20*(Supplement 1), 3505–3518.

Abdelraouf, R. E., El-Shawadfy, M. A., Ghoname, A. A., & Ragab, R. (2020a). Improving crop production and water productivity using a new field drip irrigation design. *Plant Archives*, *20*(1), 3553–3564.

Abdelraouf, R. E., Mehana, H. M., Sabreen, K. P., & Bakry, A. B. (2014). Impact of laser land leveling on water productivity of wheat under deficit irrigation conditions. *Agriculture Sciences*, *1*(2), 53–64.

Abdelraouf, R. E., Refaie, K. M., & Hegab, I. A. (2013). Effect of drip lines spacing and adding compost on the yield and irrigation water use efficiency of wheat grown under sandy soil conditions. *Journal of Applied Sciences Research*, *9*(2), 1116–1125.

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Guidelines for computing crop water requirements. *Irrigation Drain*, *56*, 300.

Asif, M., Ahmed, M., Gafool, A., & Aslam, Z. (2003). Wheat productivity land and water use efficiency by traditional and laser land-leveling techniques. *The Journal of Biological Sciences*, *3*(2), 141–146. doi:10.3923/jbs.2003.141.146

Bhatt, R., & Sharma, M. (2009). Laser leveler for precision land leveling for judicious use of water. *Punjab, Extension Bulletin, Krishi Vigyan Kendra, Kapurthala, Punjab Agricultural University -Ludhiana*. doi:10.13140/GR.2.1.3688.8806

Boydaş, M. G., & Turgut, N. (2007). Effect of tillage implements and operating speeds on soil physical properties and wheat emergence. *Turkish Journal of Agriculture & Forestry*, *31*, 399–412.

Dekemati, I., Simon, B., Vinogradov, S., & Birkás, M. (2019). The effects of various tillage treatments on soil physical properties, earthworm abundance and crop yield in Hungary. *Soil and Tillage Research*, *194*, 104334. doi:10.1016/j.still.2019.104334

Dexter, A. R. (2004). Soil physical quality: Part I. Theory, effects of soil texture, density, and organic matter, and effects on root growth. *Geoderma*, *120*(3–4), 201–214. doi:10.1016/j.geoderma.2003.09.004

Eid, A. R., & Negm, A. 2019. Improving agricultural crop yield and productivity of irrigation water via sustainable and engineering techniques. *Book Chapter in "Conventional Water Resources and Agriculture in Egypt*, *74*(2019), 561–592. Springer International Publishing AG 2018, Published online: 1 June 2018. 10.1007/698_2018_259

El-Habbasha, S. F., Okasha, E. M., Abdelraouf, R. E., & Mohammed, A. S. H. (2014). Effect of pressured irrigation systems, deficit irrigation and fertigation rates on yield, quality and water use efficiency of groundnut. *International Journal of ChemTech Research*, *07*(1), 475–487.

El-Metwally, I., Abdelraouf, R. E., Ahmed, M., Mounzer, O., Alarcón, J., & Abdelhamid, M. (2015). Response of wheat (Triticum aestivum L.) crop and broad-leaved weeds to different water requirements and weed management in sandy soils. *Agriculture (Polnohospodárstvo)*, *61*(1), 22–32. doi:10.1515/agri-2015-0007

Evans, R. G., Stevens, W. B., & Iversen, W. M. (2010). Development of strip tillage on sprinkler irrigated sugar beet. *Applied Engineering in Agriculture*, *26*(1), 59–69. doi:10.13031/2013.29476

FAO. (2016). FAOSTAT online statistical database. Retrieved April 25th, 2015, from http://faostat.fao.org

Fernández, R. O., Fernández, P. G., Cervera, J. V. G., & Torres, F. P. (2007). Soil properties and crop yields after 21 years of direct drilling trials in southern Spain. *Soil & Tillage Research*, *94*(1), 47–54. doi:10.1016/j.still.2006.07.003

Gajri, P. R., Ghuman, B. S., & Singh, S. (2002). Tillage and residue management practices in rice-wheat system in indo-zgangatic plains-diagnostic survey. *Technical Report, National Agricultural Technology Project, Indian Council Agricultural Research, New Delhi and Punjap Agricultural University, Ludhiana*, 18–32.

Hozayn, M., Abd El-Wahed, M. S., Abd El-Monem, A. A., Abdelraouf, R. E., & Ebtihal, M. (2018). Applications of magnetic technology in agriculture, a novel tool for improving water and crop productivity: 3. *Faba Bean Research Journal of Pharmaceutical, Biological and Chemical Sciences*, *7*(6), 1288–1296.

James, L. G. (1988). Principles of farm irrigation system design. *John Willey, Sons Inc, Washington State University*, *73*(152–153), 350–351.

Jat, M. L., Chandna, P., Gupta, R. K., Sharma, S. K., & Gill, M. A. (2006). *Laser land levelling: A precursor technology for resource conservation, rice wheat consortium technical bulletin series 7* (p. 48). New Delhi: Rice-Wheat Consortium for the Indo-Gangetic Plains.

Katiyar, A. K., Uttam, S. K., & Devendra, S. (2021). Relative impact of moisture conservation practices and fertility levels on pearlmillet varieties under rainfed condition. *Progressive Research An International Journal*, *16*(1), 24–26.

Kouwenhoven, J. K., Perdok, U. D., Boer, J., & Oomen, G. J. M. (2002). Soil management by shallow mould board ploughing in the Netherlands. *Soil & Tillage Research*, *65*(2), 125–139. doi:10.1016/S0167-1987(01)00271-9

López-Fando, C., & Pardo, M. T. (2009). Changes in soil chemical characteristics with different tillage practices in a semi-arid environment. *Soil and Tillage Research*, *104* (2), 278–284. doi:10.1016/j.still.2009.03.005

Małecka, I., Blecharczyk, A., Sawinska, Z., Piechota, T., & Waniorek, B. (2012). Cereals yield response to tillage methods. *Fragment Agron (In Polish)*, *29*, 114–123.

Mohamed, A. E. (2017). Effect of irrigation quantities and tillage systems on sunflower yield under Khartoum state conditions, Sudan. *International Research Journal of Arts and Social Sciences*, *7*(1), 001–007. doi:10.14303/irjas.2017.01

Molden, D., Murray-Rust, H., Sakthivadivel, R., & Makin, I. (2003). A water-productivity framework for understanding and action. *Water Productivity in Agriculture: Limits and Opportunities for Improvement*, *1*, 1–18.

Naresh, R. K., Singh, S. P., Singh, A., Khilari, K., Shahi, U. P., & Rathore, R. S. (2012). Evaluation of precision land leveling and permanent raised bed planting in maize–wheat rotation: Productivity, profitability, input use efficiency and soil physical properties. *The Indian Journal of Agricultural Sciences*, *105*(1), 112–121.

Orzech, K., Orzech, K., & Załuski, D. (2020). Effect of companion crops and crop rotation systems on some chemical properties of soil. *Journal of Elementology*, *25* (3/2020), 931–949. doi:10.5601/jelem.2020.25.1.1904

Pour-Aboughadareh, A. R., Naghavi, M. R., & Khalili, M. (2013). Water deficit stress tolerance in some of barley genotypes and land races under field conditions. *Notulae Scientia Biologicae*, *5*(2), 249–255. doi:10.15835/nsb529066

Rizk, E. K. (2007). Irrigation scheduling and environmental stress coefficient of kidney bean under some irrigation systems in North Sinai. *Egyptian Journal of Applied Science*, *22*(11), 286–296.

Sabra, D. M., Reda, A. M., El-Shawy, E. A., El-Refaee, Y. Z., & Abdelraouf, R. E. (2023). Improving barley production under deficient irrigation water and mineral fertilizers conditions. *SABRAO Journal of Breeding and Genetics*, *55*(1), 211–229. doi:10.54910/sabrao2023.55.1.20

Safina, S. A. (2010). Effect of nitrogen levels on grain yield and quality of some barley genotypes grown on sandy soil and salinity irrigation. *Egyptian Journal of Agronomy*, *32* (2), 207–22.

Shahani, W. A., Kaiwen, F., & Memon, A. (2016). Impact of laser leveling technology on water use efficiency and crop productivity in the cotton –wheat cropping system in Sindh. *International Journal of Research - GRANTHAALAYAH*, *4*(2), 220–231. doi:10.29121/granthaalayah.v4.i2.2016.2832

Shah, A. N., Tanveer, M., Shahzad, B., Yang, G., Fahad, S. . . . Souliyanonh, B. (2017). Soil compaction effects on soil health and crop productivity: An overview. *Environmental Science and Pollution Research*, *24*(11), 10056–10067. doi:10.1007/s11356-017-8421-y

Snedecor, G. W., & Cochran, W. G. (1982). *Statistical methods* (7th ed.). USA: Iowa state Press Iowa.