Development and evaluation of laser-controlled chisel plough

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Abstract: The main purpose of this study is to improve the tillage operational efficiency of a chisel plough through the use of laser levelling technology. Such technology can help farmers attain consistent tilled layer depth throughout the entire field. A modified laser control unit was attached to chisel plough and it coupled with a hydraulic system. Under the current modification, the laser unit, as it communicates with the receiver tower, would be able to adjust the ploughing depth. The readings of point levels for the subsurface layer were taken at a grid spacing of 5.0 m × 5.0 m, a resolution commonly used to show the changes in soil topography. The experiment was repeated in three plots, 1-hectare each. Irrigation water advance times and total applied irrigation water amounts were recorded and used as indicator of the performance of the developed prototype and to evaluate the effect of laser controlled ploughing on flood irrigation efficiency. Results indicated that the use of laser-controlled chisel plough improved field level and proper tilled layer enabling other field machines to work in a stable depth of tilled layers. After using the laser-controlled chisel plough, the elevation (relative to the reference point) ranged from 34.0 cm to 43.0 cm with an average recorded value of 39.8 cm and a standard deviation of 0.990 cm. Using the regular plough resulted in relative elevation values, which ranged from 22.0 cm to 52.0 cm with an average elevation value of 39.4 cm and a standard deviation of 5.7 cm. Irrigation water advance times were shorter with plots that were ploughed using the laser-controlled chisel. Total applied irrigation water was 8468 m^3 ha^{-1} and 9835 m^3 ha^{-1} for plots where the normal chisel plough and laser-controlled chisel plough were used respectively.

Keywords: land leveler, hydrophobic laser-controlled plough, precision land leveling, uniform tilled soil

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1 Introduction

Agricultural technologies have several significant impacts on the economy and society locally, regionally and nationally from different aspects (Yang, 2005). Tohidyan Far and Rezaei-Moghaddam (2020) revealed that experts considered uniform distribution of water, using conservation tillage, facilitating agricultural activities, decreased water consumption and decrease of water wasting as the most important technical impacts of laser levelling technology. The most environmentally important impacts were the decrease of soil erosion and retention of crop residues. Experts stated the most significant social impacts as improvement in villages living conditions and sense of belonging to rural areas. A lot of studies highlighted the impacts of the laser land levelling technology. Different studies have confirmed that laser levelling technology decreases farming costs (Abdullaev et al., 2007; Gulati et al., 2017). Laser land levelling enhance the use of nutritious materials and reduce chemical fertilizers consumption (Jat et al., 2006; González et al., 2009). In addition to reducing the amount of seeds and increasing yield with less fuel consumption used for pumping water and agricultural machinery (Jehangir et al. 2007). Aryal and Jat (2015) listed preferable returns such as increasing yields and reducing greenhouse gas emissions, where, laser land

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levelling considerably lowers irrigation time for rice by 47-69 hours per hectare per season and for wheat by 10-12 hours per hectare per season and it increased yields by an average 8% for both crops. They showed that laser land levelling reduced greenhouse gas emissions from saving on energy, reducing cultivation time and increasing input efficiency. Sapkal et al. (2018) observed that laser land levelling technology has the potential to provide additional income to farmers and help in conservation of scarce resources and suggested to raise the knowledge level of the farmers along with more exposure to the extension agencies to enhance the adoption of laser land levelling. Furthermore, it can improve the efficiency of agricultural mechanization and lay the foundation for precise seeding and fertilization, where, flat field surface can create favorable conditions for machine transplanting, precision direct seeding, and mechanical harvesting and can lay a solid foundation for improving the degree of mechanization in production (Luo et al., 2007; Maqsood and Khalil, 2013).

The control system of a normal laser leveling machine is mainly composed of a laser transmitter, a laser receiver, a controller, a hydraulic system, and a scraper. A laser receiver installed on the scraper's mast is used to detect the deviation of the actual elevation of the rotating laser from the expected elevation, and the elevation deviation information is then used to control the hydraulic system to drive the scraper to achieve automatic lifting, thereby achieving accurate farmland levelling (Xu et al., 2007). Modification of the normal leveling system to meet specific requirements is not studied enough. Laser controlled vertical scraper land leveler for paddy fields has been developed and tested. Using a tractor to supply power for a laser-controlled land leveler can meet the demands of precision paddy field leveling. Scrapers with a laser-controlled land leveler for paddy fields are generally driven by a hydraulic cylinder through a parallel four bar mechanism, which drives the vertical motion of the scraper for elevation adjustment (Yan et al., 2011; Hu et al., 2014). However, due to the heavy weight of the land-leveling scraper, the relative pressure difference between raising and lowering the scraper is large, which severely affects the response speed of the scraper's elevation hydraulic cylinder and the adjustment of the scraper's elevation. Another initiative was using small laser controlled land levelers for paddy fields, by using a transplanter's chassis for power, but their use is limited by their high cost, lower power, and lower operational efficiency during leveling (Chen et al., 2014; Tang et al., 2018). Hu et al. (2020) designed and evaluated a tractor-attached laser-controlled rotary scraper land leveler for paddy fields (TLRSLLPF).

Tests were conducted to characterize elevation adjustment response times and accuracy and field trials were performed to assess field-leveling performance. Results indicated that the laser receiver signal of the laser-controlled rotary scraper land leveler can accurately reflect the scraper's elevation motion. Also, they showed that the standard deviation of the relative elevations of the field decreased from 5.97 to 1.59 cm and work efficiency was 8.7 mu h^{-1} (1 mu = 0.67 ha.), which indicated that the proposed leveler worked effectively and more efficiently than the rotary leveler. So, in the current research work, the objective is to utilize laser levelling technology in ploughing, where, a chisel plough chassis was attached to a laser controlled land leveler and the developed prototype was tested as a tool to perform tillage and laser levelling in one field operation. The main goal was to prepare a uniform seedbed, which is good for germination, with relatively lower difference in the tilled layer height compared to the regular tillage operation.

2 Materials and methods

Field experiments were conducted at a private farm in Dakahlia Governorate, Egypt in year 2019-2020. The field had a clay soil with particle size distribution as in Table 1.

Table 1 Particle size distribution and $CaCO_3$ content

Depth, mm	Sand % 2-0.02 mm	Silt % 0.02-0.002 **mm**	Clay % < 0.002 **mm**	Texture Class	$CaCO_3$ %
0-200	20.5	31.4	48.1	Clay Soil	1.6
200-400	21.5	30.8	47.7	Clay Soil	1.9

Experimental field consisted of 2 main plots, 1-hectare each, located in 31.1656°N, 31.4913°E for the measurements of soil elevation topography. Each main plot was divided into 3 locations (1, 2, and 3) to replicate the measurements of irrigation water advance times as shown in Figure 1. The field was left to dry after the harvest of the previous crop. After tillage, the soil was levelled, and the field was planted with vegetable and required data was collected accordingly.

Figure 1 Layout of the experimental field

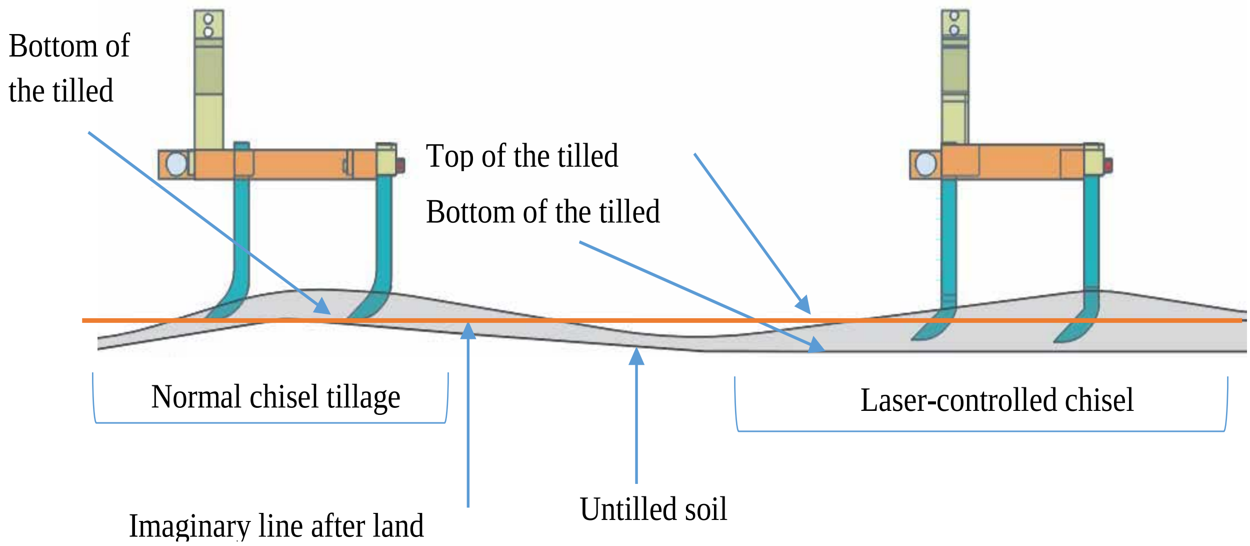

Figure 2 The concept of using laser-controlled chisel plough: differences between using laser-controlled chisel plough and regular chisel plough

2.1 Laser-controlled chisel plough unit

2.1.1 Principle of work and tilled layer elevation

When the soil is tilled with normal chisel plough, the tilled soil layer is kept depending on the original topographic profile and shape until a leveler is used to remove the minor undulations in the field. But, when the laser-controlled chisel plough is used, the tilled layer would be relatively independent from the soil topography (lower and higher parts) (Figure 2). When the plough is higher than the set level, the controller causes the elevation hydraulic cylinder to expand rapidly to lower the plough's elevation and maintain it at the set level. Conversely, when the plough is lower than the set level, the elevation hydraulic cylinder rapidly raises the plough to its set elevation, Figure 3.

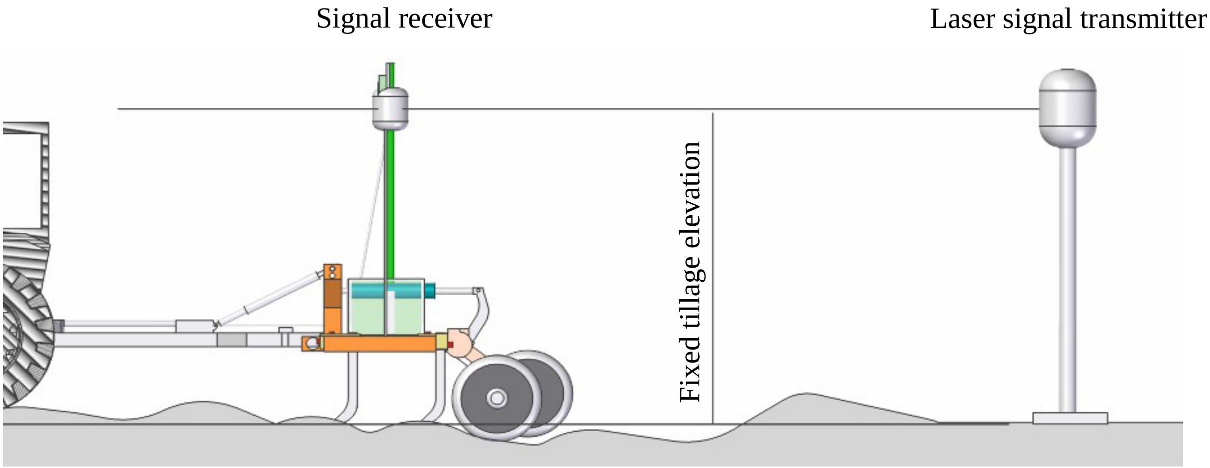

Figure 3 Theory behind using laser-controlled chisel plough: constant distance between the laser line from transmitter and the plough-soil contact surface.

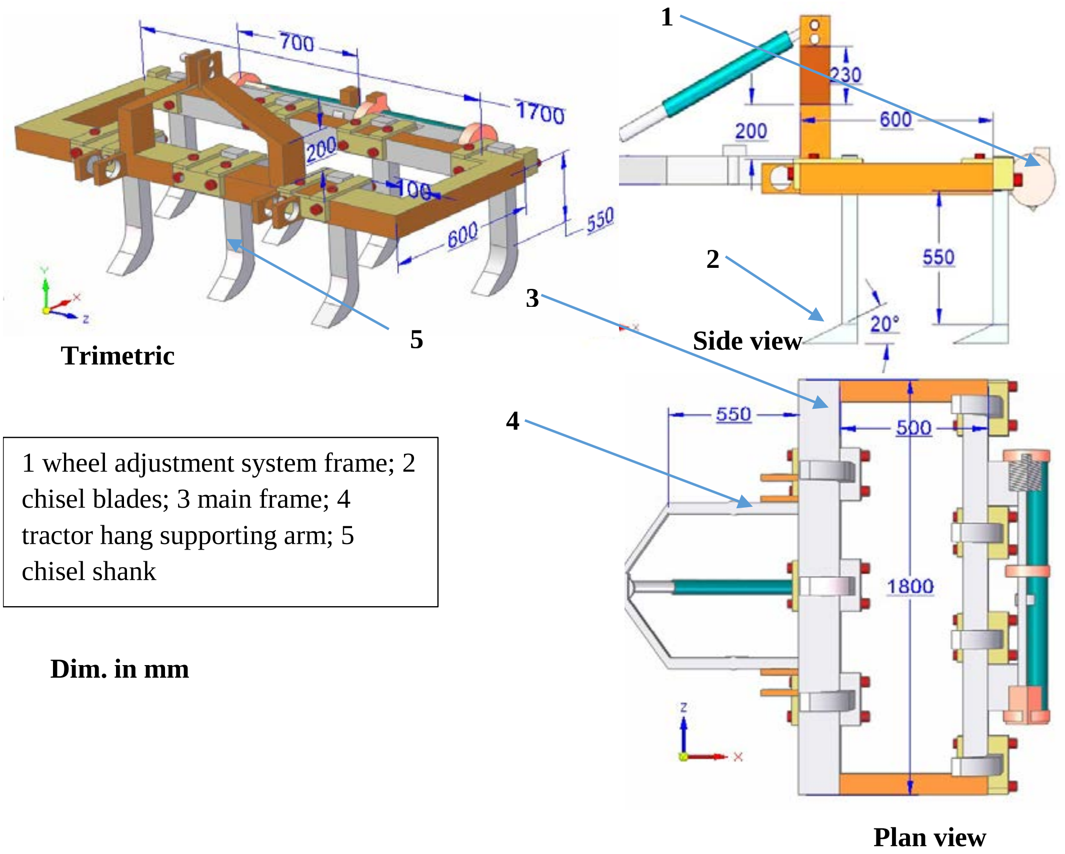

Figure 4 7-shares chisel plough used in the study

2.1.2 Chesil plough

In this study 7-share-chisel plough was used with specifications of 1800 mm, 600 mm, 550 mm, and 240 kg as length, width, height, and weight, respectively, as shown in Figure 4. All blades were quality materials and were fixed at 90º rake angle shank and 20º chisel entrance angle.

2.1.3 Laser control unit

The Laser transmitter is mounted on the ground (on a tripod). Rugby 320 SG transmitter was used to generate a long-range, rotating laser beam that can be accurately and easily positioned to provide a control plane in the X-axis (single grade) (Leica-geosystems, 2020), Figure 5. It is the ideal transmitter for laser operated machine control system and should work with any laser receiver, although operating range varies depending on the specific receiver and jobsite conditions. The laser receiver is omnidirectional, which is sensitive to the transmitted laser beam. Other light being received is usually filtered out mechanically or electronically. The receiver has three different vertical sensing areas. The middle sector indicates that the receiver is aligned with the center of the transmitted beam; the top sector indicates that the receiver is below grade and the bottom sector indicates that the receiver is above grade. The central "on grade" part of the receiver has two modes of operation, which are "wide" and "narrow" band operations. The wide band mode can reduce the number of responses of the sensing system. This reduces wear on the hydraulic system. The wide band mode makes it easier to balance a paddock at the expense of the surface finish. This can produce small reverse grades, especially on the flatter slopes. The control box processes signals from the machine mounted receiver. It displays these signals to indicate the plough's position relative to the finished grade. When the control box is set to automatic, it provides electrical output for driving the hydraulic valve. The three control box switches are On/Off, Auto/Manual, and Manual Raise/Lower (which allows the operator to manually raise or lower the plough). The hydraulic system of the tractor was used to supply oil to raise and lower the plough. The oil supplied by the tractor's hydraulic pump is normally delivered at 140.9-211.3 kg cm^{-2} pressure. As the hydraulic pump is a positive displacement pump and always pumping more oil than required, a pressure relief valve is needed in the system to return the excess oil to the tractor's reservoir.

Note: a) power button ; b) lcd display ; c) x-axis button ; d) up arrow button ; e) star button; f) down arrow button; g) circular level vial; h) 12-volt input; i) dual batteries; j) raised alignment sights and mounting plate for the optional sighting scope; k) easy grip handle; l) tripod mount

Figure 5 Components of Leica Rugby-320-Sg rotating laser

2.1.4 Laser-controlled chisel plough

The overall structure of the laser-controlled chisel plough is shown in Figure 6. Where, 7-share-chisel plough was used to replace the land leveler with a horizontal adjustment wheels fixed to the main frame of the plough by three bearings. The lifting and lowering process is controlled by a fixed arm with a hydraulic cylinder connected to an automatic control device, which receives the signal from the receiver fixed vertically on the plough. Angle of penetration of the chisel shares was adjusted to be within 20° degree, which increases the vertical forces affecting the shares, which works to attract the plough to the soil bottom, so that the function of the horizontal control wheels is only to prevent the plough from going deeper more than required. The horizontal adjustment connector was installed between the upper hitch point of the plough and plough connecting arm to ensure the horizontal adjustment according to the depth of ploughing. The new modified tillage unit was attached to 6-cylinders Duetz tractor with diesel engine of 100 kW at 2500 rpm.

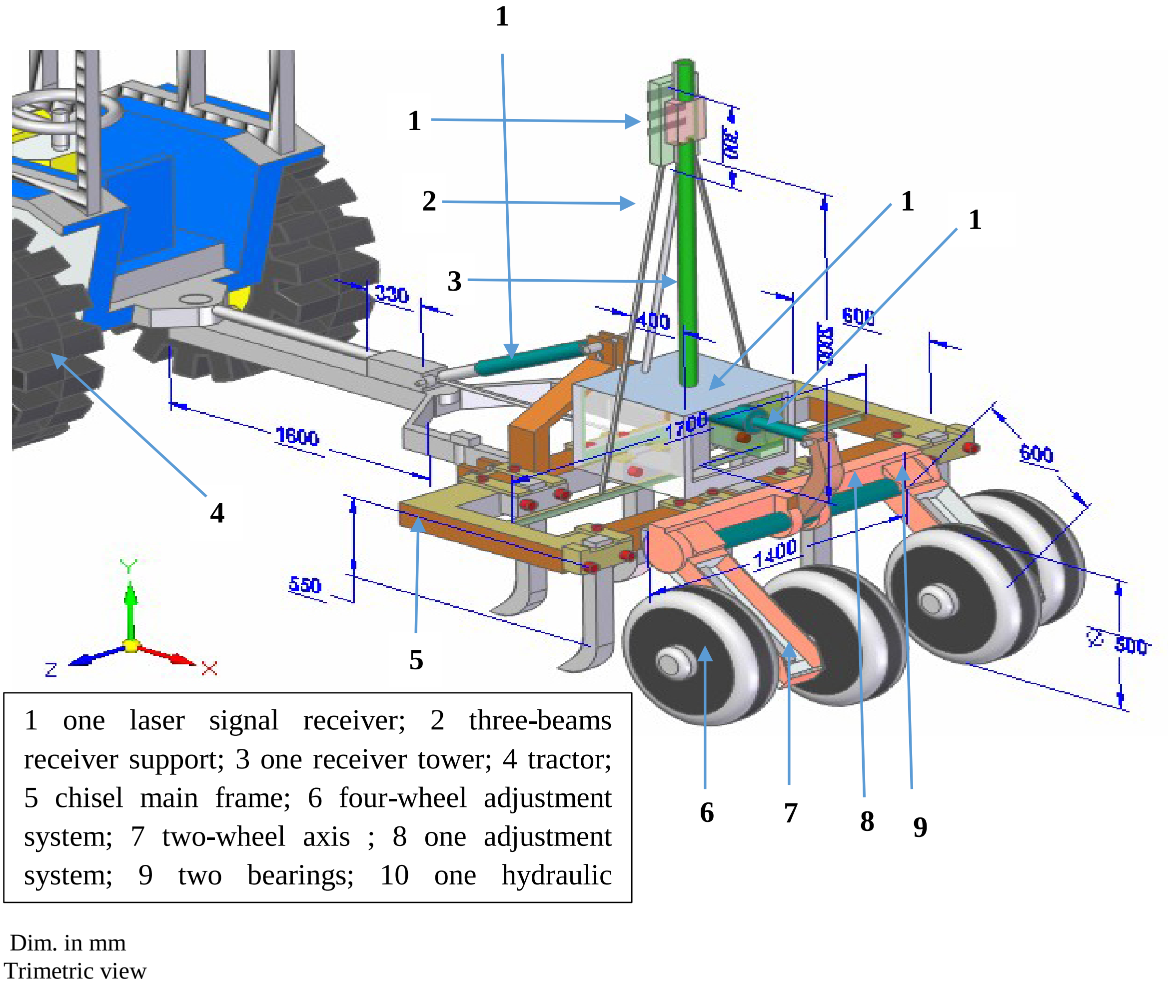

Figure 6 Structure of the laser-controlled chisel plough

2.2 Measurement of different parameters (soil elevation, topography, irrigation water advance times and total applied irrigation water)

Experimental field was cleared from any crop residues before performing the ploughing, a topographic survey conducted to record the high and low spots in the field by using ArcGIS pro and the profile validated with OriginLab version 19b program (by generating 3-D map of 400 points in field and showing the differences in points elevations) to make surveying grid maps. Figure 7 shows method of surveying grid reading. The attitude and heading reference system (AHRS) and GNSS data were collected. A fixed reference point was set on the side of experimental field. The lengths of the sides of the field and the distances from the sides to the reference point are measured using a measuring tape. Level was used to establish or verify that points are in the same horizontal plane and is used in conjunction with a levelling staff to establish the relative heights levels of objects or marks. The field was divided into a subsurface grid. The intersection points (sub-surface flatness sampling points) of the grid lines were marked (Zhou et al., 2020). The position of each sampling point relative to the reference point was measured using a measuring tape. The elevations of reference point and the sampling points were measured. A reference station for the GNSS was set up. The antenna of the GNSS was placed at the reference point. The World Geodetic System (WGS84) coordinates of the reference point were recorded. The measurement data of the AHRS and GNSS were collected after using laser-controlled chisel plough and normal plough. The readings were taken at a 5.0 m × 5.0 m grid spacing to achieve good precision in soil elevations topography changes. To evaluate the effect of using laser-controlled chisel plough on sub-surface levelling and steadiness of the tilled layer height along the entire field, total applied irrigation water was recorded, and also irrigation water advance times (time required for the water to advance to the end of the field length or to cover the field completely) were recorded at the middle and end of irrigation line for 100 m long plots. The measurements of irrigation water advance times were done after using the normal chisel plough or using laser-based chisel plough.

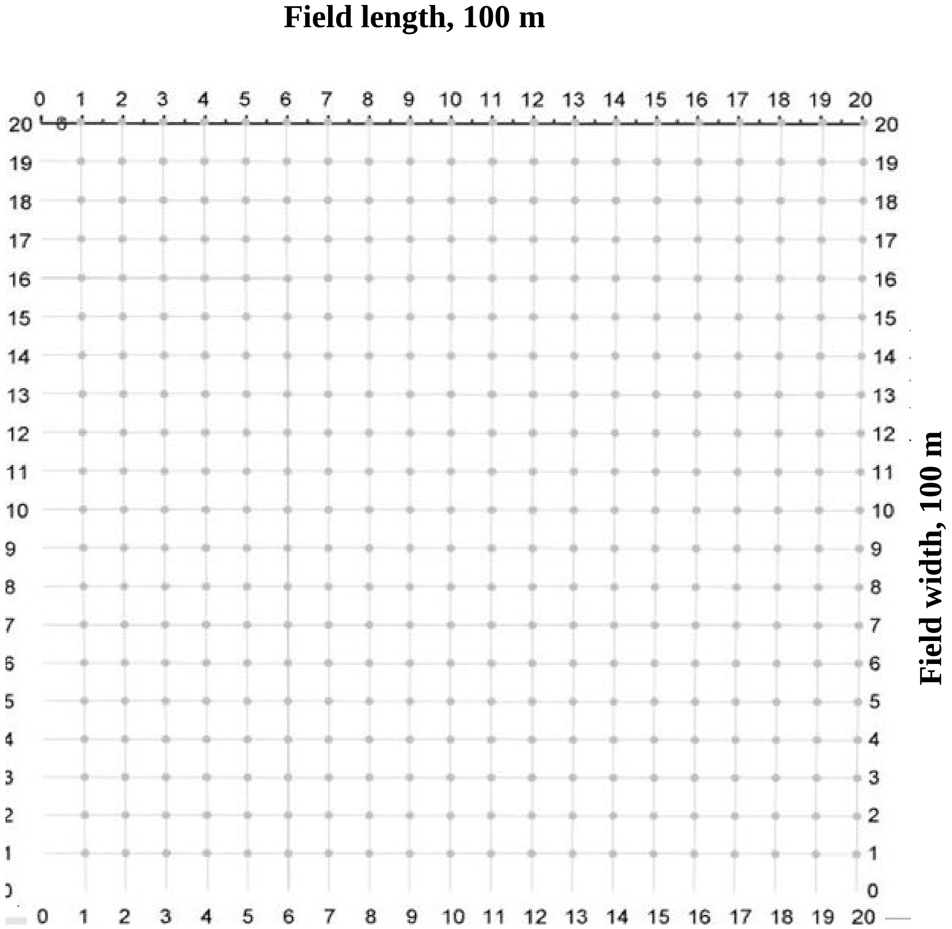

Figure 7 Field grid of sub-surface flatness sampling points

3 Results and discussion

3.1 Effect of using laser-controlled chisel plough on elevations of the tilled soil layer

Elevations of the top and bottom tilled soil layer are presented in Figures 8 and 9. Figure 8 shows the three-dimensional rendering of the field flatness after using laser-controlled chisel plough. Relative elevation values ranged from 34.0 cm to 43.0 cm with an average recorded value of 39.8 cm and a standard deviation of 0.990 cm, which indicates an insignificant variation in relative elevation when laser-controlled chisel plough is used. Figure 9 shows the three-dimensional rendering of the field flatness after using normal chisel plough. Where, relative elevation values ranged from 22.0 cm to 52.0 cm with an average relative elevation value of 39.4 cm and a standard deviation of 5.7 cm, which indicates a substantial difference in relative elevation when a regular chisel plough is used.

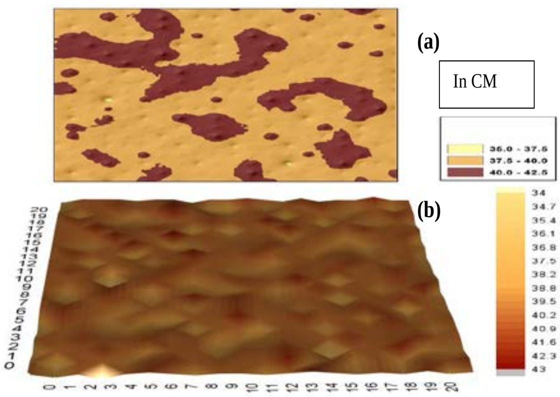

Figure 8 Relative elevations of the tilled soil layer after using laser-controlled chisel plough (a: ArcGIS pro, b: OriginLab version 19b)

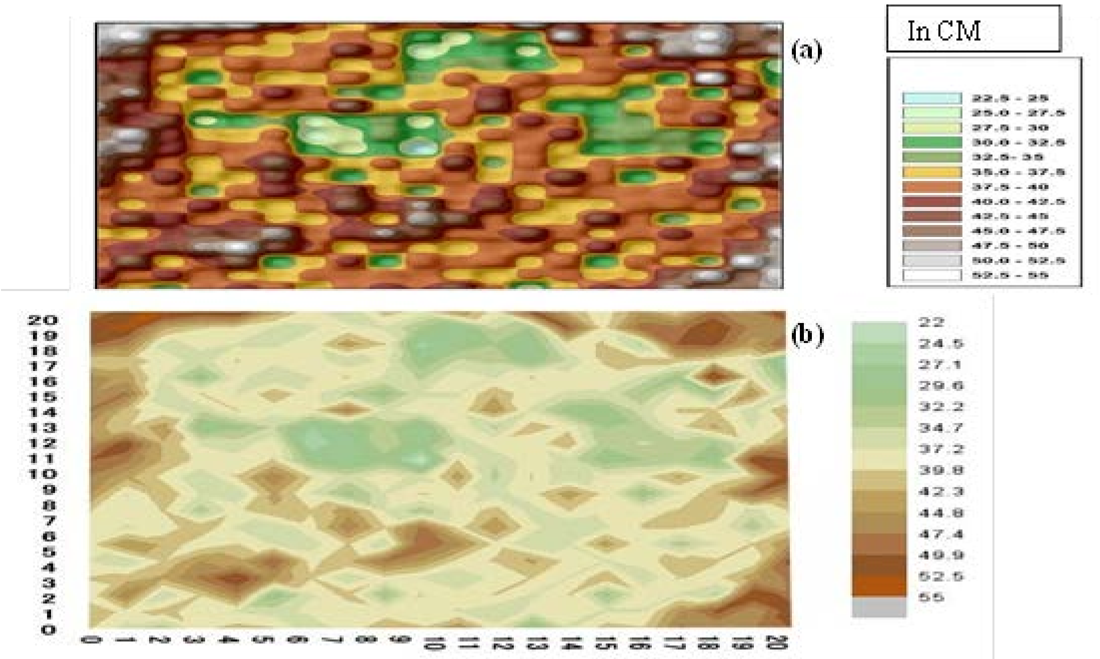

Figure 9 Relative elevations of the tilled soil layer after using regular chisel plough (a: ArcGIS pro, b: OriginLab version 19b)

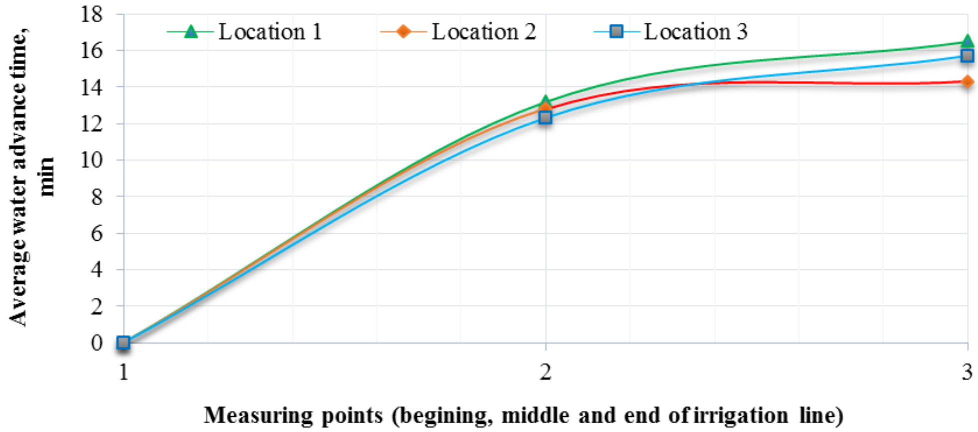

Figure 10 Irrigation water advance times for plots with laser-controlled chisel plough

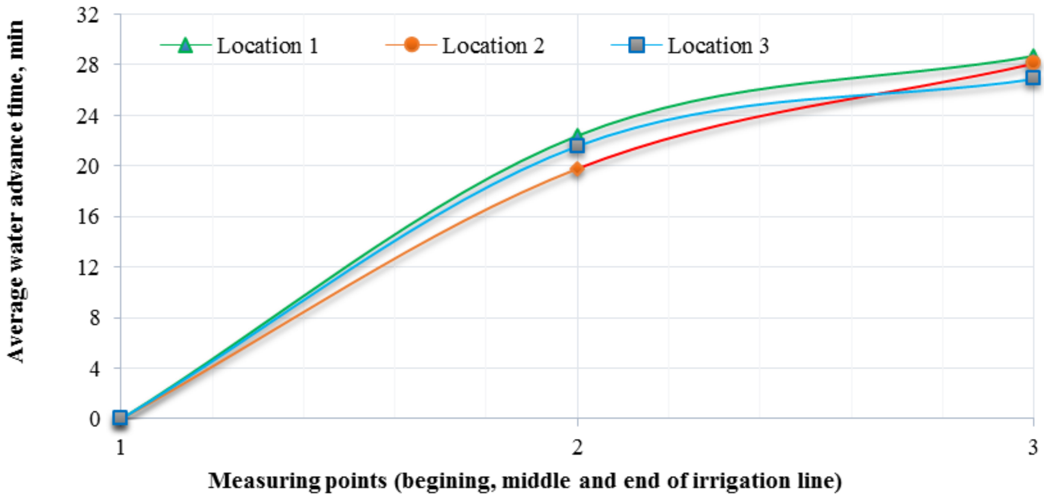

Figure 11 Irrigation water advance times for plots with normal chisel plough

3.2 Effect of using laser-controlled chisel plough on irrigation water advance times and total applied irrigation water

Irrigation water advance time was recorded in two points (middle and end of the field) for three different locations (1, 2, and 3). Irrigation water advance times were shorter with plots that were ploughed by using laser-controlled chisel. The water advance times recorded were 13.2, 16.5 min at middle and end of irrigation line respectively for location 1, as shown in Figure 10. For location 2 and 3 the data followed the same trend with a little variation without insignificant difference in recorded data. Total applied irrigation water was 8468 m^3 ha^{-1} (28.22 cm of water was applied in each replication). Much longer irrigation water advance time were observed in plots where the normal chisel plough was used. Average advance times were 22.4, 28.7 min for middle and end of location 1. While, location 2 and 3 recorded 19.8, 28.1 min and 21.6, 26.9 min water advance times, respectively (Figure 11). Total applied irrigation water was 9835 m^3 ha^{-1} (32.78 cm of water was applied in each replication). Although, in both cases, using regular or laser-controlled chisel plough, there was a laser land levelling operation after a tillage operation, but the variation in irrigation water advance time is an indicator that the laser aided chisel plough is superior to the regular one (better water application efficiency).

4 Conclusions

Considering the uniform height of the sub-surface tilled layer, the developed laser-controlled chisel plough was successful. The system can utilize an existing laser unit to perform a desirable tillage without leaving untilled soils that can affect the quality of other agricultural operations. Tilled soil elevation variation was very limited using the developed system compared to the regular chisel plough, which will make the seed placement more consistent and will result in a better yield. Irrigation water advance times were shorter with plots that were ploughed using the developed laser-controlled chisel, thus, it will lead to lower water use. In this study, the water required for irrigation was reduced by 14% when the developed prototype was used in the land preparation compared the normal chisel ploughing.

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Nomenclature

AHRS: Attitude Heading Reference System

CaCO3: Calcium Carbonate

GNSS: Global Navigation Satellite System

LASER: light amplification by stimulated emission of radiation

TLRSLLPF: Tractor-Attached Laser-Controlled Rotary Scraper Land Leveler for Paddy Fields

WGS84: The World Geodetic System () coordinates