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Contour Laser Guiding for the Mechanized "Vallerani" Micro-catchment Water Harvesting Systems

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Abstract: Mechanized construction of micro-catchments for water harvesting (WH) was successfully tested in the Badia (dry rangeland) areas in Syria and Jordan, using the "Vallerani" plow, model Delfino (50 MI/CM), manufactured by Nardi, Italy. The plow was able to construct intermittent and continuous contour ridges, and could potentially be used to rehabilitate degraded rangelands. However, one major issue for large-scale implementation is the high cost and time required to manually identify contours for the plow to follow. Most existing auto-guiding systems, as usually used in road construction and agricultural land leveling, were expensive or impractical. The objective, therefore, was to add, adapt, and evaluate an auto-guiding system to enable a tractor to follow contours without demarcation through conventional surveying. A low-cost Contour Laser Guiding (CLG) system, with specifications that suit the contour ridging in undulating topographic conditions of dry rangelands, was chosen, adapted, mounted, and tested, under actual field conditions. The system consisted mainly of a portable laser transmitter and a tractor-mounted receiver, connected to a guidance display panel. The system was field-tested on 95 ha of land where the system capacity was determined under different terrains, slopes (1-8%), and ridge spacings (4-12 m). The easy adaptation and implementation of the CLG to the "Vallerani" unit tripled the system capacity, improved efficiency and precision, and substantially reduced the cost of constructing micro-catchments for WH. The system is recommended for large-scale rangeland rehabilitation projects in the dry areas, not only in West Asia, but worldwide.

Key words: Badia, land degradation, contour micro-catchments, laser guiding, Vallerani system.

1. Background

Micro-catchment water harvesting (WH) systems have been tested in the dry rangelands for rehabilitation and combating desertification in these low rainfall areas. In the Jordanian and Syrian dry rangelands (Badia), investigations have demonstrated several successes over hundreds of hectares (Fig. 1). WH techniques included contour ridges and bunds implemented along contour lines of sloped areas; however, most of these techniques have lacked specialized machinery that supports their implementation. The conventional methods were slow, costly, and laborious. Al-Tabini et al. [1] reported that the lack of mechanized power (of unconventional machinery) in establishing WH systems has limited its large-scale implementation.

Mechanized intermittent and continuous contour ridging, the so-called "Vallerani" system, was

Fig. 1 Contour water-harvesting micro-catchments constructed by the Vallerani mechanized system (Badia, Jordan).

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successfully tested for rehabilitating the degraded dry rangelands in many West-Asian, North African, and Sub-Saharan African countries as well as in the Badia and has been the most successful method so far.

In this system, the WH structures are constructed by a special plough designed to construct open contour micro-catchments of either a continuous furrow/ridge or semicircular micro-basins (bunds) at a high capacity of 400 micro-basins/h, Antinori and Malagnoux et al. [2, 3] reported up to 700-1200 micro-basins/h. This can provide substantial soil water storage capacity of 0.200-0.600 m^3/bund [4]. In addition, its implementation provided a low cost and practical means of constructing the WH systems at 15-20 ha/d [2, 5]. Taking into account the harsh topographic conditions prevailing in the Badia, such capacity is acceptable for large-scale implementation.

The "Vallerani" system has been tested by ICARDA since 1997 in Syria and Jordan as well as many North African countries; however, it has not reached its potential capacity due to the slow pace and high cost of manual layout of the contour lines, which should precede the implementation. A team of three surveyors was able to establish contours for only 5 ha/d, which was considered as a bottleneck in its implementation. In Syria, research within the project "Communal Management and Optimization of Mechanized Micro-catchment Water Harvesting for Combating Desertification in the East Mediterranean Region" on the costing of the implementation of the system showed that manual identification of contour lines preceding the operation more than doubled the total cost per hectare of constructing the ridges [6, 7].

To overcome this limitation of the system, this work aimed at developing a mechanism to guide the tractor to run automatically along the contour lines without the need to follow surveyors' marks. Several GPS-based auto-guiding systems were considered (www.trimble.com/agriculture) for this purpose, which were either very costly and/or very complicated. The most suitable was a laser-based guiding system (LGS). The system was first adapted for land-leveling in agriculture, mining, and road construction applications in many countries such as Australia, India, Japan, and the US. The LGS in such applications consists of:

(1) A transmitter of a rotating laser beam. The transmitter is mounted on a tripod which allows the laser beam to sweep unobstructed above the tractor, with the plane of light above the field;

(2) A laser receiver mounted on a mast intercepts the laser beam, detects the position of the laser reference and sends a signal to the control panel;

(3) An electrical control panel interprets the signal from the receiver, magnifies it, and sends an actuating signal to the tractor hydraulic system;

(4) An electro-hydraulic control valve which controls oil flow, to raise or lower a leveling bucket or blade.

This system, described by Rickman and Jat et al. [8, 9], requires alteration of the tractor hydraulic system for installation of the electro-hydraulic control valve. It also requires much field preparation and a topographic survey.

Fortunately, contour ridging has no leveler (i.e. blade or bucket) needing to be lowered and raised by an electro-hydraulic valve. This encourages the use and adaptation of the LGS without the control valve (component (d) mentioned above), and the replacement of the control panel (component (c) mentioned above) with a display panel. Therefore, these changes end up with a simpler Contour Laser Guiding (CLG) system.

Thus, the objective of the current research work was to improve the capacity of the "Vallerani" mechanized system in contour ridging by adding, adapting and evaluating a CLG to enable a tractor to follow the contour lines "on-the-go" (i.e. without prior marking of the contour lines).

2. Methodology

The Vallerani WH contour ridging is a heavy load soil formation that consists of constructing deep (30-60 cm) continuous or intermittent ridges or bunds (pits) along a contour line. The ridges are made to face the upstream slope, thus runoff water flowing downstream is intercepted and collected within the created bund to infiltrate and fill the soil profile for plant use. The distance between two successive contour ridges usually ranges from 4 to 16 m, depending on the runoff coefficient, soil characteristics, slope, and the plants to be grown. Therefore, the fall in elevation between ridges varies accordingly.

The "Vallerani" machine (model Delfino (50 MI/CM), manufactured by Nardi, Italy) was attached to a 134 HP (98.5 kW) tractor (model L135 TDI, Landini, Italy) with the CLG devices mounted and operated. The system was tested on 95.4 ha in the Jordan Badia in different fields with slopes of range 2-8% and with 4, 6, 8, and 12 m spacing between successive contour ridges, on 18.2, 17.5, 33.3, and 26.4 ha, respectively. For all worked fields, the traveling speed in plowing and the speed in transporting between passes were 3.8 and 6.2 km/h, respectively. Area covered and time spent, to work fields with different spacing between successive contour rides, were recorded.

Fig. 2 The laser beam transmitter mounted on a tripod on uphill side.

Fig. 3 Laser receiver mounted on a telescopic mast on the tractor.

Fig. 4 Display panel mounted in front of the tractor operator.

2.1 CLG Devices and the Principle of Operation

The CLG can detect and measure the difference in elevation between the current tractor position (while traveling) and that of a reference point in the field as displayed on a panel in front of the tractor operator. The operator can easily steer the tractor in a way that keeps this difference unchanged, thus maintaining tractor travel on the contour line. In this case, the required CLG devices are a laser transmitter (1000-m radius of coverage) mounted on a tripod (Fig. 2), a laser receiver mounted on a mast (Fig. 3), and an electrical display panel (Fig. 4) with visual and sound display.

The laser transmitter transmits a rotating laser beam (in the horizontal plane), which is intercepted by the laser receiver mounted on a telescopic mast on the tractor and sends a signal to the display panel. The display panel interprets the signal from the receiver and displays signals for the operator. The signals indicate not only the matching of levels, but also how far (up or down) the levels do not match, so the operator can decide where to steer the tractor (left or right) to maintain travel along the contour. This is true as far as the beam is intercepted by the receiver. Therefore, the length of the receiver determines the difference in elevation that can be detected and determines the time that the display can show a reading on the panel, and hence the number of contours worked at the current position of the receiver.

When switching to the next downhill (or uphill) contour line, if the receiver can still intercept the laser beam, then the operator can continue opening ridges without any adjustments. Otherwise, the operator should rise (or lower) the receiver on its mast until the signal is displayed and then continue operation. After working a number of passes, when it becomes impossible to raise or lower the receiver on the mast due to insufficient length of the mast, the transmitter with its tripod should be either lowered (or raised) or relocated downhill (or uphill) so the laser beam can again be intercepted by the receiver.

Providing that the transmitter is located on the uphill side, the operator, while driving along the contour line, might face the following five possible guiding situations and react accordingly (Fig. 5):

(1) The signal on the display panel indicates no difference in elevation between the laser beam and the tractor (the tractor is traveling exactly on the contour line). The operator should keep traveling without steering right or left;

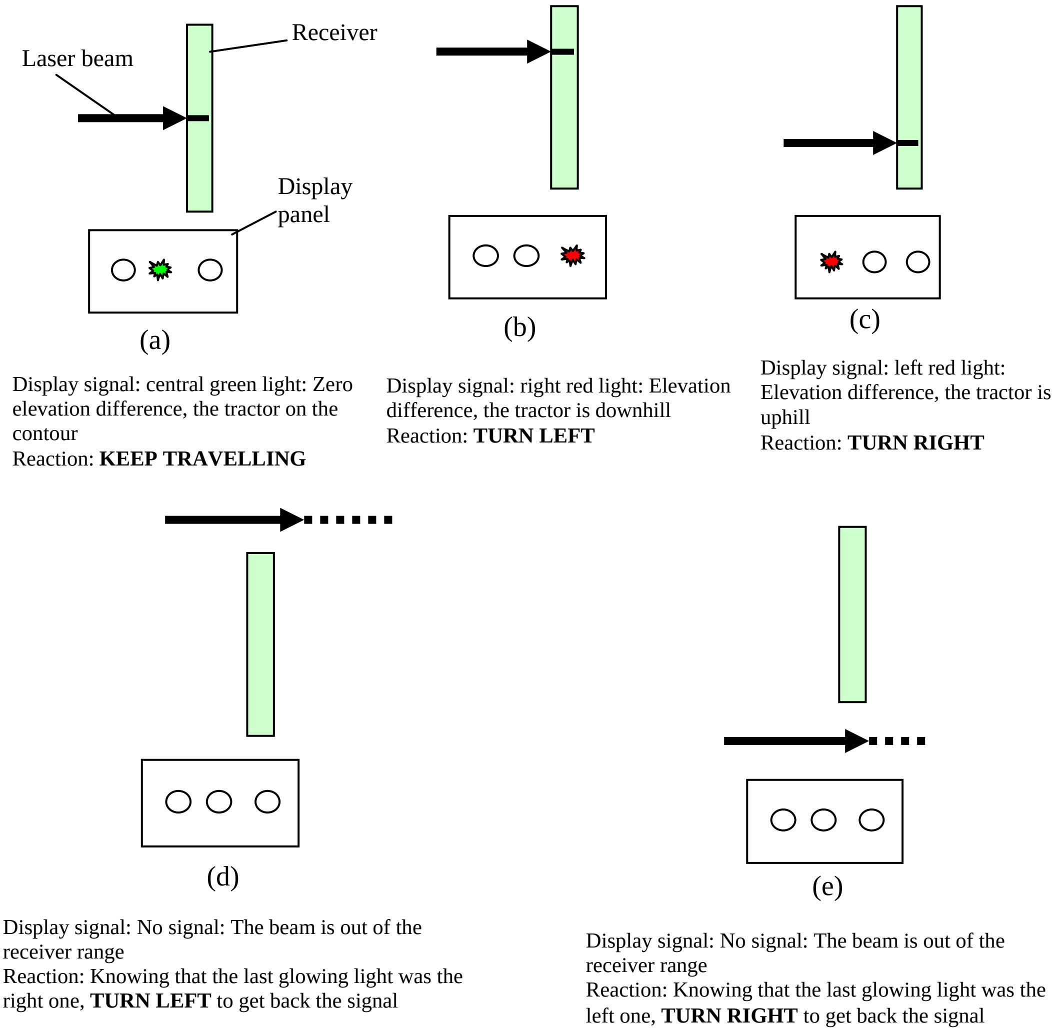

Fig. 5 Five possible guiding situations (a, b, c, d, and e) met while driving on a contour line with CLG system.

(2) The signal on the display panel indicates an increased difference in elevation between the laser beam and the tractor (the tractor is downhill of the contour line). The operator should turn the steering left (uphill) to reinstate the zero difference;

(3) The signal on the display panel indicates decreased difference in elevation between the laser beam and the tractor (the tractor is uphill of the contour line). The operator should turn the steering right (downhill) to reinstate the zero difference;

(4) Passing through situation (2), the operator reacted incorrectly and continued driving downhill until the display signal has been lost. The operator should turn the steering left (uphill) to catch the signal and reinstate a zero difference;

(5) Passing through situation (3), the operator reacted incorrectly, and continued driving uphill until the display signal has been lost. The operator should turn the steering right (downhill) to catch the signal and reinstate a zero difference.

Therefore, the operator may react differently in each situation to maintain travel along the contour line. A skilled operator should work within the first three possibilities described, i.e. (1), (2), or (3).

2.2 Determining System Capacity

The actual field capacity (AFC) of the system, measured in ha/hr for each field, was determined by dividing the area worked over actual time spent as measured in the field [10].

In evaluating the appropriateness of the CLG in practical implementation of contour ridging under prevailing conditions, the following parameters were determined:

(1) The number of contour ridges (B) that can be worked without any need to readjust the position of the receiver on the mast.

B = L/H (Rounded to the nearest whole number),

Where,

L is length of photocells on the receiver. In the installed devices, (L = 31 cm);

H is the fall in elevation when moving from an uphill to the next downhill ridge in cm. H = percentage slope × ridge spacing.

(2) The number of ridges (C) that can be constructed without any need to lower (or raise) the transmitter on the tripod or to relocate it downhill (or uphill).

C = D/H (Rounded to the nearest whole number), where

D is adjustable difference in elevation between the transmitter and the receiver on the mast according to ordered devices (D = 120 cm).

The parameters B and C can be considered as reasonable indicators for high performance during ridging application on-the-go. The higher they are the less action is required from the operator while traveling and consequently the higher the capacity and automation level of the system. Inversely, the lower B and C are the greater is the number of adjustments required.

3. CLG System Performance

The operation was successful in that the ridges were constructed on the contour lines (as checked by conventional topography survey instruments), and the operator was able to easily acquire the guiding skills within one or two passes.

The average AFC (ha/h) of the system was directly proportional to the spacing between WH ridges (Table 1). It ranged from 0.8 ha/h with 4-m spacing to 2.6 ha/h with 12-m spacing. With the accustomed spacing followed in the Badia (the 8-m), the AFC averaged 1.8 ha/h, which is equivalent to 18 ha/day in a 10-hours working day. The overall averaged AFC for all tested spacings resulted in a 16 ha/day (Table 1). This obviously showed that the use of CLG system has eliminated the low implementation pace of Vallerani WH system when traditional land surveying was used.

The parameters B and C were determined for different slopes and different spacings between ridges (Table 2). For example, with slope of 4% and contour spacing of 8 m (giving a 9-m effective working width),

Table 1 Area (A) and actual field capacity (AFC) as measured for different spacing between successive ridges in all test fields (Jordanian Badia), with average AFC for different spacings and the overall average AFC of all fields and spacings.

Ridge spacing	4 m		6 m		8 m		12 m	
	A (ha)	AFC (ha/h)	A (ha)	AFC (ha/h)	A (ha)	AFC (ha/h)	A (ha)	AFC (ha/h)
Test fields								
Field 1	2.4	0.68	2.9	0.98	4.8	1.76	7.1	2.59
Field 2	5.8	0.85	3.1	1.02	6.5	1.83	9.4	2.64
Field 3	2.9	0.79	3.4	1.20	3.4	1.81	9.9	2.63
Field 4	3.6	0.81	6.4	1.26	12.4	1.88	-	-
Field 5	3.5	0.82	1.7	1.09	4.2	1.85	-	-
Field 6	-	-	-	-	2.0	1.80	-	-
Average		0.79		1.11		1.82		2.62
Overall Av. AFC				1.59				

Table 2 Numbers of ridges that can be made on-the-go before adjusting the receiver (B), and before adjusting the transmitter (C), calculated for different slopes and spacings between contour ridges.

	Slope							
	To 2%		To 4%		To 6%		To 8%	
	B	C	B	C	B	C	B	C
Ridges spacing (m)								
4	4	15	2	7 or 8	1 or 2	5	1	3 or 4
6	2 or 3	10	1 or 2	5	1	3 or 4	1	2 or 3
8	1 or 2	7	1	3 or 4	1	2 or 3	1	1 or 2
12	1	5	1	2 or 3	1	1 or 2	1	1

the operator needed to adjust the receiver each pass (B = 1) and the elevation of the transmitter every fifth pass (C = 4). Assuming that the average length of the passes in such a case was 500 m, thus the area covered was 500m × 9 m × 4 passes, which is equal to 1.8 ha. This area was doubled with a slope of 2% and contour spacing of 4 m (Table 2). Furthermore, the automation level was considerably improved (B = 4 and C = 15). This is a quite acceptable system efficiency and is appropriate to the application.

The number of adjustments was clearly increased (low B and C) with increases in both spacing between ridges and slope (Table 2). Fortunately, in WH systems, the steeper the slope the smaller the spacing between the ridges should be. Therefore, the shaded numbers of B and C (Table 2) describe techniques that are practically not used.

The CLG system devices that were installed and adapted to be used in this work are similar to those used in land leveling applications, where slopes are mild or zero. Therefore, the relatively frequent adjustment and relocation of the transmitter and receiver (low numbers of B and C) indicate somehow a weakness in the guiding system. Such a weakness can be overcome by:

(1) Using a longer receiver and a taller mast especially manufactured for contour ridging;

(2) Using an electro-adjustable mast, so the operator can relocate the receiver while driving;

(3) Planning the field works to allow construction of long rather than short contour ridges by switching from one hill to an adjacent one, and choosing suitable locations for the transmitter to cover long fields of similar slope.

The implementation of the CLG on the "Vallerani" unit was successful in that the operation was accurately along the contour and the cost of contour layout was substantially reduced. The surveying works were completely eliminated from WH operation. The potential capacity of the mechanized contour ridging was, therefore, achieved by being able to lay out contour lines on-the-go for 15-20 ha/d. Following are some of additional advantages, compared with conventional surveyed contour ridging:

(1) Time and effort saving: In large-scale implementation of WH structures it is critical to start and finish land preparation before the first rain. This aids timeliness and hence improves WH systems management;

(2) Cost reduction: Traditional land surveying (surveyors and equipment) is more costly than CLG, especially if considered over many years, and bearing in mind that the targeted areas of interventions have low productivity;

(3) Ease of operation: While traditional surveying needs at least two skilled surveyors, the CLG can be operated by one operator with minimum training;

(4) High accuracy: The tractor driver usually moves between marks pegged by surveyors in straight lines, which affects the accuracy of tracing contour lines. However, in CLG the operator is continuously guided to trace the contours. This ensures even elevation inside the catchments and thus ensures an even distribution of harvested water along them. In addition, sometimes tractor drivers are confused by closely spaced adjacent surveyors' marks and drive toward the wrong mark;

(5) The laser guidance system can be used as surveying equipment with greater range of coverage than traditional surveying equipment, and can guide as many surveyors or receivers as needed.

4. Conclusion

The adaptation and implementation of the CLG system to the micro-catchment WH mechanical unit ("Vallerani") increased the system efficiency by at least three times and substantially reduced the cost of implementation. The improved system, after full evaluation, is recommended for large-scale rehabilitation-of-rangeland development projects in the Badia and similar dry rangelands worldwide. Furthermore, testing and evaluation revealed that the performance of the CLG system can, with the cooperation of manufacturers, be further enhanced to better suit contour ridging with minor changes to the devices' specifications.

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