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Performance and Adaptation of the Vallerani Mechanized Water Harvesting System in Degraded Badia Rangelands

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Abstract: Rainwater harvesting in micro-catchments such as contour ridges and semicircular bunds is an option for utilizing the limited rainfall, improving productivity and combating land degradation in dry rangeland areas (Badia). However, implementation of this practice using manual labor or traditional machinery is slow, tedious and costly, and often impractical on a large scale. These limitations can be overcome using the “Vallerani” plow for quickly constructing continuous and intermittent ridges. The plow (model Delfino (50 MI/CM), manufactured by Nardi, Italy) was tested and adapted to dry steppe (Badia) conditions in Jordan. The performance of the machine, its weaknesses and potential improvements were assessed in the 2006/07 season at three sites on 165 hectares of various terrain, slope and soil conditions. The performance parameters included effective field capacity (EFC), machine efficiency (ME) and fuel consumption (FC). Field tests were carried out at different tractor (134 HP) traveling speeds, pit sizes and contour spacings. Overall mean performance indicators gave an EFC of 1.2 ha/h, 51% ME and an average FC of 5.15 liter/ha. Increasing ridge spacing had a small effect on ME where, increasing traveling speed had a greater effect. A guide table was developed, relating performance parameters with ridge spacing, speed, and bund size setting. This could be a useful reference for the implementation and management of mechanized micro-catchment construction in the Badia. The system performed well in the construction of continuous ridges. However, it was unable to construct intermittent ridges at speeds over 4km/h; problems were encountered in properly staggering the bunds at successive contours.

Key words: Land degradation, contour micro-catchments, Vallerani system, machine capacity, machine efficiency, Badia.

1. Background

As pressure on land increases, more marginal areas are being used for agriculture. Much of this land is located in the arid or semi-arid belts where rain falls irregularly and over 90% of the precious water is soon lost to evaporation and surface runoff to salt sinks [1]. Recent intense droughts have highlighted the risks to human beings and livestock. Consequently, there is now increased interest and growing awareness of the potential of water harvesting (WH) as a low cost alternative for improved crop and rangeland production and combating land degradation in this fragile agroecosystem.

During the last few decades, a number of WH projects have been implemented in the Eastern Mediterranean and North and sub-Saharan African regions. They have aimed to improve plant production (usually trees, forage crops and shrubs), and in certain areas to rehabilitate abandoned and degraded lands [2]. While few of the projects were successful in combining technical efficiency with low cost and acceptability to local farmers or agro-pastoralists, others have failed because the technology used proved to be unsuitable for the specific prevailing natural and socio-economic conditions of the site. In some areas

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the technical resources and tools were limited [1, 3]. The lack of specialized (unconventional) machinery to support the implementation of techniques for water harvesting and plant establishment (catchment constructing, transplanting or seeding) was one of the most serious constraints faced. Using conventional machinery did not prove to be adequate for rehabilitating large areas. It proved to be imprecise, tedious, slow and costly. Libbin et al. [4] reported that the lack of mechanized power limited the establishment of WH systems in small-scale projects.

Significant progress came with the development of the mechanized system of collection of surface runoff known as the "Vallerani System" (named after its Italian inventor). The first experiments of the Vallerani system was carried out in 1988 in the framework of the Integrated Programme for Rehabilitation of the Damergou (FAI-Niger). In this system, the WH structures are constructed by a special plow, of which there are two versions, Delfino (dolphin) and Treno (train). The Delfino was designed to construct micro-catchments or semicircular micro-basins (bunds).

The water-holding capacity of the micro-catchment is 0.200-0.600 m^3, on either side of a continuous ridge. Using this plow, up to 400 micro-basins per hour can be constructed by Antinori et al. [5]. Malagnoux et al. [6] reported even higher rates of construction of 700-1200 micro-basins per hour. To build similar water harvesting structures using traditional tools and intensive labor required 80 man/days per hectare [6], while using the Vallerani ridge-opener [7, 8] 1 to 2 hectares of land could be treated in one hour.

Reports [5, 6, 8] indicate that this system can be used in areas with an annual precipitation of more than 200 mm and on slopes of 2%-10%. They have also shown that the use of the Vallerani plow can be economic when large areas need to be treated and if quick action is required. Since 1988, this new technology has been tested in many countries (Burkina Faso, Chad, Egypt, China, Kenya, Morocco, Niger, Senegal, Sudan, Syria, Jordan, and Tunisia), where a total of nearly 100,000 ha have been treated.

The system was first tested in the steppe rangelands of Syria [9]. The Vallerani plow was used to construct micro-catchment intermittent bunds on slopes of 4% and 6% with catchment areas of 40, 80, and 120 m^2 per bund, each planted with two Atriplex shrubs. This research showed that the mechanized bunds provided three times more water to the shrubs than those with no water harvesting bunds. Under micro-catchment, shrub survival rate was increased from 30% to 90%. Mechanically constructed bunds outperformed handmade bunds in all indicators due mainly to the impact of subsoil ripping.

In 2003 ICARDA initiated a research project "Communal Management and Optimization of Mechanized Micro-catchment Water Harvesting for Combating Desertification in the East Mediterranean Region" in the marginal steppe of Syria and Jordan. The project was centered on mechanized implementation of micro-catchment WH using the Vallerani system and was aimed at reducing land degradation and improving the livelihoods of local communities. In addition to community participation and institution related aspects, the implementation process aimed to answer questions related to the technical performance, cost-effectiveness, and impact of the mechanized system on soil-water-plant conditions at the experimental sites.

The work presented in this paper, as part of the Vallerani project, concentrated on the technical evaluation and adaptation of the Vallerani mechanized system to the prevailing conditions in the Badia. The objectives include:

(1) Performance parameters determined under varying operational and field conditions;

(2) Guidelines developed for the efficient use and management of the mechanized system for WH under Badia conditions;

(3) Technical weaknesses of the system identified and suggestions for possible improvements developed.

2. Methods and Materials

2.1 Equipment Description and Field Tests

The machine (model Delfino, Fig. 1) is a hydraulic single ridge plow with a specially shaped working body (mounted moldboard type), fitted with a sub-soiler for fissuring deep soil layers, and a programmable hydraulically-operated lifting mechanism. The implement is also equipped with a front knife that assists stability during operation and a sweeping blade designed to move back to the ridge the soil clods that are thrown up by the moldboard out to the runoff area side. The hydraulic lifting mechanism uses tractor power take off (PTO), category II as a source of power to operate the hydraulic pump.

When the lifting mechanism is activated, discontinuous ridges (semicircular micro-basins) are produced, otherwise, the plough can construct only continuous ridges. The raising and lowering action of the plow is controlled by a directional control valve (spool type). This is operated by a ground-driven wheel through a series of drive/driven sprockets and chains of different sizes. Depending on the selected combination of sprockets engaged, four (L+S) pit's sizes (Fig. 2a) can be obtained (L = 1.6, 2.5, 3.6, and 4.7 m long, and S = 0.7, 1.1, 1.6, and 2.3 m spacing between successive bunds, respectively).

The hydraulically controlled movement of the plough bottom while traveling, alternating from an upwards to a downwards motion, simulates the movement of dolphins riding the waves. With each plunge, the plough digs a semi-circular micro-basin (eye bow shape bund) and forms a pad of earth towards the uphill side for catching runoff (Fig. 2a). Each micro-basin is broken up when the plough is raised. Staggering the bunds on slopes is essential to catch the runoff effectively and prevent it from forming erosive water rills.

The machine was able to create either intermittent or continuous ridges of 50 + 50 cm wide and 50 cm high (from the bottom of the ridge), with a 40 cm ridge depth, plus sub-soiling to 15-25 cm below the ridge bottom (Fig. 2b).

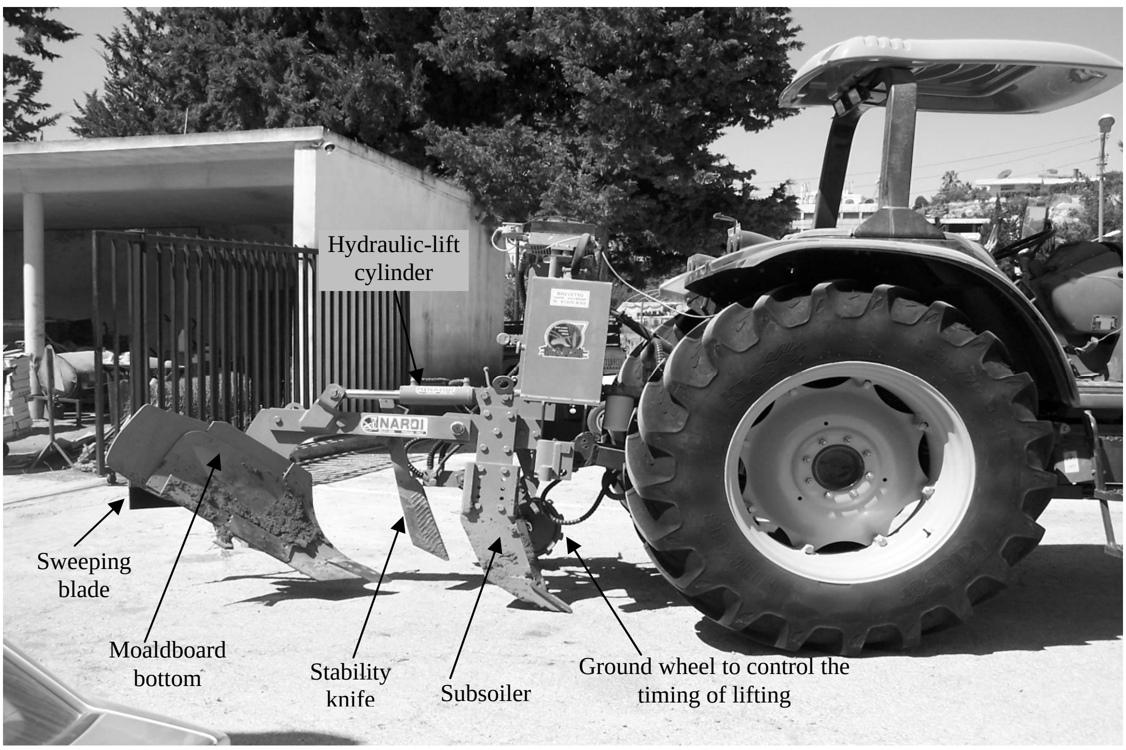

Fig. 1 The Vallerani machine (Delfino) mounted on 134-hp tractor (Category II-3PHS+540 rpm-PTO).

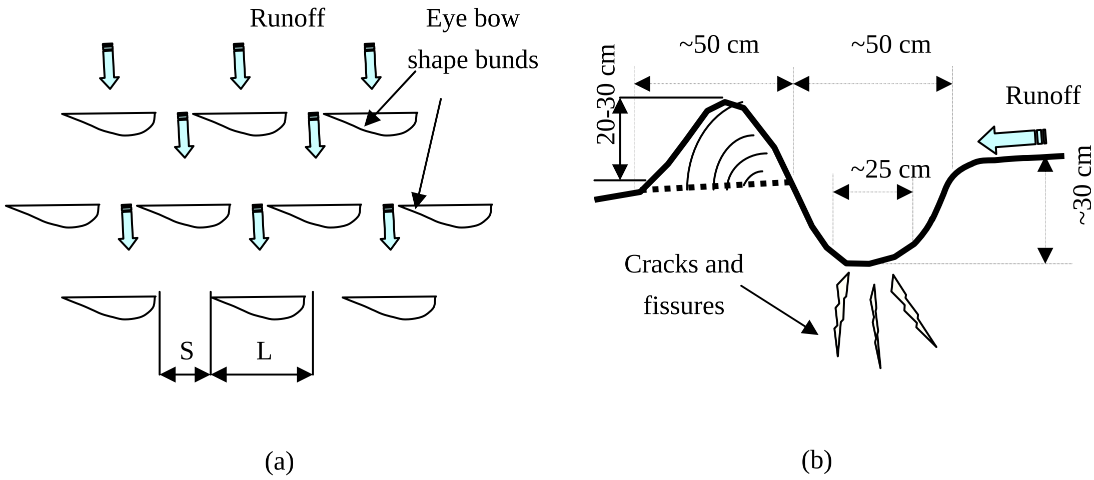

Fig. 2 (a) The staggered lay-out of the bunds in the field (top view). (b) Soil profile cut of the Vallerani micro-catchment bund with dimensions.

The machine was designed and built to allow plowing heavy soils (thick and flat soils of alluvial origin) that the African farmers were not able to work with their traditional implements [6]. For the weight of this plough to be lifted and the movement that animates it and the necessary execution speed for optimal operation, a heavy tractor with the power of at least 130-160 hp (96-119 kW) was required. Working heavy soils with less tractor power may cause improper operation of the machine, imposed reduction of working depth or damage to the hitching system of the tractor. However, lower tractor power may be allowed when working lighter soils.

The Vallerani plow (Delfino 50 MI/CM) was mounted on the 3-point-hitch system (3PHS) of a 134 HP (98.5 kW) tractor (Landini, Italy, model L135 TDI) and the pump of the hydraulic lifting mechanism of the plow was powered from the PTO of the tractor.

The field tests to evaluate the performance of the integrated unit (tractor and Delfino plow) were carried out on three project sites, in the Majdiyyeh, Mhareb, and Mafraq regions (Jordanian Badia) for 4, 8, and 6 working days (118 working hours) covering approximately 20, 85, and 60 hectares, respectively.

The dominant soils in the three test sites were silty clay loam (a few were silty clay and even fewer were clay loam and silt loam) with low organic matter, weak aggregation, platy structure, and crusty surface with poor vegetation cover. As a result of erosion by water, the soil depth decreased proportionally with increased slope. It ranged between 20-50 cm on slopes higher than 8%, while on locations where the slope was less than 2%, the soil was more than 160 cm deep. In some locations, medium-sized stones (5-15 cm diameter at depths of about 30 cm) were moved with the plow. In other locations (mostly uphill) shallow rocky pans were found. In such cases the working depth was reduced to avoid breaking the soil-engaging tools. Therefore, the soil and topography conditions of the mentioned test sites, in general, required lower operational power than that designed for conditions in Niger and sub-Saharan African regions that the machine was initially built for.

Tested on different hilly fields with slopes (Fig. 3) ranging between 1% and 8%, the machine constructed both continuous and intermittent (micro-basins) contour ridges with 4, 8, and 12 m spacing between ridges, and at different average tractor traveling speeds (2, 3, 4, and 5 km/h). Speeds greater than 5 km/h were not used due to machine and human safety considerations. The working depth ranged between 0.4 and 0.5 m while the subsoil ripper reached down to a depth of 0.5-0.6 m from the soil surface.

Trials were implemented on 165 hectares, on 145

Fig. 3 Constructing Vallerani micro basins of different sizes on the contours of different slopes (Badia, Jordan).

hectares of which 21,900 intermittent bunds of four different sizes (length and spacing) were constructed. The continuous contour ridges covered an area of 20 hectares, which was estimated to be equivalent to 3,000 bunds.

2.2 Measurements and Parameters

Direct measurements to evaluate the performance of the tractor/plow system included: time, traveling speeds, ridge lengths, number of bunds, area covered and volume of consumed fuel.

2.2.1 Theoretical Machine Capacity

According to Ref. [10], theoretical machine capacity can be determined by the following equation:

$$TMC_A = V \times E_w \times 0.1 \quad (1)$$

where

TMC_A is the theoretical machine capacity by area (worked area per time, hectare/hour);

V is the tractor traveling speed (km/h);

E_w is the effective working width (m), which equals runoff area length + micro-catchment width;

0.1 is the unit conversion factor.

Eq. (1) is used when both continuous ridges and intermittent bunds are constructed.

However, if we ignore the length of the runoff catchment, two other versions of the equation can be derived:

$$TMC_L = V \quad (2)$$

and

$$TMC_P = TMC_L / (L+S) \quad (3)$$

where

TMC_L is theoretical machine capacity by the length of constructed ridges (km/hour);

TMC_P is the theoretical machine capacity by bunds (number of constructed bunds/hour);

L_P is the length of the bund (m);

S is spacing between successive bunds (m).

Eq. (2) was used when the machine constructed continuous ridges and Eq. (3) when intermittent ridges were constructed.

In WH systems, spacing between ridges (length of runoff area) may vary considerably depending on crop water requirements, rainfall characteristics and runoff coefficient. The latter greatly depends on the slope. Theoretical machine capacity by area (TMC_A) can be conveniently used to compare techniques with similar spacing between successive ridges or bunds, though not when different spacings are to be compared. In such cases, the machine's effective working width was ignored and TMC_A (Eq. (1)) was replaced by TMC_L and TMC_P (Eqs. (2) and (3)) to express the length of the worked ridges and the number of bunds constructed per hour, respectively. Such parameters of machine capacity were thought to be more convenient for use in these cases.

2.2.2 Potential and Actual Machine Capacities

Two effective machine capacities were considered: the potential machine capacity ($PMC_{A,L,P}$), and the actual machine capacity (AMC_A). Both were assessed by determining either the area A, the ridge length L, or the number of bunds P constructed over time spent as measured in the field.

$PMC_{A,L,P}$ took into consideration real time lost on (a) turning and going back to the start at every new pass to keep the uphill side to the left side of the tractor, and (b) aligning subsequent ridges to maintain proper staggering of bunds or proper spacing between ridges.

AMC_A took into consideration the time lost on the factors mentioned above plus the time lost on (a) switching from one site or one hill to another, (b) refueling, making adjustments, checkups, maintenance and breakdowns, and (c) work planning and time lost due to the lack of skill of the operator. AMC_A counted the area covered over all work hours of all work days.

2.2.3 Machine Efficiency

According to Ref. [10], machine efficiency is the ratio of the effective machine capacity to theoretical machine capacity and hence, two types of machine efficiency were considered:

(1) Potential machine efficiency, where

$$PME_{A,L,P} = (PMC_{A,L,P} / TMC_{A,L,P}) \times 100\% \quad (4)$$

(2) Actual machine efficiency, where

$$AME_A = (AMC_A / TMC_A) \times 100\% \quad (5)$$

2.2.4 Fuel Consumption

FC was assessed per unit area (hectare) for continuous and intermittent ridges and for different spacing between contour ridges. FC was also calculated per bund and per hour for the entire 165 hectares. To measure fuel consumption, a topping-up method was used, where the fuel tank of the tractor was fully topped up before starting work, then the number of liters added to refill the tank again was determined.

3. Results and Discussion

On the three experimental sites, the tractor/implement unit constructed continuous and intermittent ridges smoothly at the preset plowing depth, traveling speed and micro-basin size, whereas no overloading incidents were encountered. No slipping situations due to overload have been met, and no breakage to the soil engaging tools or to the tractor hitching devices has occurred. This obviously indicated that the selected tractor power to operate the Vallerani machine, under soil and topographical conditions of the *Badia*, was adequate.

3.1 Capacity and Efficiency of the System

3.1.1 Machine Capacity in Constructing Contour Ridges

In constructing continuous ridges, the potential machine capacity, either by area (PMC_A) or by length (PMC_L), increased with increased traveling speed (Table 1). Nevertheless, this gain in capacity decreased as the traveling speed increased. For example, in 4 m ridge spacing, switching from 2 to 3, from 3 to 4, and from 4 to 5 km/h, resulted in 32%, 20%, and 12% gains, respectively (Table 1).

Increasing spacing between successive ridges increased machine capacity by area PMC_A (Table 1). This is due to the increase in the effective width covered by the machine. However, there was no significant effect of ridge spacing on capacity when considering machine capacity by length, PMC_L. Therefore, PMC_A should be used to evaluate the technique rather than the machine, while PMC_L should be used to evaluate the machine.

Although increased traveling speed increased machine capacity, the traveling speed had a

Table 1 Theoretical machine capacities (by area covered TMC_A and by lengths of ridges worked TMC_L), and the respective potential machine capacities (PMC_A, PMC_L) as calculated for Vallerani machine at different average traveling speeds and spacing between successive continuous ridges over 20 hectares (Badia, Jordan).

Spacing between ridges (m)	Average traveling speed (km/h)	TMC_A (ha/h)	TMC_L (km/h)[a]	PMC_A (ha/h)	PMC_L (km/h)
4	2	1	2	0.73	1.46
	3	1.5	3	0.95	1.89
	4	2	4	1.14	2.28
	5	2.5	5	1.28	2.55
8	2	1.8	2	1.25	1.39
	3	2.7	3	1.62	1.80
	4	3.6	4	2.03	2.26
	5	4.5	5	2.29	2.54
12	2	2.6	2	1.82	1.40
	3	3.9	3	2.11	1.62
	4	5.2	4	2.89	2.22
	5	6.5	5	3.21	2.47

[a] TMC_L = Average traveling speed.

noticeably reverse effect on machine efficiency. Increasing traveling speed from 2 to 5 km/h reduced the potential machine efficiency $PME_{A,L}$ from 70.5% to 50.5% (Table 2). This reduction can be attributed to: (1) the time lost by the tractor when turning and traveling back to start a new ridge was the same at 2 and at 5 km/h speeds; and (2) the theoretical machine capacity at 5 km/h was 2.5 times greater than it was at 2 km/h (Table 1), while the potential capacity at 5 km/h was only 1.7 times greater than it was at 2 km/h.

Increasing spacing between successive contour ridges (catchment length) had a slight effect on potential machine efficiency $PME_{A,L}$ (Table 2). This can be attributed to the extra time lost traveling between farther ridges.

3.1.2 Machine Capacity in Constructing Intermittent Bunds

Tests revealed that, at speeds around 2 km/h, the machine was able to construct intermittent ridges of all calibrated bund sizes (L+S). At speeds of around 3 km/h (Table 3), bund size I was lost (the plow continued constructing the ridge without being lifted to form a bund), while bund sizes I, II, and III were lost at speeds of around 4 km/h. Increasing traveling speed over 4 km/h resulted in constructing continuous ridges rather than intermittent ones, a result that has not been reported previously in any region where the Vallerani machine was used. The lifting and lowering action speed was not enough to cope with the traveling speed. This also explains why traveling speeds greater than 4 km/h were not shown in Table 3.

Moreover, measurements showed that the four factory-set bund sizes ($L + S$) were, in fact, different from those actually performed by the machine (Table 3). This can be attributed, first, to the non-synchronous performance of the hydraulic plow-lifting mechanism with the traveling speed and second, to the ground slipping conditions experienced by the tractor due to the weak structure and traction of the soils in the Badia. This also explains why the measured bund size increased with increasing traveling speed. Bund size IV, for example, measured at 2, 3, and 4 km/h was 6.3, 6.5 and 7.2 m, respectively (Table 3).

Table 2 Potential machine efficiency $PME_{A,L}$ (%) for Vallerani machine as affected by traveling speed and spacing between successive continuous ridges (Badia, Jordan).

Spacing (m)	Traveling speed (km/hour)				Average
	2	3	4	5	
4	72.0	63.3	57.0	51.2	60.9
8	69.4	60.0	56.4	50.9	59.2
12	70.0	54.1	55.6	49.4	57.3
Average	70.5	59.1	56.3	50.5	59.1

When constructing intermittent ridges (micro-basins), the effects of both spacing between successive ridges and traveling speed on machine capacity were similar to those when constructing continuous ridges. In addition, increasing bund size had a negative effect on both PMC_A and PMC_P. In 4 m ridge spacing, for example, switching from size II to size IV at 2 km/h traveling speed, greatly reduced PMC_P (from 368 to 177 bund/h), but only slightly reduced PMC_A (from 0.59 to 0.56 ha/h). Such changes in basin sizes and machine capacities should be evaluated together with WH system requirements and with the impact of these changes on soil-water-plant conditions.

The effect of ridge spacing on potential machine efficiency ($PME_{A,P}$), when constructing intermittent ridges (Table 4), was similar to that when constructing continuous ridges. However, the effect of traveling speed on machine efficiency in constructing intermittent ridges was not as high as in the case of continuous ridge. It appears that the time lost by the operator in ensuring acceptable staggering of bunds between successive contour ridges had masked the expected difference in efficiencies between different traveling speeds. This also explains why the magnitudes (Table 4) of machine efficiency (55.8%, 52.8%, and 48.3% at 2, 3, and 4 km/h, respectively) in constructing intermittent ridges were lower than those obtained (Table 2) in constructing continuous ridges (70.5%, 59.1% and 56.3% at 2, 3, and 4 km/h, respectively).

Table 3 Theoretical machine capacities (by area covered TMC_A and by number of bunds constructed TMC_P), and the respective potential machine capacities (PMC_A, PMC_P) as calculated for Vallerani machine at different spacing between intermittent ridges, different traveling speeds, and different bund sizes over 145 hectare (Badia, Jordan).

Spacing between ridges (m)	Average traveling speed (km/h)	Bund size			TMC_A (ha/h)	TMC_P (bund/h)	PMC_A (ha/h)	PMC_P (bund/h)
		Size	L + S (m)					
			Factory set	Actually measured				
	2	I	2.3	2.1		952	NM	NM
		II	3.6	3.2	1	625	0.59	368
		III	5.2	4.8		416	NM	NM
		IV	7	6.3		317	0.56	177
	3	I	2.3	NA	NA	NA	NA	NA
4		II	3.6	3.3		909	0.84	510
		III	5.2	5	1.5	625	NM	NM
		IV	7	6.5		462	0.79	244
	4	I	2.3					
		II	3.6	NA	NA	NA	NA	NA
		III	5.2					
		IV	7	7.2	2	556	0.96	267
	2	I	2.3	2.1		952	NM	NM
		II	3.6	3.2	1.8	625	1.08	375
		III	5.2	4.8		416	NM	NM
		IV	7	6.3		317	0.97	171
	3	I	2.3	NA	NA	NA	NA	NA
8		II	3.6	3.3		909	1.45	490
		III	5.2	5	2.7	625	NM	NM
		IV	7	6.5		462	1.49	256
	4	I	2.3					
		II	3.6	NA	NA	NA	NA	NA
		III	5.2					
		IV	7	7.2	3.6	556	1.73	267
	2	I	2.3	2.1		952	NM	NM
		II	3.6	3.2	2.6	625	1.46	350
		III	5.2	4.8		416	NM	NM
		IV	7	6.3		317	1.29	158
	3	I	2.3	NA	NA	NA	NA	NA
12		II	3.6	3.3		909	1.93	448
		III	5.2	5	3.9	625	NM	NM
		IV	7	6.5		462	1.94	230
	4	I	2.3					
		II	3.6	NA	NA	NA	NA	NA
		III	5.2					
		IV	7	7.2	5.2	556	2.55	272

L:length of bund, S:spacing between successive bunds, NA:not Applicable, NM:not Measured.

Working 165 hectare in 118 hours gave an actual machine capacity by area of 1.4 ha/hr Dividing by the average theoretical machine capacity TMC_A calculated over all worked sites (2.7 ha/h), and multiplying by 100%, the actual machine efficiency over 18 working days was:

$$AME_A = (1.4\ \text{ha}\cdot\text{h}^{-1}/2.7\ \text{ha}\cdot\text{h}^{-1}) \times 100\% = 51\%.$$

This efficiency calculated over 18 working days was lower than the efficiency calculated by averaging all potential efficiencies of continuous ridging (59.1%) (Table 2) or the efficiency of intermittent ridging (53.1%) (Table 4). Such differences were due to the fact that time losses (such as time needed to switch from one location to another or time for rests, maintenance and field work planning) were taken into consideration when calculating actual machine efficiencies, but they were not considered when potential machine efficiencies were calculated.

In general, either potential or actual efficiencies, if compared with efficiencies of regular ridging (or plowing with a moldboard of similar effective width), which usually ranges between 75% and 85% [10, 11], seem to be even lower. Nevertheless, in constructing WH contour ridges, a level of 53% machine efficiency is still acceptable knowing that a one-way plow has to keep plowing in one direction, whereas the tractor has to spend time turning and going back to the start at every new pass to keep the basin facing the uphill side in order to capture the runoff water.

3.1.3 Fuel Consumption

Working 165 ha (~ 24,900 bund) in 118 hours, the total volume of used fuel was 846.6 L. Thus, the actual average FC was 5.13 L/ha, 7.17 L/h and 0.034 L/bund.

In working separate fields, increasing spacing between ridges from 4 to 8 m and from 8 to 12 m decreased the FC measured per hectare by 19% and 11%, respectively (Table 5). Due to the continuous implement engagement with soil, constructing continuous ridges consumed 14% more fuel than intermittent structures. Averaging FC of both continuous and intermittent construction (taking into account the number of worked hectares) resulted in 4.98 L/ha (Table 5), a measure excluding the fuel consumed on traveling from one field to another.

3.2 Technical Issues and Potential Solutions

Working under the soil and topographical conditions of the Badia, the performance of the hydraulic lifting mechanism was affected by the soil depth. When the machine encountered rocky or shallow soil (lass than 50 cm), the plowing depth had to be reduced forcing the ground wheel of the hydraulic mechanism to loose its continuous contact with the soil and thus delaying the lifting action of the plow, which consequently affected the micro-basin set size and further led to irregular staggering of bunds on successive contour ridges. Therefore, it was more stable and convenient to construct shallow continuous ridges, on the uphill sides, rather than intermittent ones.

In some circumstances and due to terrain roughness, the sweeping blade either lost contact with ground and was therefore not able to throw the soil clods produced by the moldboard back to the ridge, or it scraped the soil surface instead of sweeping it, causing damage to the entrance of the basin. To overcome this problem a rubber extension was added to the metal blade. This improved the contact with the soil making it flexible but not rigid and enabled soil sweeping instead of scraping.

Staggering between bunds of s ubsequent

Table 4 Potential machine efficiency $PME_{A, P}$ (%) for Vallerani machine as affected by traveling speed and spacing between successive intermittent ridges (Badia, Jordan).

Traveling speed	2 km/hour		3 km/hour		4 km/hour		
Bund size	II	IV	II	IV	II	IV	
Spacing (m)							Average spacing
4	59	56	56	53	NA	48	54.4
8	60	54	54	55	NA	48	54.2
12	56	50	49	50	NA	49	50.8
Average speed	55.8		52.8		48.3		53.1

NA = Not applicable.

Table 5 Fuel consumption (L/ha) as measured in the fields for continuous and intermittent ridging at different ridge spacings.

Spacing (m)	Continuous ridges (20 ha)	Intermittent ridges (145 ha)	Average row
4	6.58	5.81	5.90
8	5.41	4.70	4.79
12	4.79	4.19	4.26
Average column	5.59	4.90	4.98

intermittent ridges was irregular when: (1) contour ridges were not parallel, which was very common on the double grade slopes of Badia; and (2) when the hydraulic system guide wheel lost contact with the ground due to the rough surface or to shallow plowing. To overcome this problem, the guide wheel was modified so that in these circumstances, it was lifted to roll against the rear wheel of the tractor instead of the ground.

The programmable hydraulically-operated lifting mechanism of the machine began to fail at traveling speeds of around 4 km/h. At higher speeds, either the ridge tended to be continuous rather than intermittent, or the bund size was noticeably increased. This means that the lifting mechanism had not been fast enough to raise the plow from the soil (due to insufficient fluid flow) before the cycle of constructing the next bund had started. This problem can be attributed to the relatively low capacity of the system's pump when higher flow rates at greater traveling speeds were required. Replacing the hydraulic pump and the spool valve with higher capacity ones may be an effective solution of overcoming such system weakness.

4. Conclusions

The actual capacities and efficiencies obtained in this study were lower than those previously reported for Vallerani plows. Nevertheless, the Vallerani mechanized system for the implementation of micro-catchment water harvesting bunds and ridges proved to be a practical way of eliminating much tedious manual work or even traditional mechanized systems. The machine field capacity, its effective efficiency, and its energy consumption were all quite satisfactory for large-scale rehabilitation and improvement of dry rangelands productivity in the East Mediterranean region, as has been previously shown in other regions.

The machine was easily adapted to Jordanian Badia condition. The results of the technical tests performed at different sites under different conditions of the Badia provide useful guidance for the technical management of water harvesting systems to be implemented in the region. With some technical improvements to the existing machine that were suggested in this study, the performance tables could be further enhanced for more effective management of the system.

The main technical problems encountered were first, the slow speed of the hydraulic plow-lifting mechanism, which can be overcome by using a higher capacity hydraulic system, so enabling the machine to work at a higher traveling speed and increasing significantly both the potential field capacity and the actual efficiency, and second, the improper bund staggering across the field, which can be partly improved by modifying the contact conditions of the ground wheel of the plow-lifting mechanism.

Replacing the one-way plow with a reversible one will enable the machine to work on slopes in two directions, which can be expected to significantly increase the machine's effective efficiency.

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