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Article in *International Journal of GEOMATE* · August 2017

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LASER LAND LEVELING FOR CROP YIELD AND WATER EFFICIENCY IN EASTERN AFGHANISTAN

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ABSTRACT: Herein, the impact of land layout improvement (LLI) and laser land leveling (LL leveling) has been studied. In Afghanistan, LLI and LL leveling has been undertaken by the Ministry of Agriculture Irrigation and Livestock through an important project On-Farm Water Management (OFWM) in five regions, wherein poor farm layout and existence of uneven fields, unnecessary bunds, and ditches are responsible for significant water losses (at the farm level) and yield reduction, thereby increasing water and labor demand. Moreover, irrigation systems are used to supply water to the highest levels of the fields. However, this practice often leads to over-irrigation and the reduction of resources and yield. The present field experiments comprised two parts, Farm-A LLI and LL leveling. Farm-B was the control farm; all other practices were maintained constant in Farm-B except for LLI and LL leveling. Farm-A was separated into 29 small, even, and appropriately irrigated fields of less than 0.075 ha. The entire Farm-A area was leveled, and the size of each field increased to 0.19 ha and farm area was enlarged by (6%). The number of fields decreased from 29 to 12, and the number of water inlets decreased from 39 to only 14. These reductions showed a decrease in the labor requirements. In the two fields (Farm-A (leveled) and Farm-B (unleveled)), water demand for the production of wheat, corn, and eggplant decreased by 21%, 27%, and 17%, whereas the yield increased by 21%, 40%, and 38%, respectively. Furthermore, water productivity increased by 39%, 53%, and 37%, respectively.

Keywords: *Laser land leveling, Land layout improvement, Water saving, Yield increase, Area increase*

1. INTRODUCTION

One of the major challenges faced by the agricultural sector of Afghanistan is the high demand for irrigation water [1]. The economy of Afghanistan mostly relies on agriculture, particularly on irrigated agriculture. However, farmers still use traditional farming techniques wherein oxen provide the draught power. The farmers' knowledge of new irrigation technologies and cultural practices is insufficient. Consequently, the efficiency of the irrigation system is quite low (25%–30%) mainly due to high conveyance losses in the traditional watercourse with earth canals, high operational losses in modern schemes with lined conveyance canals, and high on-farm distribution losses (e.g., over-irrigation, poorly leveled land) in both traditional and modern schemes. The productivity levels are low even by regional standards. About 20% of both the traditional and modern irrigation systems require upgrading of the on-farm water management in order to improve the low crop yield or to address water logging and salinization. In fact, the land production potential under low and variable rainfall can be improved by promoting technological transfer [8]–[9].

Irrigated agriculture is the mainstay of food security and income for most of the rural population in Afghanistan. It accounts for more than half of the country's GDP and 70% of the total crop production; moreover, it provides a reliable and sustainable

production base for several rural communities. The total cultivable area of Afghanistan is about 8 million hectares, which is 12% of the total area of the country. Approximately 3.9 million ha of cultivated land exists in Afghanistan, of which 1.3 million ha is rain-fed and 2.6 million ha irrigated. This irrigated area produces almost 85% of the total agricultural production [10]. The cropping intensity varies widely between systems depending on water availability. It reaches 200% in the upper part of the irrigation schemes, whereas in the lower parts, up to two-thirds of the command area are kept fallow each year on a rotational basis. Floods often damage irrigated land, particularly in the large schemes supplied by rivers changing their course frequently due to their high sediment load and unfavorable geomorphological conditions [8]–[9].

In traditional as well as modern irrigation schemes, the dominant irrigation method is basin/border irrigation for cereals and furrow irrigation for vegetables and grapes. Farmers are usually not aware about crop water requirements, and over-irrigation is a common practice. The overall efficiency is only about 25%–30% for both modern and traditional irrigation schemes, resulting in water losses and low productivity [4].

Due to the low water use efficiency and lack of input (chemical fertilizer, improved seed, etc.) crop yields are very low. At present, drought has caused further reduction in the crop yields, e.g., the average

yield of wheat is 0.8 tons/ha today, as opposed to about 1.1 tons/ha in 1978. The total area (irrigated and rain-fed) for cereal crops is about 3.39 million ha. The total cereal production is 4.15 million tons, 2.65 million tons of which is dedicated only to wheat [8-9].

Traditional management practices of the irrigation supplies and conveyance systems often contribute to high water losses. Moreover, low irrigation efficiency is further accentuated by farmers' traditional irrigation methods and practices, as well as inadequate land leveling [12]. Water shortage can be overcome by improving the water use efficiency at the field level [11]. With traditional application of water availability to the fields, the crop yields decrease by 75%–85% on an average, a percentage that varies widely among farms.

Furthermore, poor farm design and uneven fields are responsible for 30% of the water losses [6]. About 18 million acre-feet of water are lost while irrigating uneven fields in Pakistan [2].

Laser land leveling (LL leveling) and agricultural technology transfer were implemented from 2008 to 2011 for wheat crops in the Kama district (Nangarhar and Balkh Province, Afghanistan). The maximum reported wheat yield was 6.18 tons/ha and the minimum was 4.01 tons/ha [7].

The present study was conducted at the irrigation demonstration site of the On-farm Water Management Project in Bahrabad village, (Bihsud district, Nangarhar Province; Fig 1). The objectives are (i) to explore the impact of farm layout improvement; (ii) to investigate the agricultural benefits of LL leveling against the traditional unlevelled field; and (iii) to present an approach for increasing water crop productivity.

2. MATERIALS AND METHODS

This study was conducted at the irrigation demonstration site in 2014. The province is located in eastern Afghanistan (34.27° N, 70.24° E, elevation = 572 m). The climate is subtropical, semi-arid, Mediterranean-type, with frost in during winter. Climatic data collected from Shishum Bagh Agricultural Research Farm indicate that the maximum annual temperature is 42°C and the minimum is -2°C. The annual precipitation varies from 178 mm to 324 mm. Monsoon starts from January and lasts until May, with few showers during summer. The wind velocity is approximately 30 km/h. The maximum wind pressure is observed in July and November [3] [5].

The field experiments comprised two parts. The first part included Farm-A layout improvement, and the second part involved LL leveling. The entire

Farm-A was investigated before commencing the actual experiment. Thus, permanent benchmarks were established.

After installing the benchmarks, a topographic map by total station theodolite (TST) was constructed to survey Farm-A in detail. Next, the features of Farm-A were indicated on the map, and detailed information was given about the slope, the elevations of the low and higher points of the fields, the number and sizes of the fields, the quantities of water inlets, and the available water channels. In the same way, the main water channel and the secondary water channels were surveyed, and their profiles were prepared.

The water channels were designed for earthen lining. In the next step, each field in Farm-A was carefully analyzed to improve the farm's layout. With the new layout, the area size of each field was expanded, and regular straight boundaries were established for all the fields. In addition, the water inlets and control structures were considered as suitable points for the installation of the farm's irrigation system. They were chosen based on the irrigation demand.

Then, the cut-and-fill soil ratio of the low and high points was calculated for each field and indicated in the site plan to facilitate field leveling for the machinery operators. The irrigation channels and the water inlets were adjusted based on the quantity required for the fields. Moreover, the water channels were earthen improved, and brick water inlets and a control structure were proposed. Subsequent layout improvement and water channels (contours, unwanted bunds, and water inlets) were removed.

In the next stage, we applied rough leveling and LL leveling. To implement LL leveling, the maximum elevation difference between the different land points should not be more than 12–15 cm. In this case, however, most of the selected fields exhibited greater differences in elevations. Therefore, to solve this problem, another tractor was hired to plow and make the soil soft for leveling.

LL leveling is also called laser-guided land leveling or precision-custom farming laser land leveling, and it is a process applied for smoothing a land surface up to ± 2 cm from its average elevation with the help of a laser-guided drag bucket.

All the fields were laser-leveled, and their sizes increased to at least 0.19 ha. Thus, 12 fields were established instead of 29 (Fig. 2 and 3). All unnecessary water channels, undesired field boundaries, and ditches were removed, and new straight field bunds were established. After the Farm-A was laser-leveled, leveled fields in Farm-A were chosen to observe the impact of LL-leveling, and unlevelled fields were selected in the adjacent Farm - B (Fig.1).

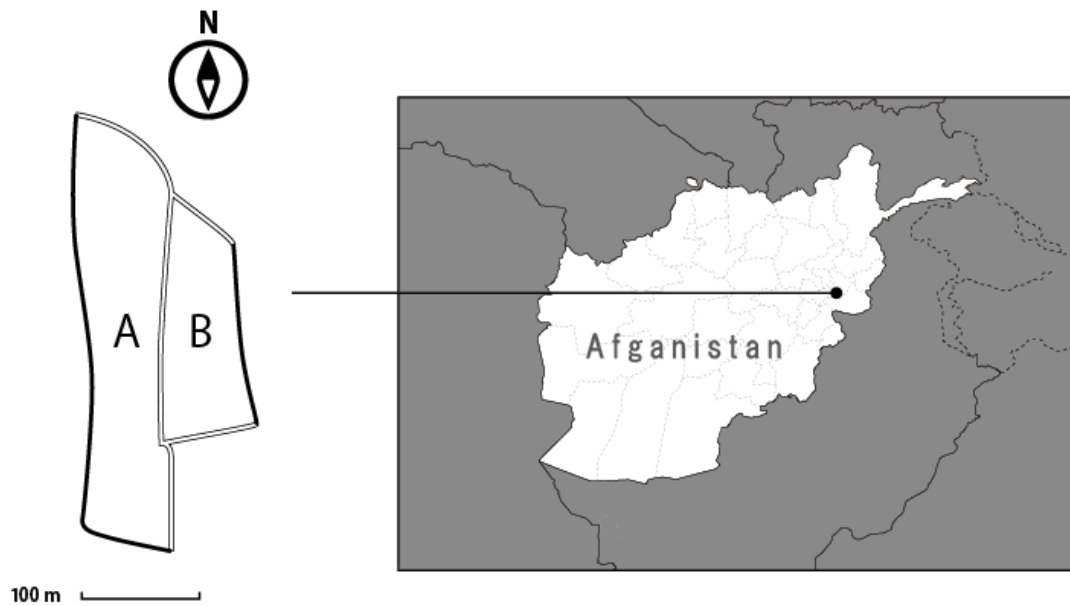


Fig 1 The location of Farm-A and Farm-B, in Nangarhar, Afghanistan (latitude 34.27° N and longitude 70.24° E; elevation = 572 m; Source: Google maps, 2016)

Overall, the leveled fields covered 2054 m², 2052 m², and 1924 m² for wheat, corn, and eggplant, respectively. On the other hand, the unleveled fields covered 1875 m², 2000 m², and 1680 m², respectively. The condition of the crops without LL leveling was considered equal.

The cutthroat flume was used to determine water depth (*WD*) that was applied in the irrigation. The flume was installed in a uniform, straight, and vegetation-free channel. The flume sides were entirely stopped with dirt to prevent water leakage from the sides and beneath the flume. The flume was installed at appropriate points to maintain free-flow conditions for easy calculation. Whenever the water flow became stable, constant readings were recorded; five to six readings were taken during irrigation. The duration of irrigation was recorded, and the area of the fields was measured by TST. Then, the depth of the applied water was calculated for each irrigation line using the hydraulics formula given in Eq. 1. Then, all the crops were harvested manually from both the laser-leveled and the unleveled fields. The productions were weighed using a digital scale measurement device. The water productivities were computed using Eq. 1. The net crop harvested yields and the applied water volume *Q* were used to calculate water productivity. The harvested yield quantity for a single crop was recorded from the field, and irrigations applied were determined based on *WD* (mm) and the later converted into volume.

$$WD = \frac{QT}{A} \quad (1)$$

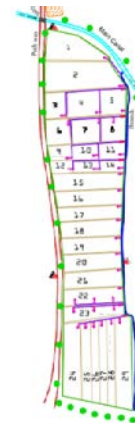


Fig. 2 Layout of Farm-A before improvement

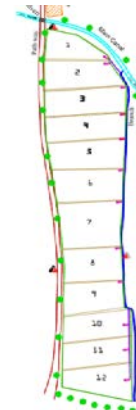


Fig. 3 Layout of Farm-A after improvement

where Q is the discharge (m^3/s), T is the irrigation duration in seconds, A is the field area (m^2), and WD is the applied water depth (m).

$$WP = \frac{\text{Yield}}{Q} \quad (2)$$

where WP is the water productivity, yield is the total seasonal agricultural production (kg), and Q is the total seasonal irrigation water inflow (m^3).

3. RESULTS

3.1 Farm Design

Table 1 Farm-A features before and after improvement

State	No. of fields	No. of water channels	No. of water inlets	Total Farm-A area		Average field area (m^2)
				(ha)	(%)	
Before	29	14	39	2.18	100	752
After	12	2	12	2.31	106	1925
Impacted	17	12	27	0.13	6	1173

3.3 Crop Yield

The wheat yield from Farm-A was 4.4 tons/ha, whereas the harvested yield from Farm-B was 3.5 tons/ha. The wheat yield from Farm-A was almost 21% higher than that from Farm-B. Similarly, after LL leveling, the corn yield was 5.25 tons/ha higher from Farm-A and 3.15 tons/ha higher from Farm-B; thus, the corn yield from Farm-A was larger by 40%. The Farm-A eggplant yield was 41 tons/ha and the Farm-B yield was 25.5 tons/ha. The eggplants yield in the Farm-A field was about 38% higher than the Farm-B eggplant yield (Fig. 4).

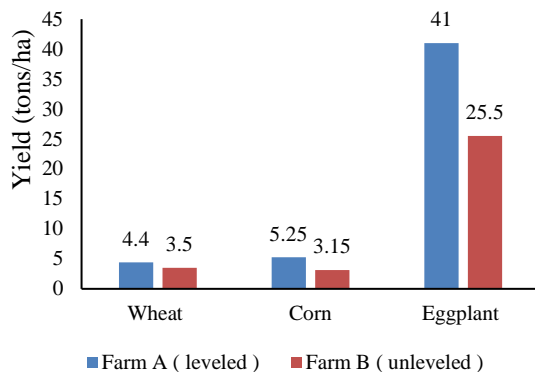


Fig. 4 The 2014 yields (tons/ha).

3.2 Applied Water Depth

The WD of Farm-A was estimated at 420 mm, whereas in Farm-B, it was 529 mm. The water demand for irrigation was smaller in the laser-leveled

The average area size of the unleveled (Farm-A) field was 752.41 m^2 (0.075 ha), as shown in the old farm layout (Fig. 2). After modification of the layout, the average area size of the new field was increased to 1925 m^2 (0.19 ha). The number of fields decreased from 29 to 12 because several fields were unified. Moreover, the farm water channels were properly lined, and all unnecessary water channels and water inlets were removed. The number of water channels was reduced from 14 to 2. In addition, the number of water inlets decreased from 39 to 12. As a result, the cultivated area of the farm larger by about 6%, and the Farm-A area expanded from 2.18 ha to 2.31 ha (Table 1).

field by 21%, and the WD was lowered by 109 mm, which was different from the Farm-B for the wheat crop.

Furthermore, the total seasonal water applied depth for corn crop was 539 mm in Farm-B, whereas it was 394 mm for Farm-A. WD was smaller by 27% in Farm-A field and WD was lower by 145 mm compared to the Farm-B (Fig. 5). The maximum WD for the eggplant crop was 1264 mm for Farm-A and 1052 mm for Farm-B. The eggplant water demand was lower by 17% in the Farm-A field, and WD was smaller by 213 mm (Fig. 5).

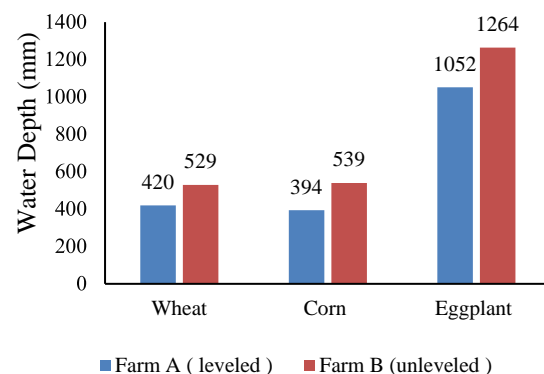


Fig. 5 WD s for wheat, corn, and eggplant in 2014.

3.4 Water Productivity

After LL leveling, the water productivity was analyzed for the three crops: wheat, corn, and

eggplant. The water productivities for all three crops in the leveled fields were compared with those of the unleveled fields.

The water productivities of unleveled field crops were 0.64 kg/m³, 0.63 kg/m³, and 2.33 kg/m³ for wheat, corn, and eggplant, respectively. The LL fields' water productivities for wheat, corn, and eggplant were 1.05 kg/m³, 1.33 kg/m³, and 3.67 kg/m³, respectively (Table 2).

Table 2 Water productivity of Farm-A and Farm-B in (kg/m³)

Crop	A (Leveled)		B (Unleveled)	
	Water Volume (m ³)	WP (kg/m ³)	Water Volume (m ³)	WP (kg/m ³)
Wheat	863	1.05	1009	0.64
Corn	808	1.33	1005	0.63
Eggplant	2148	3.67	2130	2.33

4. DISCUSSION

4.1 LL leveling for crop yield and water efficiency

The present results indicate that the poor farm layout and the existence of uneven fields, unnecessary bunds, and ditches are responsible for water losses at the farm level and overall yield reduction, thereby increasing water and labor demand. In addition, it is now necessary to apply irrigation at the highest levels of the fields, which results in over-irrigation and reduction of resources and yields. Farm-A is separated into 29 small fields with an average area size of 752 m² (0.075 ha; unleveled field), as depicted in the old farm layout (Fig. 2). After modification of the layout, the average area size of the new field is expanded, because several fields have been unified (number of fields in the new layout: 12).

Moreover, the farm water channels were properly lined and all unwanted water channels and water inlets were removed. The number of water channels decreased from 14 to 2. In addition, the number of water inlets decreased from 39 to 12. Finally, the cultivated area of the farm increased by about 6%, and Farm-A area expanded from 2.18 ha to 2.31 ha. Land layout improvement (LLI) should allow using the land and water resources more efficiently and effectively in those areas.

Moreover, the yield from Farm-A was 4.4 tons/ha, whereas the yield from Farm-B was 3.5 tons/ha. The wheat yield from Farm-A is about 21% higher than that from Farm-B. After LL leveling, the corn crop yield was 5.25 tons/ha for Farm-A, against 3.15

tons/ha for Farm-B. Thus, the corn crop yield larger by 40% from Farm-A (Fig. 4). The yield of eggplant crop from Farm-A was 41 tons/ha and from the Farm-B is 25.5 tons/ha. The eggplant crop yield from Farm-A is about 38% higher than that from Farm-B. LL leveling creates homogenous water distribution on the land surface, uniform soil moisture condition, constant seed germination, proper crop growth, stand and maturity, and productive utilization of nutrients (Fig. 4).

Fig. 5 shows the difference between the total applied depth of water for wheat, corn, and eggplant crops from Farm-A and Farm-B. The total seasonal applied depth of water for each single crop is measured from the both Farm-A and Farm-B. The Farm-A *WD* is recorded at 420 mm, whereas in Farm-B, it was 529 mm. The water requirement for irrigation is smaller in the laser-leveled field by 21%, and the *WD* decreased by 109 mm, which is different from Farm-B for the wheat crop.

Moreover, the total seasonal water applied depth for corn crop was 539 mm in Farm-B and 394 mm in Farm-A. The *WD* was recorded smaller by 27% in the Farm-A field and the *WD* was saved by 145 mm for Farm-A compared to the Farm-B (Fig. 5). The highest *WD* applied for the eggplant crop is 1264 mm for Farm-A, whereas it is 1052 mm for Farm-B. The eggplant water demand is lowered by 17% in the Farm-A field and the *WD* decreased by 213 mm (Fig. 5). The water demand reduction is probably due to the similar elevation of the fields' surfaces, the reduced lag in water consumption between the different parts in the fields, or to the compaction of the land layers.

On other hand, in Farm-B, the water demand was higher due to the inhomogeneous elevation between the different parts of the fields, since a greater water volume was required for water to reach the highest levels of the fields. This also led to over-irrigation of the lower parts and under-irrigation of the higher points. As the total duration of irrigation in the laser-leveled fields decreased, the required labor for the irrigation system was also reduced.

In addition, as the total *WD* requirement in Farm-A is lowered after LL leveling, so did the water demand for irrigation by 21%, 27%, and 17% for wheat, corn, and eggplant, respectively. The water volume used in the leveled fields (Farm-A) is 863 m³/2054 m², 808 m³/2052 m², and 2148 m³/1924 m² for wheat, corn, and eggplant, respectively. However, the unleveled fields' (Farm-B) water volumes are 1009 m³/1875, 1005 m³/2000 m², and 2130 m³/1680 m², respectively. Consequently, the water productivities were recorded higher for Farm-A after LL leveling by 39%, 53%, and 37% for wheat, corn, and eggplant, respectively (Table 2). LL leveling limitations include a high initial cost and technical requirements, which are not met in the study area.

5. CONCLUSION

Given these points, LL leveling and LLI resulted in higher crops yields, enhanced water use efficiency, and water productivity. Water application, labor requirements, and irrigation problems are reduced after LL leveling in Farm-A in comparison to Farm-B.

Applying a traditional farm layout adversely affects water productivity, land productivity, and labor requirements. The results of the present study indicate that with appropriate farm layout improvement and LL leveling, it is possible to conserve and use the available water and other farm resources more efficiently and effectively. Moreover, such practices can increase crop production per unit water and land. More importantly, it can expand the cultivable area, lower the labor requirements for irrigation operation, and lower weeds problems.

The improvements proposed in this study provide significant benefits for the traditional farm layout and unlevelled fields. Therefore, a shift toward modifying the existing poor farm layout to mitigate water issues in a specific area is highly recommended.

Improving the traditional farm layout and applying LL leveling should be the best options to resolve agriculture-related water management issues in central Asia. These methods can show us higher crop productions, enhanced water productivity, expand the cultivable area and thus the overall farm return, contributing to the rural economic of those areas.

6. ACKNOWLEDGMENTS

The authors would like to thank the On-farm Water Management Project, Afghanistan (OFWMP) for supporting this research.

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