Double cropping and supplementary irrigation potential of harvested drainage water on Vertisols at Enewari district in North Shewa

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Abstract

It is common to get high surface runoff from drained Vertisols in rainfall seasons. There is a great move in Ethiopia towards harvesting and using this runoff for double cropping in every Vertisols without assessing their practical potentials. In this experiment, runoff water drained from wheat field growing on broad bed and furrows (BBF) in 'meher' season was collected in a trapezoidal water harvesting structure. Water balance of the pond and soil erosion losses from the runoff-areas of wheat field was estimated. The potential of collected drained water was assessed for supplementary irrigation of wheat and lentil arranged in Randomized Complete Block design replicated four times. Monitoring of seasonal drainage water balance showed that there was excess water that can be harvested for further use, but storing the water for double cropping or supplemental irrigation was found difficult because of evaporation and seepage losses. Seepage and evaporation losses were enhanced by increased surface area of the structure which was done to compensate for the shallow depth of the pond limited by the depth of soil in the area. As a result, the stored water in the pond was empty on November 29 (first year) and on November 12 (second year). Hence, the study proved runoff collected in such scenarios of the study area cannot support either full (for double cropping) or supplementary irrigation. Based on the findings, the potential of reuse of drained water was hindered due to the environmental losses, as a potential option shallow to deep ground water sources were considered in the study area.

Keywords: Double cropping, drainage water, supplemental irrigation, water harvesting.

Introduction

Since agriculture in Ethiopia is mainly dependant on rainfall, farmers usually wait with anxiety for its timely onset. But, the rain may not usually start at the right time and the unpredicted rainfall may be so heavy that the runoffs produced erode the most fertile land. Annually 112,450 million m^3 runoff water is lost into rivers from 12 highland watersheds in

Ethiopia (MWR, 1998). On the other hand, the excess rain causes water logging on heavy clay soils.

Regardless of the huge coverage of Vertisols in the Ethiopian highlands, 7.6 million ha, the productivity of these soils is below their potential mainly due to water logging in the main rain fall season. In the main rainy season, sowing usually starts late and continues to the end so as to grow on the residual soil moisture (Astatke *et al*, 1991), as a result crop productivity is low. In the Ethiopian highlands, a very high percentage of the land area is drained by some form of indigenous artificial drainage networks in addition to the natural streams and channels. These indigenous drainage practices take many different forms such as broad bed and furrows (BBF), ridge and furrows (RF), and simple open ditches in the moderate to flat slope lands on Vertisols. The primary aim of the drainage is to reduce the level of excess soil-water and improve conditions for cultivation.

Enewari plane, where this study was conducted, is the Vertisols areas having water logging problem. Farmers in this area practice BBF to avoid water logging and improve crop yield. The work of Jutzi *et al.* (1986) also showed that the construction of BBF aids in draining excess water and improves productivity of Vertisols. It has also been suggested that if drained water can be harvested in ponds, there can be various cropping options to utilize the entire growing period. The early sowing of main season crops, such as wheat, could allow an early harvest thereby making the second crop possible. Harvested water can be used to irrigate a second crop during dry season (Astatke *et al.*, 1986). Experiences also showed that at the end of the rainy season the surface layer of the highland Vertiols is frequently quite dry while there is plenty of available soil moisture in the deeper soil layers. This seriously impairs the possibility of crop sowing in the post-rainy season; if sown in such scenarios, the plant stands become poor (Astatke and Saleem, 1998).

Selamyihun (2003) showed that tef-based cropping system of highland Vertisols transformed 23-41% of the seasonal rainfall (July-September) into runoff, which is equivalent to 102-307 mm runoff water per hectare annually. This amount of runoff water would be more than enough to raise a second crop on one hectare of land in the post rainy season (Kamara and Haque, 1988). This suggests that water harvesting from the Vertisol drainage system can be promoted by harmonizing the local system with small farm ponds. Wheat and lentil are the major crops being produced on separate fields of Vertisols at Enewari. Ample amount of drainable water has been wasted unused for supplementary irrigation for crops grown under rainfed condition or to support double cropping system. It is time to reuse the drainage water for double cropping of wheat with lentil in such a way that wheat is to be grown under rainfed condition as usual whereas lentil is to be grown following the harvest of wheat under full irrigation. However, the amount of water required for lentil production under full irrigation condition must be determined to estimate whether the amount of drainable water collected and stored in shallow ponds could be enough to support this production system.

Therefore, this study was conducted with the objectives of estimating drainage runoff water and associated soil loss from BBF based crop land, and evaluating the potential of trapezoidal storage structure to store and conserve enough water for double cropping and supplementary irrigation so as to improve crop productivity of the area.

Materials and methods

The study area

The experiment was conducted in the District of Moretina Jiru at Enewari research testing site, North Shewa zone of Amhara national regional state. Geographically, Enewari testing site is located at 9^0 52’ N, $39^0$10’ E and an altitude of 2680 m above sea level. The area is characterized by a unimodal rainfall, receiving annual average of 929 mm. The annual average maximum and minimum air temperatures are 21.4 and 9.0 ^{0}C, respectively. Vertisols are dominant in the area, hosting production of wheat, teff, faba bean, and lentil whereas chickpea and grass pea have low area coverage.

Pond construction and water balance data collection

A trapezoidal shape of runoff water storage structure having respective top and bottom width of 10 m and 8 m, depth limited to the Vertisols depth (1 meter), and 1:1 side slopes was constructed when the soil had enough moisture to compact the side walls and bed of the structure. After compaction, the floor and all sides of the pond were plastered with 5 cm thick layer of selected pellic soil and of mud prepared by mixing soil and chopped teff straw during the first year and second year, respectively, to reduce the seepage loss that could be caused by the cracking of the Vertisols. The runoff drained from BBF on a specific delineated area cultivated with wheat was diverted by main channel into the storage structure. A small silt trap of 1 x 0.5 x 0.5 m size was dug at the inlet to the main pond so that debris and suspended sediment along with overland runoff could settle down. Relatively filtered runoff water would enter to the pond.

Daily stored volume of water in the pond was determined by measuring the water depth at different corners of the pond in the morning (8-8:30 am) every day. The average water depth multiplied by wetted area of the pond gives volume of daily stored water in the pond. Runoff amount entering the pond was calculated using the following water balance equation.

$$dRo = Rf + Ro - E - Sp \ldots\ldots\ldots\ldots\ldots\ldots . Eq. 1$$

$$Ro = dRo - Rf + E + Sp \ldots\ldots\ldots\ldots\ldots\ldots . Eq. 2$$

Where: Ro is Runoff entering the pond, Rf is Rainfall directly falling in the pond, E = Evaporation loss from the pond, Sp = Seepage loss from the pond, and dRo = Change in runoff volume of the pond.

Soil loss from the total experimental area was determined by summing up of the soil deposit in the storage pond and in the silt trap. Amount of soil loss in the stored water was determined by filtering and oven drying the sediment from one litre runoff sample taken from the pond immediately after heavy storms. Multiplying sediment concentration obtained from one litre runoff water sample by the total stored volume of water gave the total suspended sediment loss in the stored runoff water. Soil loss from the silt trap was determined by weighing the deposited sediment directly from the silt trap at regular interval. Daily rainfall was recorded from the nearby rain gauge. At same time daily evaporation was recorded from standard evaporation pan, assuming there is equal potential evaporation from the pond and pan.

Experiment setup and data analysis

The area delineated for runoff harvesting was sown to wheat during the main rainy season. In the first year, water balance of the pond was computed to evaluate whether the harvested water has the potential to produce the second crop after harvesting wheat. Thus the water balance analysis showed that the stored water was not enough to support double cropping (Figure 1) as the pond was empty before the harvest of the main rainy season crop, wheat. Consequently, the experiment was modified for supplemental irrigation during the second year of the project life. The source of water for the supplemental irrigation was from another non experimental pond so that the water balance data of the experimental pond would not be disturbed.

Based on the modifications, two independent supplemental irrigation experiments were conducted one for wheat and the other for lentil arranged in RCBD with four replications at Enewari testing site in 2006. Bread wheat (HAR 604 variety) and lentil (Var.: Alemaya) were sown on 13 July and 30 August 2006, respectively, using broad-bed and furrows to drain excess soil water. The experimental plot size was 3.6 by 2.6 m for lentil, and 4.8 by 3 m for wheat. The recommended fertilize levels of 87/20 kg N/P ha^{-1} for wheat and 18/20 kg N/P ha^{-1} for lentil were applied while other management practices were also done as per the recommendations of the area. The experimental treatments were: T_1 = No supplementary irrigation (control), T_2 = Irrigated at eight days interval starting from 03 October to 24 November for lentil while only one irrigation at 50% booting stage for wheat, T_3 = One irrigation at 50% flowering for lentil while at 50% heading for wheat and T_4 = One irrigation at 50% pod stage for lentil while one irrigation at 50% heading and one irrigation 15 days later at grain filling stage for wheat.

Irrigation was applied to the level that the soil moisture content reaches to field capacity based on the soil moisture level determined to the depth of 40 cm prior to watering. Field capacity and bulk density of the testing site was determined to be 55% by volume and 1.22

g cm^{-3} using field method procedures. Wheat and lentil were harvested on 15 December and 29 December 2006, respectively. Statistical analysis of variance for yield was done using procedure of mixed model of SAS Version 8 of 1999-2000. Of the four treatments, T_3 (one irrigation at 50% flowering) for lentil was excluded in the analysis for its performance was very low due to its poor establishment that was not related to the treatment effect.

Results and discussion

Pond water balance and potential of harvested water for double cropping

Since water balance is highly sensitive to temporal climatic variation, the two years water balance data were analyzed and presented separately. In both cases similar trend of water stored in the pond and loss from it were observed during the monitoring seasons. In the first year, of the total 81 m^3 storage capacity of the pond, about 38.18 m^3 (47% of the pond storage capacity), 42.26 m^3 (52%), and 11.68 m^3 water was accounted to direct rainfall, lost by evaporation, and removed from the pond for it was beyond the pond capacity, respectively, during mid July up to end of November. Regardless of the plenty of runoff and rainfall water entering the pond, the pond was totally empty just on November 29/2005 (Figure 1). In a similar case, during the second year, 70.94 m^3 (87.60% of the total storage capacity), 59.6 m^3, and 46.9 m^3 water was from direct rainfall, removed from the pond to avoid overflow, and lost through evaporation, respectively. Again, the pond was empty just on November 12/2006 (Figure 1). Just on the offset of rainfall, nearly between September 15 and 20, there was only 49.59 m^3 stored water in the pond. As compared to the first year, significantly higher amount of water was received from direct rainfall and subsequently discharged from the pond in the second year because of comparatively high rainfall.

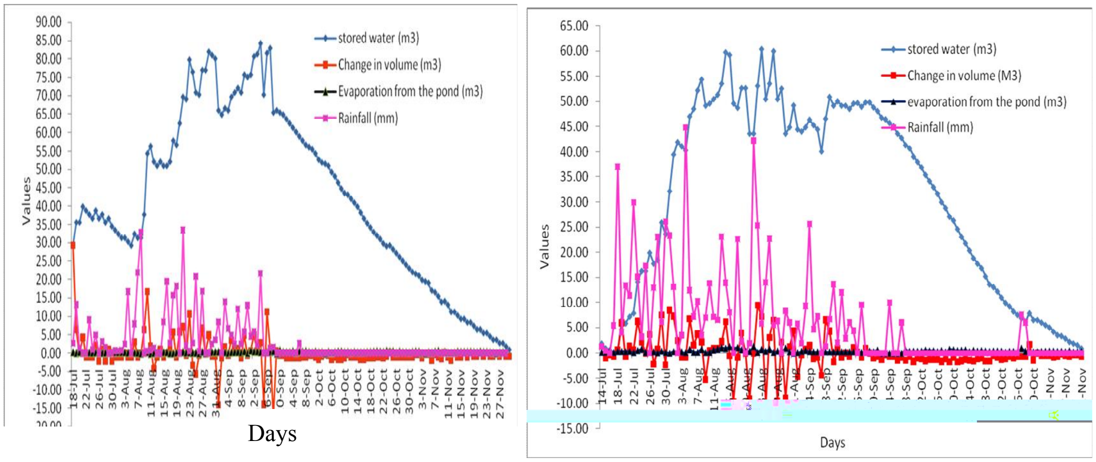

Figure 1. Pond water balance (m^3) in 2005 (left) and in 2006 (right).

Generally, results of the two-year study show the same trend. Regardless of large amount of water entering the pond, all the water was lost from the pond before the harvest of the first crop. The amount of runoff water entering the pond from the drained area and from direct rainfall was more than the storage capacity of the pond. This shows that there is very high amount of water for harvesting, but the major challenge was storing it for few months. In Enewari and other similar Vertisol areas where the soil depth is shallow (<1.5 m), the storage capacity of ponds could be increased by increasing pond area rather than the depth. However, this exposes the water for high surface area contact which increases seepage loss to the ground and evaporation loss from the water surface. Hence, the dual loss of evaporation from the top surface of the pond and seepage from the bottom and sides caused early drying of the pond. Similarly, Ahmad (1993) reported that this dual loss in shallow ponds is the main reason why the ponds often dry just at the time when water is most needed to keep crops more productive. In such heavy Vertisols areas of Enewari, the soil dried and cracked immediately after the rainfall ceases. This affected the sidewalls of the pond regardless of the efforts done to compact and line it, and led to high seepage loss. Cracking of the land also increases the water demand for land preparation for the next crop. The suspended and eroded soil sediment channeled through the traditional broad bed furrows was estimated to be 3.67 ton ha^{-1} per year in the first year and 8.5 ton ha^{-1} per year second year.

Evaluation of supplementary irrigation

Application of supplementary irrigation at every eight days interval gave significantly ($p<0.05$) high grain and straw yield of lentil compared to the un-supplemented lentil plot. However, there was no significant yield difference between supplementary irrigation at every eight days and once application at 50% pod stage. Supplementing irrigation at 50% pod stage did not provide significant yield advantage over the un-supplemented one (Table 1). The yield increment obtained from eight days irrigation application was about 38 % for seed yield and 45% for straw yield over the control.

Table 1. Mean yield and supplementary irrigation data for lentil at Enewari, 2006.

Treatment	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Amount of irrigation water supplemented		Irrigation frequency
			Litre plot-1	(m^{3}ha^{-1})	
Without supplemental irrigation (T_1)	959^{B*}	1445^{B}	0	0	0
Irrigation at every eight days interval (T_2)	1326^{A}	2095^{A}	1232	1316.24	8 days interval
One irrigation at 50% flowering stage (T_3)			200	213.68	One irrigation
One irrigation at 50% pod stage (T_4)	1204^{AB}	1574^{AB}	224	239.32	One irrigation

**Means in a column followed by the same letters are not significantly different at P<0.05.*

All supplementary irrigation treatments did not significantly ($p<0.05$) improved grain and straw yield of wheat as compared to the control (Table 2). However, the supplemental irrigation application at 50% flowering stage increased the grain yield by 33%; similarly supplemental irrigation application at 50% pod stage increased the straw yield by 28% over the control. The variety HAR604 used in this experiment did not perform well and appeared to be low yielder as compared to its past history when its resistance to yellow rust was intact. Moreover, the recommended sowing date, i.e., early planting immediately after the onset of rainfall, had shown low performance of bread wheat as opposed to the farmers' usual practice, late-sowing (24-30 July). The recent research work also shows that late sowing gives significantly higher yield of bread wheat on heavy Vertisols areas of Enewari (Adamu Molla, Personal communication).

Table 2. Mean yield and supplementary irrigation data for bread wheat at Enewari in 2006.

Treatment	Grain yield ($kg\ ha^{-1}$)	Straw yield ($kg\ ha^{-1}$)	Amount of irrigation water supplemented		Irrigation frequency
			(Litre $plot^{-1}$)	($m^3\ ha^{-1}$)	
without supplemental irrigation (T_1)	1240	2066	0	0	0
One irrigation at 50% booting stage (T_2)	1511	2517	372	258.33	One irrigation
One irrigation at 80-85% heading stage (T_3)	1651	2613	360	250	One irrigation
Two irrigations: one at 50% heading and one at grain filling stage (T_4)	1496	2643	780	541.66	Two irrigations
LSD (5%)	197	355			

The yield increment level obtained from supplementary irrigation seems not attractive as compared to the land lost for pond construction and the laborious irrigation practice. As the clay soil depth was only 1.3 m on the testing site (it was also less than 1.5 m in most of the sampled farmers' fields), it was only possible to prepare a pond of 10 m wide at the top and 8 m wide at the bottom having the depth of 1 m that was able to store 81 m^3 of water. If we consider supplementary irrigation every eight days interval for lentil, 81 m^3 of the stored water (with the assumption of no seepage and evaporation loss) can only irrigate about 615 m^2 of lentil field. This is discouraging compared to the yield results obtained without supplementary irrigation (Million, 1994). It is also more challenging when we realize that the pond had only about 50 m^3 of water in the beginning of October at which the first supplementary irrigation was about to start. Again, due to seepage and evaporation loss, the pond became empty on the last week of November, at which only about half the supplementary irrigation water requirement could be met. From the wheat yield data, it is implied that no significant advantage of supplementary irrigation was obtained for early sown wheat. This needs further investigation to see whether late sown wheat needs supplementary irrigation. Therefore, under the present experimental condition when the harvest of first crop is beyond November and December, potential of double cropping as well as supplementary irrigation of field crops using runoff water from Vertisols drainage systems is difficult. Runoff stored in ponds is not enough to satisfy the water demand for both land preparation and growing crops starting from late November at which soil cracks are too many. Under such scenarios, both supplementary irrigation and double cropping needs sufficient water sources like deep wells to guarantee continuous water supply during the application period in the dry season.

Ground water assessment

Besides the potential evaluation of water harvesting systems on Vertisols, assessment of ground water potential was also one of the activities of the study. Around Enewari, many farmers have practiced shallow hand dug wells for domestic water consumption. Stored water depths were measured in May at which maximum ground water depletion is usually expected low (Table 3).

Table 3. Assessment results of farmers' hand dug wells in Enewari areas in 2006.

Well #	Number of users	Depth of well without water (m)	Stored water depth (m)	Total well depth (m)
1	Three villages for livestock	2.9	0.6	3.5
2	Three villages for drinking	2.33	0.5	2.83
3	8-10 household (HH) for drinking	3.9	0.4	4.3
4	2-3 HH for drinking	3.56	0.4	3.96
5	6-8 HH for drinking and onion growing	2.6	0.8	3.4
6	1 HH for drinking	2.1	0.25	2.35
7	10-12 HH for drinking and livestock	5.25	1	6.25
8	10-12 HH drinking + livestock	1.95	1	2.95
9	Unknown HH	5	1.27	6.27
10	Unknown HH	5.4	1	6.4

Despite the high domestic consumption during the assessment time and very shallow depth, most wells had good water potential. In addition to the surveyed hand dug wells, an observation made on 3.2 m depth hand dug well at Bollo village in Enewari had a discharge rate of 0.26 l sec^{-1}, indicating a promising potential if properly utilized and managed. In general, the assessment of hand dug wells indicates there is high potential of deep wells as an alternative in the study area.

Conclusion and Recommendations

Most of the soil depth of Vertisols at Enewari was less than 1.5 m. Consequently, more land is required to increase the surface area of the pond as a compensation for reduced soil depth, which affects the water storage and losses from the pond. First, the shallow farm pond has high surface area in relation to its volume and hence enhances excessive evaporation. Second, the increased surface area contact increased the probability of soil cracking that resulted in high seepage loss. The dual losses of evaporation and seepage are the main causes why the ponds often go dry just at the time when water is most needed. Hence, though there is no problem of runoff water for harvesting, storing the water for later use is challenging because of the mentioned losses. Runoff collected in such practices cannot support supplementary irrigation or even cannot satisfy the wide and deep cracks of Vertisols occurred in November let alone supporting double cropping of field crops. Therefore, it is better to think of deep wells that can continuously supply water for double cropping or supplementary irrigation on Vertisols while runoff collection ponds can serve in recharging ground water so as to keep deep wells as sustainable source for irrigation water.

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