**Ademe, 2015. 2:12. Journal of Environmental and Agricultural Sciences (ISSN: 2313-8629)**

**Research Article** **Open Access**

# Effects of Run-on Area Treatment of Semicircular Bund on Infiltration Rate and Moisture Storage on Clay Soil at Dhera Hillside, Ethiopia

Fitih Ademe*
Melkassa Agricultural Research Center, P.O. Box 436, Nazareth, Ethiopia

**Article History**
**Received**
October 25, 2014
**Revised**
January 28, 2015
**Accepted**
February 10, 2015
**Published Online**
February 23, 2015

**Keywords:**
Water
Infiltration
Gravel mix
Gravel mulch
Moisture storage
Water conservation

**Abstract:** Water is vital for tree seedling growth and survival, however, it is a limited resource especially in dryland areas and therefore its efficient utilization is crucial. Soil surface and subsurface management is thus an important practice one should consider to avail water in the root zone for proper and effective implementation of afforestation in dryland areas. On the basis of this, a study was conducted at Dhera hillside to evaluate the effects of gravel mix and gravel mulch treatments of run-on area on infiltration and soil moisture storage of semicircular bund. The experiment was laid out in randomized complete block design with seven treatments (12.5, 25 and 37.5% gravel mix and 12.5, 25 and 37.5% gravel mulch and control). Soil parameters relevant to the study were determined both in the field and laboratory and climatic data were collected from nearby meteorological station. The results revealed that initial infiltration rate and steady state infiltration were improved considerably by the treatments. Accordingly 12.5, 25 and 37.5% gravel mixes improved the steady state infiltration rate by 3.9 62 and 86%, respectively. Similarly the 12.5, 25 and 37.5% gravel mulch treatments improved the steady state infiltration by 4.7, 40.3 and 25.6%, respectively. Following this the cumulative infiltration depth was also improved considerably by the treatments. Accordingly, 12.5, 25 and 37.5% gravel mixes improved the cumulative infiltration by 3.9 62 and 86%, respectively. Similarly, the 12.5, 25 and 37.5% gravel mulch treatments improved the cumulative infiltration by 4.7, 40.3 and 25.6%. Soil moisture storage was also significantly ($p < 0.01$) increased by the treatments. Consequently gravel mulch treatments followed by the gravel mix treatments resulted in higher soil moisture storage as compared to the control. The experiment concludes that semicircular bunds constructed on heavy soils needs surface and subsurface amelioration of the run-on area to efficiently utilize runoff water which is mainly lost by evaporation and waterlogging.

***Corresponding author:** Fitih Ademe **Email:** fitihademe@gmail.com **Phone**: +251-911-376034

**Cite this article as:** Ademe. 2015. **Effects of run-on area treatment of semicircular bund on infiltration rate and moisture storage on clay soil at Dhera Hillside, Ethiopia.** *Journal of Environmental & Agricultural Sciences*. 2:12.

## 1. Introduction

Increasing population has forced human being to convert marginal area suitable for agriculture. However, plenty of this marginal land is located in the arid or semi-arid belts where rainfall distribution is irregular and much of the precious water is soon lost as evapotranspiration or surface runoff. For successful afforestation to be undertaken, researchers have devised several methodologies under semi-arid climatic conditions. For example, site preparation targeted to enhance water storage in the soil profile to improve water availability and reducing water loss from soil surface by evaporation have got a remarkable attention (Dent and Murtland, 1990).

Recent studies indicated that semicircular bunds possess tremendous potential for both water harvesting and storage, and well suitable for soil conservation, therefore preferred by the local farmers (Fitih and Ermias, 2007). Soils with very low infiltration rate and subsequent evaporation loses however are becoming a threat to water harvesting systems in heavy textured soils. Measures to improve infiltration of water and reduce evaporation losses will thus be crucial for water harvesting and storage in semi-arid areas. Amount of available water in soil can be increased by surface mulching and other soil management practices like proper tillage (Wang et al., 2009). On this regard gravel mulch has long been practiced to reduce soil surface evaporation where gravel availability is not a problem. It was found that the gravel mulches dramatically reduced the evaporation from bare soil surface, particularly when soil water contents were at high levels (Yuan *et al*., 2009).

Studies to substantiate the effects of gravel on soil physical property related to infiltration and moisture storage on soils of water logging problem has not been undertaken yet; even though, the application of gravel as a surface mulch has been practiced to reduce evaporation losses. Hence, the study was proposed to evaluate the effects of gravel mix and gravel mulch treatments of run-on area of semicircular bund on infiltration rate and cumulative moisture storage of semicircular bund.

## 2. Material and Methods

### 2.1 Site Description

The experiment was conducted at Dhera hillside which is in the Oromia Regional State, Arsi Zone of Dodota Sire woreda during the main season of 2009. The site is located at 125 km south east of Addis Ababa. The area is situated at 08°20' N latitude and 39°19' E longitude. The location has an altitude of 1680 meters above sea level (m.a.s.l) and the Agro-ecology falls under Tepid semi-arid mid highlands (MoARD, 2005).

The area receives a mean (1990-2009) annual rainfall of 667.3 mm and has mean annual maximum and minimum temperatures of 27.5 and 8.8 °C, respectively. The rainfall of the area has a bi-modal distribution pattern with the *belg* rainfall extending from February/March to April/May and the *kiremt* season from mid-June to mid-September. The maximum rainfall occurs during the months of July and August whereas the minimum mean rainfall occurs in November and December. During the *belg* season, the highest mean rainfall occurs in April followed by May and March (Figure 1).

### 2.2 Treatment

A randomized complete block design was used to set up the treatments in four replications. Before planting, soil dug out of the pit was thoroughly mixed with gravel as per the treatment (12.5, 25 and 37.5% by volume of the excavated soil), to enhance infiltration. Similarly, gravel mulch, the same rate as gravel mix, was evenly spread on the surface of the run-on area immediately after planting the seedlings. The area covered by gravel mulch was 0.1256 m$^2$ per infiltration depth. We further want to investigate the effect of gravel mulching and gravel mixing on soil single pit. Gravel originally present in the soil was analyzed and the treatments were applied after modifications as per the results of the analysis while the gravel that is present in the control soil was removed during planting.

### 2.3 Construction of the semicircular bund

The semicircular bunds were constructed by using the soil excavated from the catchments area during construction. The structures were arranged in staggered way in order to utilize the runoff not harvested by the preceding structure. The size and bund height were constructed based on FAO's recommendation for tree establishment using semicircular bund micro basin. Accordingly, the diameter of a single structure was 2 m wide with a bund height of 25-30 cm. The size of the infiltration area where the seedlings were planted was 40 cm in diameter and 30 cm deep.

### 2.4 Soil sampling and analysis

Representative soil samples, both disturbed and undisturbed, were collected from different points within the experimental site from 0-30 and 30-60 cm depths. The disturbed samples were thoroughly mixed to make one composite sample per depth. The samples were then taken to laboratory. After preparing the samples for laboratory analysis, the disturbed samples were used for determination of particle size distribution, soil pH, soil organic carbon and CEC. The undisturbed samples were used for determination of bulk density and water retention characteristics.

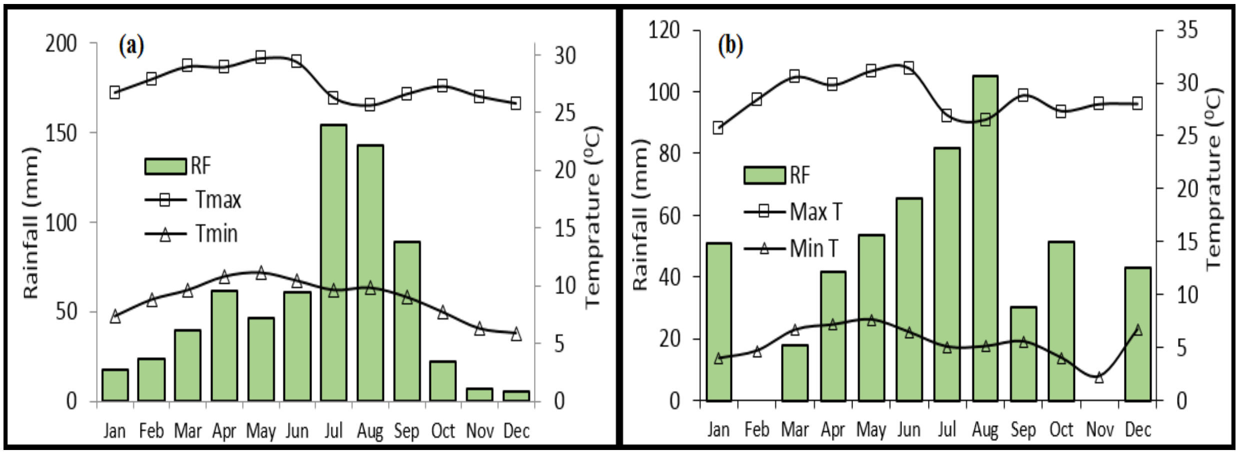


**Figure 1. Long term (a) (1990-2009) and annual (b) (2009) mean monthly rainfall, mean maximum and minimum temperatures of Dhera, Ethopia.**

To construct soil water characteristic curve of the experimental soil, water contents were measured at six matric potentials namely -0.25, -1, -5, -10, -33.3 and -1500 kPa. The equilibrium water contents at -0.25 to -10 kPa were measured after draining the samples using suction table. Similarly, the equilibrium water contents at -33.3 and -1500 kPa were determined gravimetrically after placing the samples in pressure plate extractor and draining the samples with application of the respective pressures. Total available water holding capacity (TAWC) of the soil was determined as the difference in water content between field capacity and permanent wilting point. Infiltration was measured in the field using standard double ring infiltrometer with 30 and 60cm diameter. The infiltration measurement was done for the site and on individual plots of the respective treatments.

### 2.5 Data Analysis

Descriptive statistics was used to compare those parameters that were not subjected to Analysis of variance. Soil moisture storage was analyzed by SAS for each treatment and depth while mean differences were compared by using LSD for those means which are statistically different.

## 3. Results and Discussion

Priming with different concentrations of various salts significantly influenced all germination and vigor indices in two cabbage cultivars. Final germination (%) and germination index was not increased by any priming treatments over control in both cabbage cultivars rather decreased final germination percentage (FGP) value except $KNO_3$ (1%) which enhanced FGP values of cv. Green Ball over the control (Fig. 1and 2).

### 3.1 Selected physico-chemical properties of soils of the experimental site

In both the surface and subsurface layers, clay is the dominant fraction. The sand and silt fractions, on the other hand, were lower in the subsurface than the surface layer and hence the dominant soil textural class varied from clay loam at the surface to clay at the subsurface.

The bulk density, contrary to the usually known trend, was low in the subsurface layer presumably due to the relatively higher proportion of the sand and silt fractions at the surface and clay fraction in the subsurface layer. The total porosity, as it was calculated from bulk density and constant particle density of 2.65 $g/cm^3$, contrary to the decrease in bulk density, increased with depth. Looking at the total porosity and the water content at field capacity, it can be inferred that the air-field porosity of both the layers was not more than 11%, indicating the dominance of meso and micropores over the macro pores. Under such conditions, there is a possibilty of impeded water and air movement.

Owing to the relatively higher clay content in the subsurface layer, the water content at both field capacity and permanent wilting point were slightly higher in the same than those at the surface layer. However, this was not reflected in the total available water holding capacity. The total available water holding capacity of the upper 60 cm of the soil was 163 mm per meter of soil depth.

The pH was strongly alkaline as per the pH rating provided by Tekalign (1991) apparently due to limited leaching associated with low rainfall of the area and basic nature of the parent material from which the soils have developed. The organic matter content of the soil was in the low range (Berehanu, 1980), for the area has limited vegetation cover that can add organic matter to the soil. Perceptibly, as the organic matter content decreases, its contribution in improving aggregation and thereby increasing the inherently low infiltration rate of fine textured soils will be very much limited (Miller and Donhahue, 1995).

**Table 1. Physico-chemical properties of the soil at the experimental site**

| Property | | Soil Depth (cm) | |
|---|---|---|---|
| | | **0-30** | **30-60** |
| Particle size distribution (%) | Sand | 30 | 28.0 |
| | Silt | 33 | 25.3 |
| | Clay | 37 | 46.7 |
| Textural class | | Clay loam | Clay |
| Bulk density ($g/cm^3$) | | 1.32 | 1.28 |
| Porosity (%) | | 50.2 | 51.7 |
| Water content (%) at | FC | 39.6 | 41.2 |
| | PWP | 23.2 | 25.0 |
| TAWC (mm) | | 49.2 | 48.6 |
| pH | | 8.1 | 8.1 |
| OC (%) | | 0.60 | 0.60 |
| CEC (cmol (+)/kg of soil | | 32.1 | 31.9 |

### 3.2 Soil water retention curve of the soil at the experimental site

The soil retention curve shows that with any increase in suction applied, the decrease in moisture content or the amount of moisture released from the soil was comparatively low. This indicates that the release of moisture is very gradual and the soil has high water retention capacity. It also indicates that the soil has slow drainage characteristic. Furthermore, the moisture content retained at each matric potential is considerably high.

### 3.3 Infiltration rate and cumulative infiltration rate of the experimental site

The trends portrayed in the figure indicate that there were irregularities in initial infiltration rate until 30 minutes since the start of the infiltration process. During this period, the infiltration rate varied between 6 and 9.6 cm/hr. This irregularity could be related to the surface seals, which were observed at the time of measurement of infiltration. After 30 minutes were elapsed, however, the infiltration rate decreased monotonically until it approached a more or less constant value of 4 mm hr$^{-1}$, which is in the range of fine textured soil and regarded as low (Miller and Donahue, 1997). Physically, fine textured soils have low infiltration rate due to the dominance of meso and micro pores, which transmit water at a very slow rate and retain it with greater tension.

Cumulative infiltration is the time integral of infiltration rate and it is an increasing function of time. As can be seen from Figure 4, the cumulative infiltration increased sharply at the beginning of the infiltration process after which the rate of increase decreased. This is because at the beginning of the process, though irregular, the initial infiltration rate was relatively resulting in absorbtion of large quantity of water. The decrease in rate of increase of the cumulative infiltration might be related to the monotonic decrease in infiltration rate with time due to decrease in matric suction gradient and gradual deterioration of the surface soil structure by water. The total amount of water infiltrated during seven hours of infiltration process was only 9.3 cm of water.

### 3.4 Effects of Gravel Mix and Gravel Mulch on Infiltration Rate

The results indicate that the applied treatments improved both the initial and steady-state infiltration rate of the soil a great deal. Accordingly, the 25 and 37.5% gravel mix treatments improved the initial infiltration rate of the control soil by 190 and 200 %, respectively, whereas the 12.5 % gravel mix resulted in the same initial infiltration rate as that of the control. Similarly, the 12.5, 25 and 37.5 % gravel mulch treatments increased the initial infiltration rate of the control soil by 40, 170 and 170 %, respectively.

Considerable improvements were also obtained in steady-state infiltration rate. The 12.5, 25 and 37.5 % gravel mix treatments increased the steady-state infiltration rate of the soil by 3.9, 62 and 86 %, respectively. Likewise, the 12.5, 25 and 37.5 % gravel mulch treatments increased the steady-state infiltration rate of the soil by 4.7, 40.3 and 25.6 %, respectively.

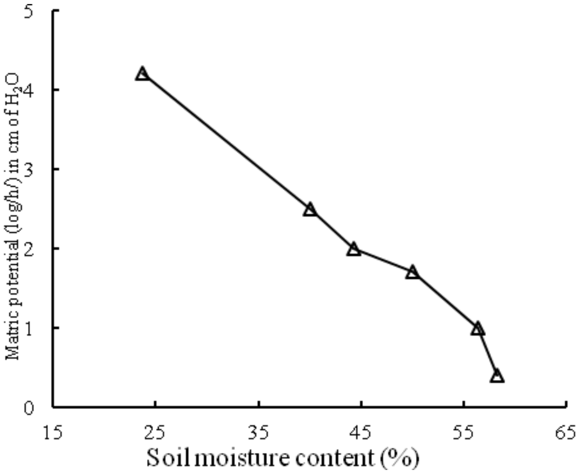


**Figure 3. Soil water retention curve of the soil at the experimental site.**

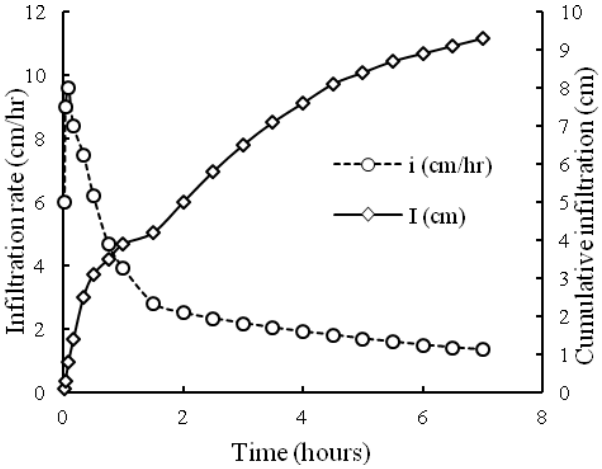


**Figure 4. Cumulative infiltration (I) and infiltration rate (i) curves of the soil at the experimental site**

The high rates of both initial and steady-state infiltration rates obtained under gravel mix treatments could be attributed to the likely improvement in the proportion of macro pores similar results have been indicated by Connoly *et al.* (1998). In this study, the initial and steady-state infiltration rates increased with increment in gravel mix rate. By similar token, the improvements in initial and steady-state infiltration rates due to application of gravel as mulch might be the result of the favorable effects of this material on maintaining the surface structure of the soil.

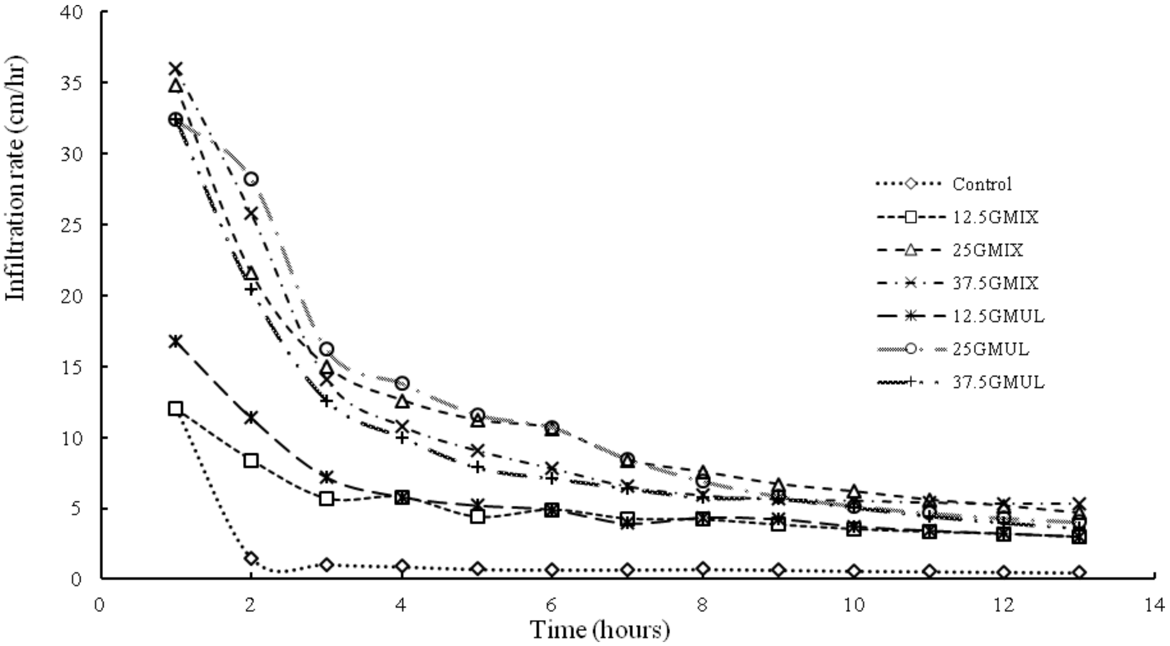


**Figure 5. Infiltration rate as affected by gravel mix and gravel mulch treatments. (C = Control, GMIX = gravel mix, GMUL = gravel mulch)**

The gravel mulch can protect the surface aggregates from raindrop impact and, thus, from dispersion and slaking. It dissipates the energy of the raindrops. If the surface aggregates are not dispersed, the sealing and crust formation will be minimized. This will maintain more pores for water to infiltrate. However, the gravel mulch resulted in higher infiltration rate at the 25 % rate. At 37.5 % gravel mulch rate, the steady-state infiltration rate was lower than that at 25 %. This is so seemingly as the mulch rate increases the area of the soil available for infiltration (absorbing water) will decrease.

### 3.5 Effects of gravel mix and gravel mulch on cumulative infiltration depth

Similar to the results obtained in infiltration rate, the treatments also improved the depth of water infiltrated into the soil. Consequently, the 12.5, 25 and 37.5% gravel mixes increased the cumulative depth of water infiltrated during 4.5 hours by 3.9, 62 and 86%, respectively, as compared to the cumulative infiltration depth of the control soil. Similarly, the 12.5, 25 and 37.5% gravel mulch rates improved the cumulative depth of water infiltrated by 4.7, 40.3 and 25.6%, respectively, compared to the cumulative infiltration depth of the control soil. It is also interesting to note that, except at 12.5% gravel mix and mulch rate, the gravel mixes improved the cumulative depth of infiltrated water better than their corresponding mulch rates and the parameter increased consistently with increase in gravel mix rate but not with gravel mulch rate. Owing to this, the highest cumulative depth of infiltration (24 cm) was recorded in the soil that received 37.5% gravel mix followed by 25% gravel mix (20.9 cm) and the least (12.9 cm) was recorded in the control soil. The improvements in cumulative depth of infiltrated water are related to the improvements in infiltration rate. Reports (Wells *et al*., 2003) showed that gravel mulch results in higher cumulative infiltration depth by reducing raindrop impact and protecting the surface soil from sealing and cumulative infiltration is also highly affected by surface sealing and, therefore, soil surface management, such as mulching, is thus highly important.

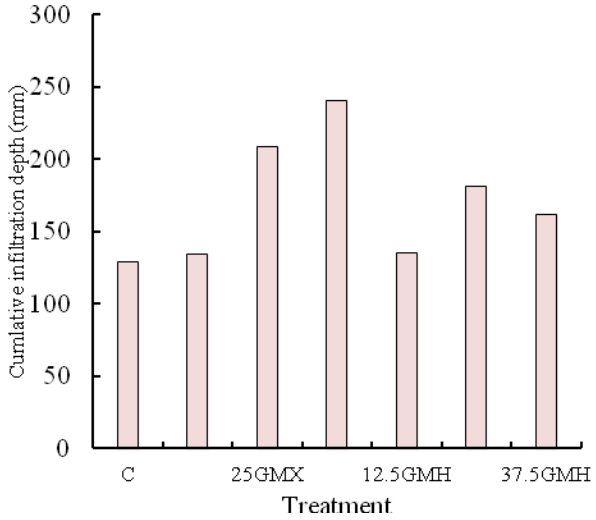


**Figure 6. Cumulative infiltration depth as affected by gravel mix and gravel mulch treatments** (C = control, GMX = gravel mix, GMH = gravel mulch).

### 3.6 Soil Moisture Storage and its Change with Time

The results of statistical analysis (Table 2) indicate that the treatments applied affected mean soil moisture storage of the upper 60 cm soil depth significantly ($P < 0.01$) during all the measurement times. Accordingly, the control stored the lowest moisture during all the measurement times as compared to all the other treatments. Similarly, from among the gravel mix and mulch treated soils, the 12.5 % gravel mix treated soil stored the lowest moisture during most of the measurement times compared to the other treatments. Furthermore, the 37.5 % gravel mulch treated soil, except at one occasion where high rainfall was recorded, stored the highest moisture throughout the experimental period.

The observed differences in soil moisture storage among the different treatments could be related to the improved infiltration rate and cumulative infiltration depth and reduction of water loss from the soil surface by evaporation at the higher rates of treatments.

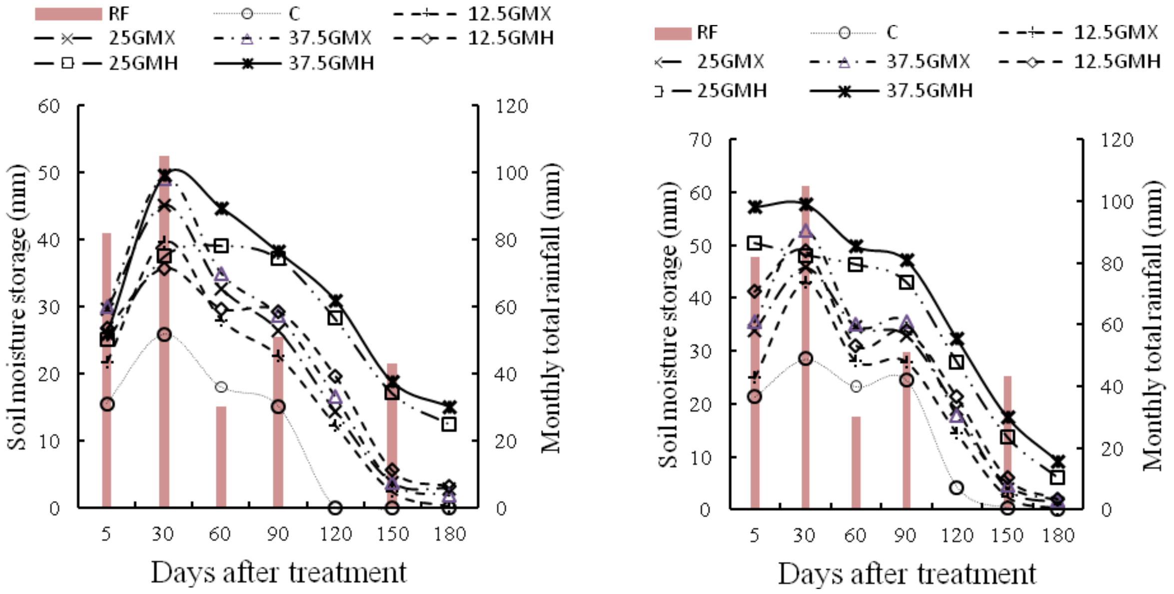
The seasonal dynamics of the soil moisture storage with depth and its relation with monthly rainfall in Figure 8 indicate that, regardless of the depth and rate and modes of the treatments applied, the soil moisture storage increased between 5 and 30 days after planting and then decreased consistently afterwards. It, therefore, followed the rainfall pattern only up to the 30 days mark. The rainfall that occurred after the 30 days after treatments was not large enough to satisfy the moisture deficit that occurred during the dry spells. As a result, the soil moisture storage did not increase to the expected level. Also, the moisture storage in the control plots became almost zero 120 days after planting.

**Table 2. Total soil moisture storage of the upper 60 cm of the soil profile as affected by gravel mix and gravel mulch treatments.**

| Treatment | **Total soil moisture storage (mm/m)*** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Days after planting** | | | | | | |
| | **5** | **30** | **60** | **90** | **120** | **150** | **180** |
| **Control** | 66.7e | 90.7c | 69.2f | 66.2d | 7.0f | 0.5d | 0.0b |
| **12.5GMX** | 77.8d | 137.8b | 93.8d | 84.5c | 44.8e | 8.2c | 0.7b |
| **25.0GMX** | 106.2c | 151.7b | 112.5cd | 99.2bc | 55.8d | 13.0c | 7.0b |
| **37.5GMX** | 109.3c | 170.0a | 116.8c | 107.0b | 57.3d | 14.2c | 6.0b |
| **12.5GMH** | 113.5c | 141.2b | 101.5d | 105.3b | 68.7c | 19.5c | 9.0b |
| **25.0GMH** | 125.7b | 142.8b | 142.5b | 133.8a | 93.8b | 51.7b | 31.2a |
| **37.5GMH** | 139.2a | 179.3a | 158.0a | 142.5a | 105.8a | 60.7a | 40.5a |
| **RF** | 81.9 | 105.0 | 30.2 | 51.2 | 0.0 | 0.0 | 0.0 |
| **CV** | 5.27% | 12.6% | 6.95% | 8.60% | 10.14% | 21.51% | 16.7% |
| **LSD** | 9.214** | 32.1** | 13.2** | 15.15** | 9.66** | 6.85** | 12.2** |

*means followed by the same latters in a column are not statistically different at 0.01 significant level. (C = control, GMX= gravel mix, GMH = gravel mulch, RF= Total Rainfall in millimeter)

.



a) Soil moisture drying curve (0-30cm)    b) soil moisture drying curve (30-60cm)

Figure 7. Soil moisture drying curve of the 0-30 cm (a) and 30-60cm (b) depth as affected by gravel mix and gravel mulch treatments and rainfall(C=Control, GMX = gravel mix, GMH = gravel mulch, RF= Rainfall).

Nevertheless, there were remarkable differences in the rate of decrease of the soil moisture storage. Accordingly, for most of the measurement times, the gravel mulch treatments retained better moisture than the gravel mix treatments, for reasons explained above. The results obtained in this study are consistent with the findings of other researchers (Li et al., 2000), who reported that covering the surface soil reduces surface evaporation.

## 4. Conclusion

Soil surface and subsurface management is vital practice one should consider for effective implementation of afforestation in dryland areas. Water is an essential factor for plant survival and development though scarce in the arid and semiarid areas. A study was undertaken to see the effect of different rates of gravel mix and gravel mulch on infiltration rate and moisture storage on clay soils under the dry condition using semicircular bunds. Results depicted that both infiltration rate and moisture storage have been enhanced significantly through application of gravel as a mulch and mixed with soil during seedling plantation. The experiment concludes that semicircular bunds constructed on heavy soils needs surface and subsurface amelioration of the run-on area to efficiently utilize runoff water which is mainly lost by evaporation and waterlogging.

### Acknowledgment

Colleagues at Melkassa agricultural research center and Dr. Kibebew Kibret for their assistance during producing the paper and EIAR for financial support are acknowledged.

### Competing Interests

The authors declared that they have no conflict of interest about the contents of this article

## References

Berehanu Debele, 1980. The physical criteria and their rating proposed for land evaluation in the highland region of Ethiopia. Land use planning and regulatory department, ministry of agriculture. Addis Ababa, Ethiopia.

Connolly, R.D., D.M. Freebairn and B.J. Bridge. 1997. Change in infiltration characterstics associated with cultivation history of soil in south-eastern Quensland. Aust. J. Soil Res. 35:1341-1358.

Dent, D. and R. Murtland, 1990. Land evaluation for afforestation in a semi-arid environment: The montane plains of the central highland of North Yemen. *Catena*, 17:509-523.

Ademe, F. and E. Alemu. 2007. Hillside rehabilitation with area closure and enrichment plantation of multipurpose trees at Marko Hillside, Ethiopia. Progress report (Unpublished), MARC, EIAR.

Li, X.Y., J.D. Gong and X.H. Wei, 2000. In situ rainwater harvesting and gravel mulch combination for corn production in the dry semi-arid region of China. Arid Environ. 46:371–382.

Miller, W.R. and R.L.Donahue, 1995. Soils in our environment. 7th ed. Englwood cliffs, New Jersey, USA.

Miller, W.R. and R.L. Donahue, 1997. Soil in our environment. 7th ed. Printice Hall of Indian Private Limited, New Delhi.

MoARD, 2005. Major Agro-ecological zones of Ethiopia. Forestry, Land use and soil Conservation Dept. Addis Ababa, Ethiopia.

Tekalign Tadesse, 1991. Soil, plant, water, fertilizer, animal manure and compost analysis. Working Document No. 13. Innternational Livestock Researh Center for Africa, Addis Ababa.

Wang, Y., X. Zhongkui, S. M. Sukhdev , L.V. Cecil, Y. Zhang and J. Wang, 2009. Effects of rainfall harvesting and mulching technologies on water use efficiency and crop yield in the semi-arid Loess Plateau, China. Agricul. Water Manag. 96:374-382.

Wells, R.R., D.A. DiCarlo, T.S. Steenhuis, J.Y.Parlange, M.J.M. Romkens and S.P. Prasad. 2003. Infiltration and surface geometry features of a swelling soil following successive simulated rainstorms. Soil Sci. Soc. Am. J. 67:1344-1351.

Yuan, C., T. Lei, L. Mao, H. Liu and Y. Wu, 2009. Soil surface evaporation processes under mulches of different sized gravel. China Agricultural University, 100083 Beijing, China.