4. RESULTS AND DISCUSSION

4.1. Assessment of meteorological data of the region:

4.1. Meterological data:

The study area at El- Qasr area in Wadi Washka at west of Marsa Matruh North-Western coastal zone, Egypt is, dominated by a Mediterranean- type climate characterized by cool and rainy winter and temperate dry summer. Automatic weather station was installed in the experimental site to record, rainfall (mm), air temperature (ºC), wind speed (ms^{-1}), relative humidity (%), sunshine (hours) solar radiation (MJ/m^2) and evapotranspiration ETo (mm). Table 2 illustrates the obtained meteorological data from October 2002 to October 2004. Climatic data are shown in Table 2.

4.1.1. Temperature:

The data show that average air temperature varied from 14.0 to 29.9ºC during the first season, and 12.8 to 25.5 ºC during the second season. The maximum air temperature varied from 17.6 to 30.0ºC during the first season and 18.0 to 29.7ºC during the second season. The minimum air temperature varied from 10.1 to 22.9ºC in the first season, and 8.4 to 21.1ºC during the second season. The data indicate that the highest temperature occurred during August and the lowest one occurred during January or February.

4.1.2. Humidity:

The main of relative humidity (RH%) values ranged from 61.0 to 76% during the first season and 61 to 73% during the second season. In general the highest monthly RH value was obtained during July 2003 and August 2004. These values were 76 and 73% respectively. The lowest monthly RH was obtained during October, 2002 and March. These values were 61%.

Table (2): Meteorological data for the study area from October 2002 to October 2004

Months of year	Avg Temperature (ºC)	Max Temperature (ºC)	Min Temperature (ºC)	Main relative Humidity (RH%)	Main wind speed (m/see)	Sun shine (Hours)	Solar Radiation (MJ/M^2)	Total months Rain fall (mm)	ETo (mm)
Oct. -2002	22.6	27.4	19.3	61	5.5	7.0	14.2	0.0	4.3
Nov. –2002	18.4	23.8	14.7	64	8.4	6.4	12.7	0.0	2.7
Dec. –2002	14.0	20.0	11.0	69	9.5	3.1	5.8	18.6	2.0
Jan. -2003	14.9	17.6	10.5	73	10.8	4.8	9.4	29.0	1.6
Feb. –2003	14.6	17.7	10.1	71	10.2	4.5	9.6	18.8	1.9
Mar. –2003	17.2	19.6	10.7	61	11.0	5.3	12.8	5.0	2.4
Apr. –2003	18.3	22.5	13.4	64	9.6	8.7	22.1	0.0	3.7
May.–2003	20.6	25.4	17.1	74	9.5	6.4	15.8	0.0	4.2
Jun. –2003	23.7	27.8	20.2	68	8.7	10.2	23.5	0.0	4.9
Jul. –2003	25.6	29.4	22.7	76	7.4	11.6	26.2	0.0	5.3
Aug. –2003	29.9	30.0	22.9	76	6.8	10.6	23.9	0.0	5.4
Sep. –2003	26.4	28.9	21.5	70	6.5	9.1	20.2	0.0	4.6
Total rain fall								71.4	
Oct. -2003	21.6	26.9	16.9	67	8.1	7.6	15.7	0	4.0
Nov. –2003	18.1	23.2	13.4	68	9.1	6.0	11.4	0	3.1
Dec. –2003	14.4	19.5	10.1	66	11.1	5.2	9.6	34	2.8
Jan. -2004	12.8	18.0	8.4	66	11.5	5.7	10.7	45	2.7
Feb. –2004	13.0	18.8	8.6	65	11.5	6.3	13.3	20	3.0
Mar. –2004	15.1	20.4	10.2	63	11.9	7.0	17.0	3	3.8
Apr. –2004	17.4	22.7	12.1	61	10.2	8.2	20.9	0	4.6
May.–2004	20.1	25.4	14.7	64	9.3	9.7	24.3	0	5.2
Jun. –2004	23.3	28.1	18.4	68	9.7	11.8	27.6	0	5.9
Jul. –2004	24.9	29.1	20.4	73	9.8	11.8	27.4	0	5.8
Aug. –2004	25.5	29.7	21.1	73	8.9	11.0	25.2	0	5.6
Sep. –2004	24.3	28.6	19.7	68	8.3	9.4	21.0	0	5.1
Total rain fall								102	

4.1.3. Wind, sunshine and Solar radiation:

The main of wind speed ($m.s^{-1}$) values during the first varied from 5.5 to 11.0 $m.s^{-1}$ and 8.1 to 11.9 ms^{-1} during the second season. Generally, the highest wind speed occurred during March (11.0 ms^{-1} in season 1 and 11.9 ms^{-1} in season 2). The lowest wind speed occurred during October (5.5ms^{-1} in season 1 and 8.1ms^{-1} in season 2). The values of sun shine varied from 3.1 to 11.6h during the first season and 5.2 to 11.8h during the second season. The data indicated that the highest values of sun shin occurred during July, 2003 and July, 2004 where these values were 11.6 and 11.8h respectively, while the lowest values of sun shin occurred during December, 2002 and December, 2003 where these values were 3.1 and 5.2h respectively. The solar radiation (MJ. m^{-2}) values ranged from 5.8 to 26.2 $MJ.m^{-2}$ during the first season and 9.6 to 27.6 $MJ.m^{-2}$ during the second season. Generally, the highest solar radiation was recorded during, July, 2003 and June 2004 where these values were 26.2 and 27.6 MJ. m^{-2} respectively, while the lowest solar radiation were recorded during December 2002 and December 2003 where these values were 5.8 and 9.6 $MJ.m^{-2}$ respectively.

4.1.4. Rain:

The amounts of rainfall (mm) during the study period. Rain fall during the 4 months of December, January, February and March in the first season where rainfall amounts for these months were 18.6, 29.0, 18.8 and 5.0 mm respectively. In the second season they were 34.0, 45.0, 30.0 and 3.0 mm respectively.

The total annual rainfall amounts were 71.4 and 102.0 mm for the first and second seasons respectively.

4.1.4.1. Assessment of rain data:

The number of rainfall events producing runoff is a more reliable indicator for the potential of water harvesting than the total amount of rainfall. The runoff volume depends on the total amount of rainfall and the rainfall characteristics, such as frequency, duration and intensity of rainfall events. **Madanat (1988)** reported that a threshold storm of 2.2 mm and an intensity of as low as 1mm h^{-1} could produce runoff.

In the current study, the rainfall distribution during the two is presented in Table 3 and Fig. 5. The data show that in the nine storms which occurred during the first winter season 2002/2003, rainfall per storm ranged from 4.6 to 13mm. In the eleven storms which occurred during the second winter season, rainfall per storm ranged from 3 to 20mm. The total amount of rainfall for the first season was 71.4 mm. This amount occurred in four months from December, 2003 to March, 2004. The total amount of rainfall for second season was 102 mm, it occurred in four month from December 2003 to March 2004.

The distribution of rainfall during the two winter seasons 2002-2003 and 2003-2004 show that the highest rainfall was recorded during January 2003 and January 2004 giving amounts of 29.0 and 45.0 mm respectively, while the lowest rainfall was recorded during March, 2003 and March 2004 giving 5.0 and 3.0 mm respectively. **Render and Klemm (1999)** reported that rainfall rate in the North-West costal zone of Egypt decreases from north to

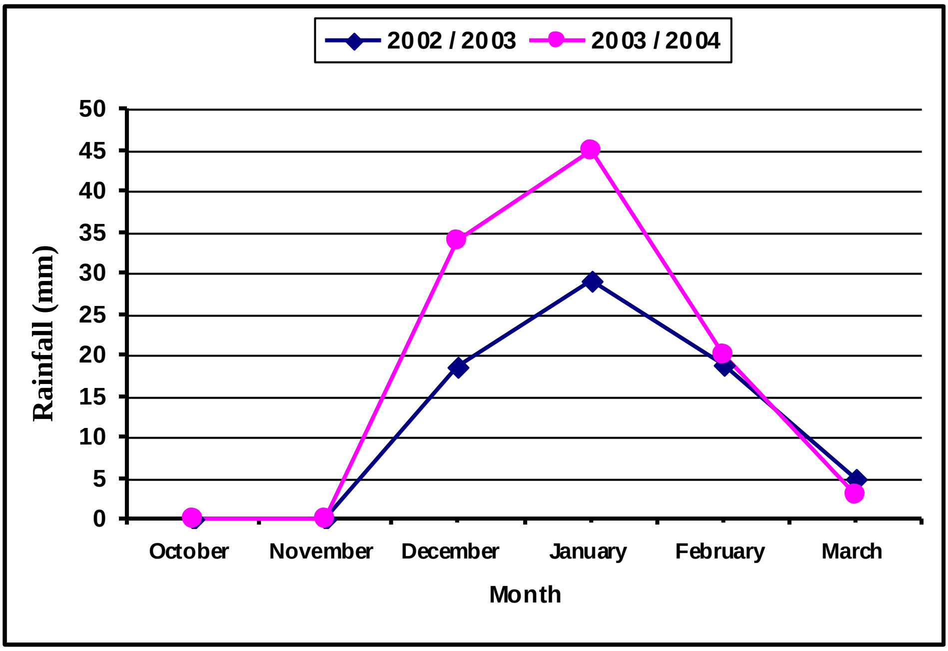


Fig. (5): The distribution of rainfall during the two winter seasons 2002/2003 and 2003/2004.

south direction. They observed maximum daily rainfall during a 15-year study was generally within 20 to 50 mm. They found that significant amounts of rainfall occur usually during October to March with highest monthly rainfall occurring in December and January.

4.1.5. Evapotranspiration:

The values of evapotranspiration ETo (mm) varied from 1.6 to 5.4 mm during the first season and 2.7 to 5.8 mm during the second season. The data indicate that the highest ETo was recorded during August, 2003 and July, 2004 where these values were 5.4 and 5.8 mm respectively, while the lowest values of ETo recorded during January, 2003 and January, 2004 where these values were 1.6 and 2.7 mm respectively.

4.2. Assessment of water-harvesting efficiency:

Assessment of water harvesting was performed in two perspectives. The first was on data collected from in field study regarding comarison between two water-harvesting systems (earth versus stone embankment) which were in use by farmers of El-Qasr area. The second was on data collected from the field factorial experiment studying the 3 cropped / non-cropped ratios and the 3 surface soil treatment.

Efficiency of runoff (ER) expresses the ratio of the amount of runoff water collected from the catchment area: the amount of rain water falling on the catchment area. Efficiency of runoff storage (ES) on the other hand expresses the ratio of the amount of runoff water stored in the root zone of the cropped area: the amount of water collected from the catchment area. The overall efficiency (Eo) expressed the combined effect of ER and ES.

4.2.1. Efficiency of El-Qasr water harvesting systems (stones and earth embankment).

The tested water harvesting systems such as non embankment, earth embankment and stone embankment were evaluated in an area of 2.5 feddans, for the water harvesting systems in concern.

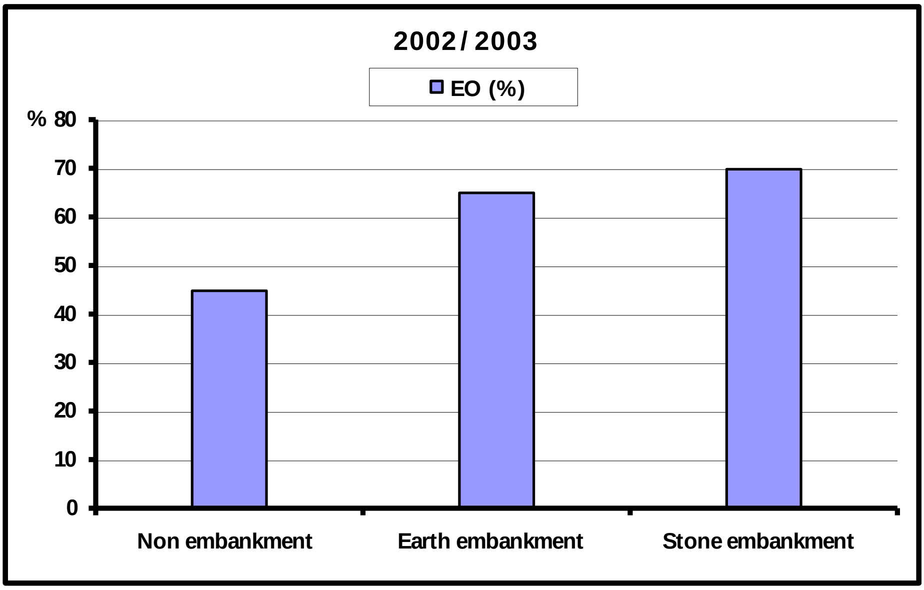
Two types of embankments are used in water harvesting i.e., stone and earth bunds. When loose stone is available, it should be preferred to earth bunds. Stones can be used together with grasses; this helps to stow runoff and deposit suspended soil while allowing the water to slowly flow down the land slope.

The data presented in tables (4) and (5) and Fig. (6) show the evaluation of different water harvesting systems in the first season (2002/2003) and second season (2003/2004).

4.2.2. Non embankment water harvesting :

Overall system efficiency for non- embankment varied from 31.2 to 62.5% in the first season and 27.6 to 64.0% in the second season.

Average overall system efficiency non- embankment for all storms was 44.8 and 42.7% respectively for the first and second seasons, respectively computed overall system efficiency depended on both volume of runoff water after each storm and volume of water stored in root zone which depended on both soil moisture in root zone after and before rainstorm event, and ET. data (Evapotramspiartion).



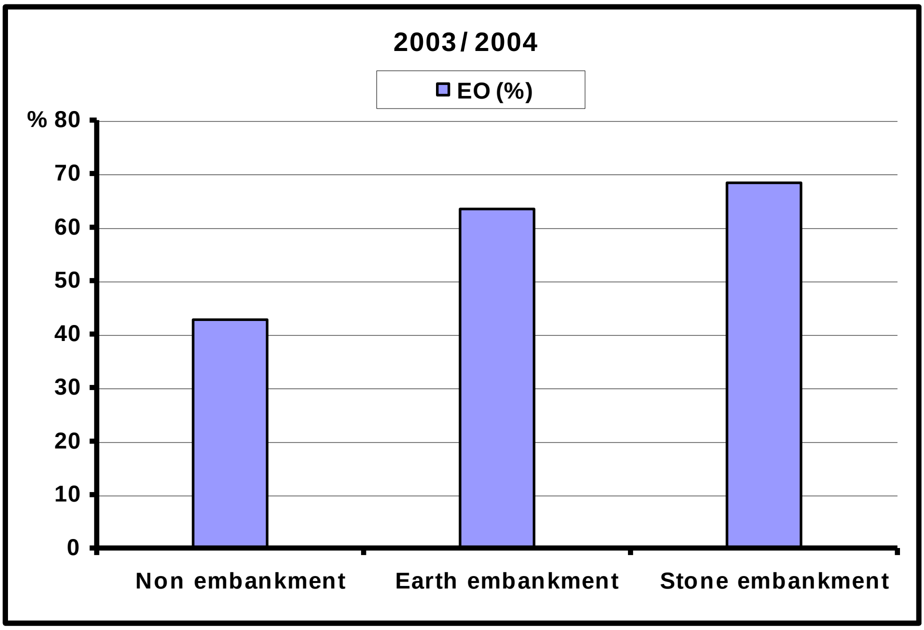


Figure (6): Efficiency evaluation of water harvesting systems at Al-Qasr area after rain stroms occurring in the seasons of 2002/2003 and 2003/2004.

4.2.3. Earth embankment:

Overall system efficiency for earth embankment varied from 49.5 to 81.7% in the first season and from 48.3 to 85.7% in the second season.

Average overall system efficiency for earth embankment for all storms was 64.9 and 63.4% respectively for first and second seasons, respectively.

This type of earth embankment is classified as external catchment (long slope catchment up to 1ha) technique suitable for different crops.

The main advantages of this technique are:

(a) Simple design and construction

(b) Minimum maintenance required

Structures similar to earth bunds have been reported in Somalia, **(Abdi, 1988)**. He a technique in the North west of Somalia which is simply called "bunding". The bunds are about 1m high and laid out on the contour.

4.2.4. Stone embankment:

Two types of embankments are used in water harvesting i.e. stone and earth bunds. When loose stone is available, it should be preferred to earth bunds. Stones can be used together with grasses; this helps to slow runoff and deposit suspended soil while allowing the water to slowly flow down the land slope. The selected site and the size of small dams depend on the topography, size and characteristics of precipitation of the catchment area. In addition, it depends on the social and economical benefits for the target group at that area.

Various research conducted for improved stone bund construction, comparison of the effects of stone bunds and earth bunds, and the impact of stone bunds on runoff, erosion and yields. **(Martinelli and Serpantie, 1987; Minoza *et al.,* 1987 and Rodrigues and Yameogo, 1988).**

Overall system efficiency for stone embankment varied from 53.6 to 86.2% in the first season and 53.6 to 91.7% in the second season.

Average overall system efficiency for stone embankment for all storms was 69.8 and 68.3% respectively for first and second season.

This type at stone embankment is classified as external catchment (long slope catchment) technique. They are small stone bunds constructed on the contour at spacing of 13-35m a part to slow suited to small scale applications on farmer's field with adequate supply of stone.

Also, it is suited for crop production under rainfall of 200-250mm. This technique is simple and easy to learning and was quickly adopted to the farmers.

Regner and Klemm (1999) pointed out that the dry stone dams are used in a large of applications.

This types from stone dams most used in the North- west coastal zone. This type is utilized for low investment low income cereal cultivation and for the best and highest yielding fruit tree plantations. The stone dams are contructed from field stones that are found on the surface or come from a caliche, zhorizontal half-meter thick layer of hard time stone. However, the farmers themselves collect most of the stones for dams. They dig up the stones with a hoe, the common tool or nearly all field work. In the reclamation process of large wadis, dry stone dams are needed for the first 2 years after heavy leveling. They are positioned across the flood direction on the completely level terrace, which is generally larger than 2 feddans.

Commonly, the results indicated the greatest of overall system efficiency were found in the stone embankment system while the lowest in the non-embankment and earth embankment.

The great of overall system efficiency of stone embankment due to the high volume of water stored in root zone behind the stone embankment compared with non- embankment and earth embankment. The results showed the means of volume of water stored in root zone for non-embankmebt, earth embankment and stone embankment for all storms was 40.66, 57.44 and 61.52m^3 respectively in the first season, while it was 48.02, 67.85 and 72.83m^3, respectively in the second season.

Rengner and Klemm (1999) reported that the volume of water stored in root zone for earth dams due to the water that was intended to be stored behind the dams is lost through the breakage.

4.2.2. Efficiency of the experimental water harvest systems (comparison of different catchment ratios).

Efficiency parameters were done using data collected from the fields experiment since practical difficulties were encountered data rain, soil moisture and other related data used for calculation of the efficiency parameters were collected from one replicate only. Therefore comparisons are done on basis of means of the storms in each season, and overall means of the two seasons. However, considering each season as a replicate, statistical analysis was performed on the two-season data.

The ratio treatment (i.e. ratio of areas of cropped "cultivated" : non-cropped "water-catchment") are as follows a narrow ratio, R1 (1: 2), a medium ratio, R2 (1: 4) and a wide ratio R3 (1: 6). The soil-surface conditioning treatments are as follows: a control non-conditioned "O" treatment, a soil-surface subjected to compaction "C" treatment and a soil surface treated with bitumen "B" treatment.

There were 9 storms in season 1 (71.4 mm rain) and 11 in season 2 (102 mm rain). Detailed data for each storms are shown in the appendix.

Efficiency parameters under discussion are (1) efficiency of runoff (ER), (2) efficiency of run off storage (ES), and (3) Overall efficiency (Eo).

4.2.2.1. Efficiency of runoff "ER" (Table 6 and Fig. 7).

Efficiency of runoff by storm ranged from 43.4% (storm 2 of 4.6 mm, R1O) to as high as 96.5% (storm 8 of 13 mm, R2B). Data of the average of 9 storms of season 1, and those of 11 storms of season 2 are discussed. The trend and pattern of season 1 was very much similar to that of season 2. The average of the two seasons would thus represent a reliable indication.

Season 1:

Values of ER ranged from 70.7% (R1O) to 80.3% (R2B). The main effect of the ratios shows R2 > R3 > R1, a pattern which stresses the superiority of R2, and a least effect of R3. Such a pattern occurred under conditions of no-surface treatment as well as under surface compaction of bitumen. Under the latter treatment, the superiority of R2 over R1 was more apparent.

The main effect of surface soil treatment shows that bitumen gave the highest ER. The response was as follows B > C > O. Such superiority of bitumen was considerable under conditions of R2 catchment area enables more water to infiltrate. Although the wide 1: 6 (R3) ratio, was more efficient than narrow 1: 2 (R1) ratio, it was not as efficient as the 1: 4 (R2) ratio. **Cooley *et al.* (1995)** reported that a very wide ratio was associated with loss of water by deep percolation. **Luebs and laage (1975)** evaluated ratios of different magnitudes up to a ratio of 1: 6 and found that all ratios gave positive efficiency. **Kamara *et al.* (1986)** recommended a ratio of 1: 4.

The greater effect of bitumen over surface compaction indicates the favourable effect of bitumen in giving soil structure leading to more water retention. Efficiency of bitumen application to soil surface was reported by **Mehdizadeh *et al.* (1978)** and **Fink *et al.* (1979).**

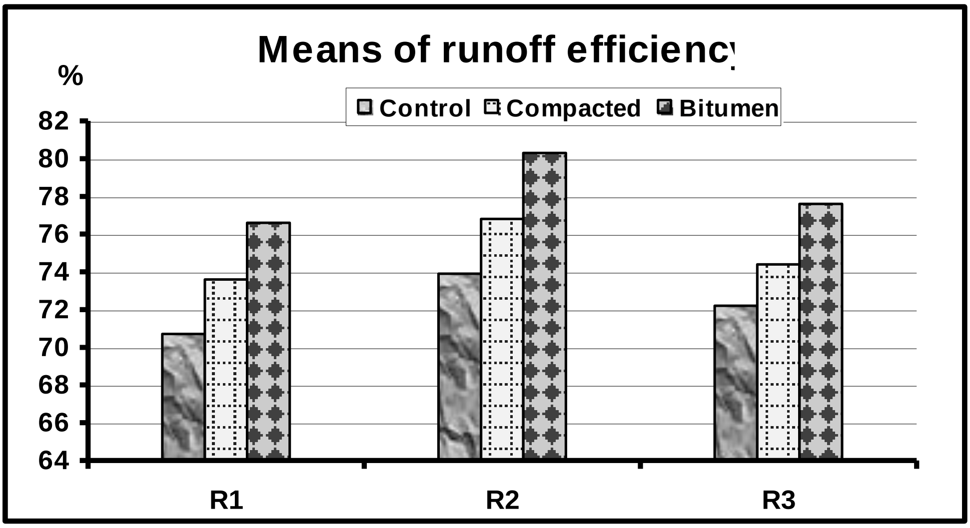
Table (6): Means of runoff efficiency (ER)% after rain storms occurring during study periods under various catchment areas and soil-surface treatments.

Ratio (R)	Means of runoff efficiency %			
	Soil-surface treatment (A)			
	O	C	B	Means
Season 1				
R1	70.7	73.6	76.6	**73.6**
R2	74.0	76.8	80.3	**77.0**
R3	72.2	74.5	77.7	**74.8**
Means	**72.3**	**75.0**	**78.2**	
Season 2				
R1	70.6	73.4	76.3	**73.4**
R2	76.0	79.6	83.1	**79.6**
R3	73.0	76.0	79.5	**76.2**
Means	**73.2**	**76.3**	**79.6**	
Mean of 2 seasons				
R1	70.7	72.0	76.5	**73.1**
R2	75.0	78.2	81.7	**78.3**
R3	72.6	75.3	78.6	**75.5**
Means	**72.8**	**75.2**	**78.9**	

L.S.D.	R	A	R x A
0.01	1.57	1.57	1.37
0.05	1.08	1.08	1.20

R1, R2 and R3 are 1: 2, 1: 4 and 1: 6 ratios of cropped : water catchment area.
O, C and B are non-treated, surface compaction and bitumen application.
L.S.D. concern means 2 seasons; each season was considered a replicates.

2002/2003



2003/2004

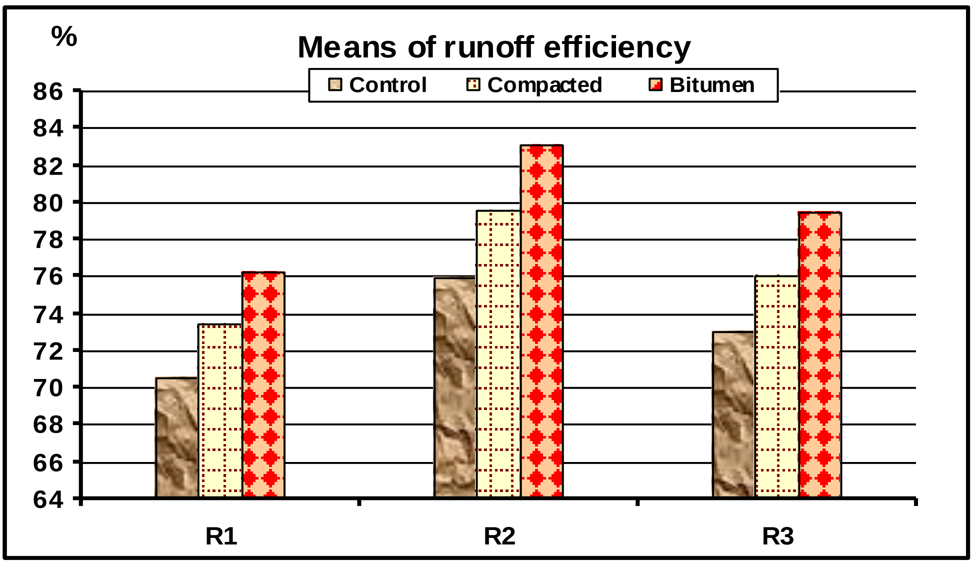


Fig. (7): Means of Runoff efficiency after rain storm occurring in the first and second season 2002/2003 - 2003/2004 under various catchment areas and surface treatments.

Season 2:

Values of ER ranged from 70.1% (R1O) to 83.1% (R2B). The main effect of the ratios shows R2 > R3 > R1 such a pattern occurred under all surface treatments, although it was more pronounced under bitumen treatment.

The main effect of surface soil treatment shows that bitumen was more effective than compaction. The response was B > C > O. The effect of bitumen was more apparent under R2.

Means of 2 seasons:

Since both seasons showed values of ER which were rather similar, and patterns which were nearly identical, therefore data for means of the two seasons are close to those of each season. Values of ER ranged from 70.7 (R1O) to 81.7% (R2B); and the trend for ratios was R2 > R3 > R1.

Superiority of R2 was particularly prominent where bitumen was added to the soil surface. Therefore the medium 1: 4 (R2) ratio was the most efficient being 1.07 times (overall average) as efficient as the narrow 1: 2 (R1) ratio. It follows that a rather large water catchment area is efficient.

4.2.2.2. Efficiency of runoff storage“ES” (Table 7 and Fig. 8).

Runoff storage efficiency was determined as the ratio of the amount of runoff water stored in the root zone of the crop to the amount collected from the catchment area. The calculation of runoff storage efficiency depended on both soil moisture in root zone after and before rain storm event, and ETo (Evapotranspiration). That soil moisture affected by runoff water volume which obtained from catchment area.

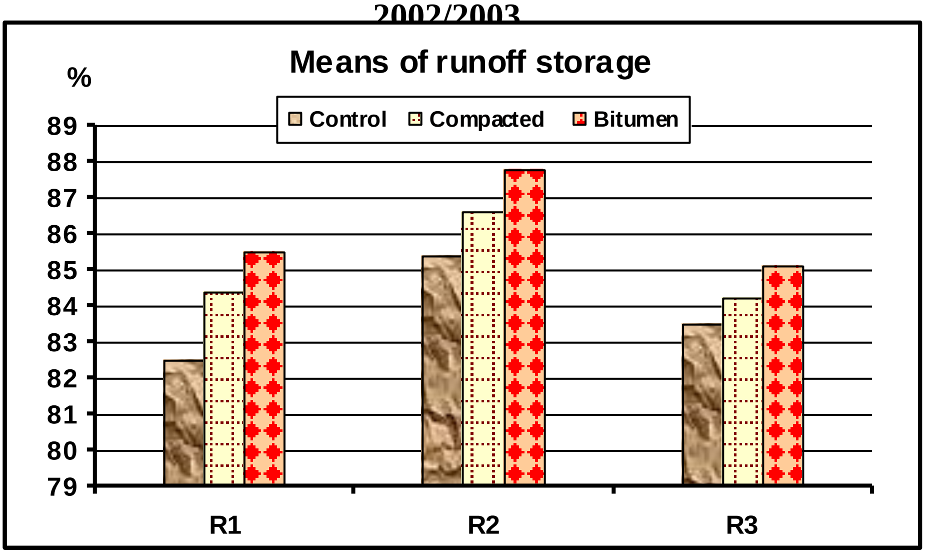
Table (7): Means of runoff storage efficiency (ES)% after rain storms occurring during study periods under various catchment areas and soil-surface treatments.

Ratio (R)	Means of runoff storage efficiency %			
	Soil-surface treatment (A)			
	O	C	B	Means
Season 1				
R1	82.6	84.4	85.5	**84.2**
R2	85.4	86.6	87.8	**86.6**
R3	83.6	84.2	85.2	**84.3**
Means	**83.9**	**85.1**	**86.2**	
Season 2				
R1	84.2	77.9	80.9	**77.7**
R2	80.1	82.9	84.2	**82.4**
R3	76.6	79.3	81.6	**79.2**
Means	**77.0**	**80.0**	**82.2**	**79.8**
Mean of 2 seasons				
R1	78.4	81.2	83.2	**80.9**
R2	82.8	84.8	86.0	**84.5**
R3	80.1	81.8	83.4	**81.8**
Means	**83.4**	**82.6**	**84.2**	
L.S.D.	**R**	**A**	**R x A**	
0.01	2.27	2.27	1.76	

0.05	1.54	1.54	1.23

R1, R2 and R3 are 1: 2, 1: 4 and 1: 6 ratios of cropped : water catchment area.
O, C and B are non-treated, surface compaction and bitumen application.
L.S.D. concern means 2 seasons; each season was considered a replicates.

2002/2003



2003/2004

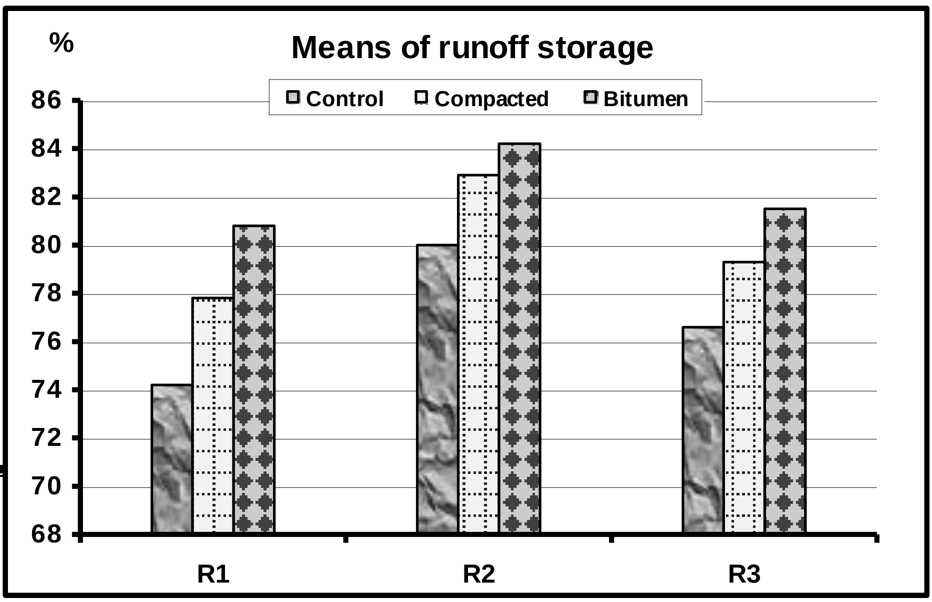


Fig. (8): Means of Runoff storage after rain storm occurring in the first and second season 2002/2003 - 2003/2004 under various catchment areas and surface treatments.

Efficiency of runoff storage by storm ranged from 70.5% (storm 2 of 4.6 mm; R1O) to as high as 94.5% (storm 4 of 11 mm, R2B). Data of the average of 9 storms of season 1, and those of 11 storms of season 2 are discussed. The trend and pattern of season 1 was very much similar to that of season 2. The average of the two seasons would thus represent a reliable indication.

Season 1:

Values of ES ranged from 82.6% (R1O) to 87.8% (R2B). The main effect of the ratios shows R2 > R3 > R1, a pattern which stresses the superiority of R2, and a least effect of R3. Such a pattern occurred under conditions of non-surface treatment as well as under surface compaction of bitumen. Under the latter treatment, the superiority of R2 over R1 was more apparent. The main effect of surface soil treatment shows that bitumen gave the highest ES. The response was as follows B > C > O. Such superiority of bitumen was considerable under conditions of R2.

Season 2:

Values of ES ranged from 74.2% (R1O) to 84.2% (R2B). The main effect of the ratios shows R2 > R3 > R1 such a pattern occurred under all surface treatments, although it was more pronounced under bitumen treatment.

The main effect of surface soil treatment shows that bitumen was more effective than compaction. The response was B > C > O. The effect of bitumen was more apparent under R2.

Means of 2 seasons:

Since both seasons showed values of ES which were rather similar, and patterns which were nearly identical, therefore data for means of the two seasons are close to those of each season. Values of ES ranged from 78.4% (R1O) to 86.0% (R2B); and trend for ratios was R2 > R3 > R1. Superiority of R2 was particularly prominent where bitumen was added to the soil surface. Therefore the medium 1: 4 (R2) ratio was the most efficient being 1.04 times (overall average) as efficient as the narrow 1: 2 (R1) ratio. It follows that a rather large water catchment area is efficient.

Oweis and Taimeh (1996) reported large differences in storage efficiency, which vary from lowest to highest under various rainfall conditions and management alternatives, which show the importance of determining the proper catchment size and surface treatment for more efficient use of the harvested water. Since water requirements of a deciduous crop in the winter are usually low, then attaining high storage efficiency suggests that the system should be designed to avoid filling the root zone too early in the season. On the other hand, there is a risk of not having enough rain late in the season to fill the root zone. The optimal strategy then is to secure a full soil reservoir at the end of the rainy season with maximum possible storage efficiency. Also, they reported that the run off storage efficiency depends mainly on the soil storage available in the root zone at the time when runoff occurs. The target then should be to bring this soil reservoir to full capacity at the end of the rain season with minimum deep percolation. The higher the ET rate during the rainy season and longer the period between run off storms, the more space needs to be filled. They showed that if the catchment area is larger than the proper size storage efficiency can be very high at the beginning of the season, but later it may drop to a very low level where most of the harvested water is lost in deep percolation. On the other hand, catchment area should be large enough to ensure a root zone full of water at the end of the season.

4.2.2.3. Overall efficiency of the water-catchment systems "EO" (Table 8 and Fig. 9).

Overall efficiency of the water-catchment systems is the ratio of the amount of water stored in the root zone of the crop to the amount of rain received by the catchment area. The efficiency of the system as a whole is an important indicator of its performance. It reflects the total loss of rainfall from the system. Small catchment areas produce reasonable overall efficiency but may sacrifice part of the storage capacity of the root zone so that at the end of season there is still some space for additional storage. Much larger catchment area, while substantial amount of water subjected to be lost via deep percolation.

Efficiency of overall of the water-catchment systems by storm ranged from 30.5% (storm 2 of 4.6 mm; R1O) to as high as 88.8% (storm 4 of 11mm; R2B). Data of the average of 9 storms of season 1, and those of 11 storms of storms of season 2 are discussed. The trend and pattern of season 1 was very much similar to that of season 2. The average of the two seasons would thus represent are liable indication.

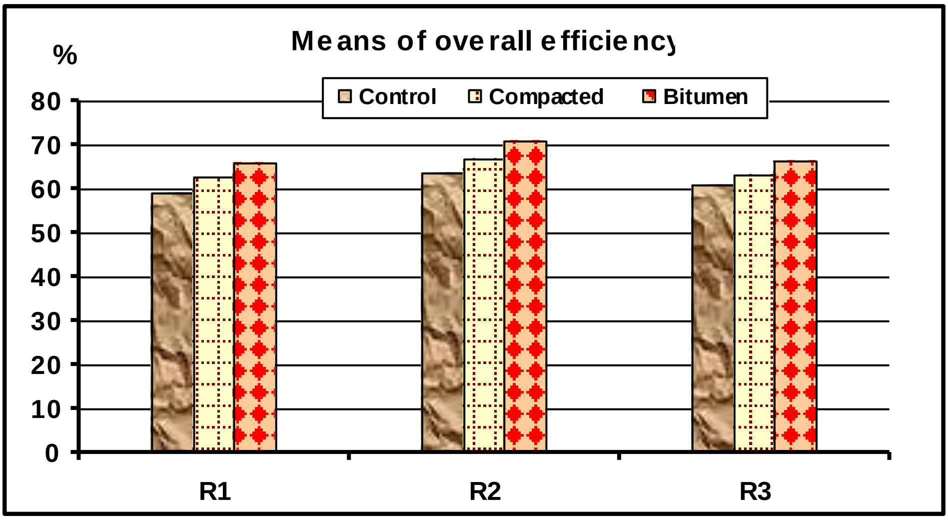
Table (8): Means of overall efficiency (EO)% after rain storms occurring during study periods under various catchment areas and soil-surface treatments.

Ratio (R)	Means of overall efficiency (EO)			
	Soil-surface treatment (A)			
	O	C	B	Means
Season 1				
R1	58.9	62.7	66.1	**62.6**
R2	63.7	67.0	70.9	**67.2**
R3	60.8	63.3	66.3	**63.5**
Means	**61.1**	**64.3**	**67.7**	
Season 2				
R1	53.0	58.1	62.8	**58.0**
61.7	61.7	66.9	70.9	**66.5**
R3	56.6	61.2	65.8	**61.2**
Means	**57.1**	**62.1**	**66.5**	
Mean of 2 seasons				
R1	56.0	60.4	64.5	**60.3**
R2	62.7	67.0	70.9	**66.9**

R3	58.7	62.3	66.1	**65.5**
Means	**59.1**	**63.2**	**67.2**	
L.S.D.	**R**	**A**	**R x A**	
0.01	1.46	1.46	1.24	
0.05	1.01	1.01	1.16	

R1, R2 and R3 are 1: 2, 1: 4 and 1: 6 ratios of cropped : water catchment area.
O, C and B are non-treated, surface compaction and bitumen application.
L.S.D. concern means 2 seasons; each season was considered a replicates.

2002/2003



2003/2004

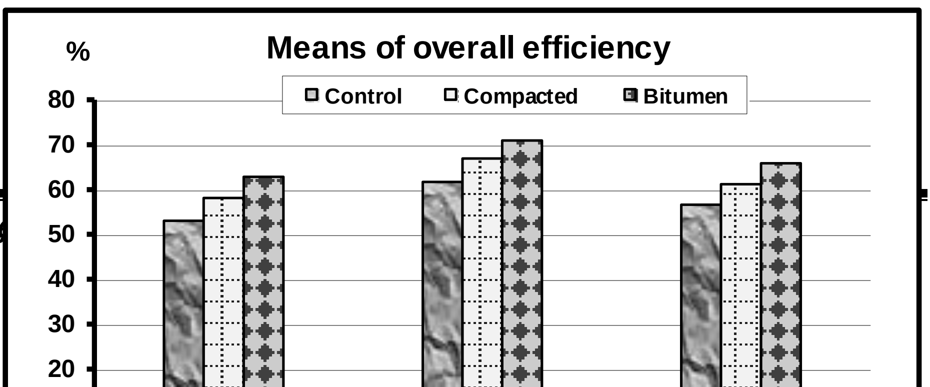


Fig. (9): Means of overall efficiency after rain storm occurring in the first and second season 2002/2003 - 2003/2004 under various catchment areas and surface treatments.

Season 1:

Values of EO ranged from 58.9% (R1O) to 70.9% (R2B). The main effect of the ratios shows R2 > R3 > R1, a pattern which stresses the superiority of R2, and a least effect of R3. Such a pattern occurred under conditions of non-surface treatment as well as under surface compaction of bitumen. Under the latter treatment, the superiority of R2 over R1 was more apparent. The main effect of surface soil treatment shows that bitumen gave the highest EO. The response was as follows B > C > O. Such superiority of bitumen was considerable under conditions of R2.

Season 2:

Values of EO ranged from 53.0% (R1O) to 70.9% (R2B). The main effect of the ratios shows R2 > R3 > R1 such a pattern occurred under all surface treatments, although it was more pronounced under bitumen treatment.

The main effect of surface soil treatment shows that bitumen was more effective than compaction. The response was B > C > O. The effect of bitumen was more apparent under R2.

Means of 2 seasons:

Since both seasons showed values of EO which were rather similar, and patterns which were nearly identical, therefore data for means of the two seasons are close to those of each season. Values of EO ranged from 56.0% (R1O) to 70.9% (R2B); and trend for ratios was R2 > R3 > R1. Superiority of R2 was particularly prominent where bitumen was added to the soil surface. Therefore the medium 1: 4 (R2) ratio was the most efficient being 1.10 times (overall average) as efficient as the narrow 1: 2 (R1) ratio. It follows that a rather large water catchment area is efficient.

Oweis and Taimeh (1996) showed that total losses under small runoff- basin system include those occurring in the catchment area (expressed in the runoff efficiency) and those lost from the crop root zone as deep percolation and/or seepage (expressed in the storage efficiency). The overall efficiency is sums of the losses from two components of the water harvesting system. They reported that lower runoff- efficiency values associated with small catchment area reduced the amount of water that could have been lost to deep percolation. Also, they showed that the low values of runoff efficiency strongly affected the overall system efficiency.

4.2.2.4. Conclusive assessment on the catchment ratios:

Commonly, the results indicate that the greatest runoff efficiency, runoff storage efficiency and overall system efficiency were found under the medium 1: 4 (R2) ratio and bitumen treatment (B), while the lowest one was found under the narrow 1: 2 (R1) ratio and non-treated (O).

4.3. Assessment of response of crop performance and soil fertility to the experimental water catchment ratios:

In the arid and semi-arid regions water is an important limiting factor of crop growth.

One of the main criterla for the selection of water harvesting technique is its suitability for the types of plant one wants to grow.

Tejwani and Gupta (1975) showed that the water harvesting techniques may a from region to region depending on the amount and distribution of rainfall, nature and properties of soils, crops grown and socio-economic conditions. **Ruddle and Manshard (1981)** found that the perennial crops like pomegranate, vine pistachio, apricots, olive, carob, alomds, vegetables, cut flowers and to a lesser extent citrus fruits were suited to micro catchment planting. Barley, wheat and forage crops also have been grown under such systems. **(Yadav *et al.*, 1980 and Sharma *et al.*, 1982)** pointed the microcatchment water harvesting for increasing crop production on dry lands has been the subject of considerable research for the last several decades.

In this study two successive field experiments water harvesting microcatchment system were conducted in the season 2002/2003 and season 2003/2004 using wheat (*triticum valgure*) plant.

The data presented in Tables (9) and (10) and Fig. (10) show the plant height (cm), grains weight and straw (kg/fed) of wheat plants under different catchment ratios (R1, R2 and R3) and different of soil-surface treatments i.e. non-treated, compaction and bitumen in both first (2002/2003) and second (2003/2004).

4.3.1. Plant height (Tables 9 and 10).

The pattern of plant height in the two seasons was rather similar and followed a trend not different from those of the yield of straw and the yield of grains.

Season 1 (Table 9):

Plant height ranged from 29.4 (R1O) to 43.6 (R2B). The main effect of rations was R2 > R3 > R1 with increases of 15.8% and 6.4% due to R2 over R1 and R3 respectively. The superiority of R2 over R1 and R3 was particularly significant where bitumen was used in treating the soil surface, giving 20.0% and 10.4% respectively. The differences between R1, R2 and R3 under non-surface treatment were not significant.

Bitumen treatment showed an average increase of 30.4% as compared with a lower average increase of 18.1% caused by compaction. Superiority of bitumen over compaction was particularly significant under R2 or R3 but not under R1 where the superiority was slight and not statistically significant.

Season 2 (Table 10):

Height (cm) of plants ranged from 32.9 (R1O) to 49.2 (R2B). The main effect shows R2> R3 > R1 with increases of 19.1% and 9.4% due to R2 and R3 over R1 respectively.

The superiority of R2 over R3 as well as R1 was particularly significant under conditions of bitumen application (giving height increases of 9.5% and 20.5% respectively, and also under conditions of compaction (giving height increases of 10.1% and 22.4%). However, both R2 and R3 were of non significant difference under conditions of no-surface treatment.

The positive effect of compaction as well as that of bitumen addition showed main increases of 18.1% and 27.2% respectively.

The superiority of bitumen over surface compaction was slightly more apparent under R1 or R2. The compaction treatment was slightly effective with R1, but strongly effective. **Tenbergen *et al.*, (1995)** showed that plants which grew below minicatchment were positively affected by the additional water supply. The shoot length of plants growing below the minicatchement showed an increase of 25 cm compared to 1cm under normal conditions. **Joseph (1995)** studied the improving of crop yields by means of water harvesting. He found that highest millet and sorghum yields were achieved under micro- catchment water harvesting showing a promising cropping system for land- poor farmers or in areas where conventional practice produce relatively low yields.

4.3.2. Yield of wheat grains (Tables 9 and 10).

Season 1 (Table 9):

Yield of wheat grains (kg/fed) ranged from 590 (R1O) to 1200 (R2B). The main effect of ratios show R2 > R3 > R1. The magnitudes of increases of R2 and R3 over R1 was 47.5 and 29.7% respectively. Superiority of R2 over R1 was most pronounced where bitumen (B) was used giving 59.9% as compared with increases of 45.1% and 38.1% under surface compaction (C) and no-surface treatment (O) respectively. Both R2 and R3 were not significantly different, except where bitumen was used.

The positive effect of surface compaction and bitumen treatment showed mean increases of 19.8% and 39.9% respectively over the non-treated soil. The superiority of bitumen over the no-treatment was greater under R2 (47.2%) than R1 (29.7%) or R3 (39.9%).

Season 2 (table 10):

Yield of wheat grains (kg/fed) ranged from 681 (R1O) to 1630 (R2B). The main effect of ratios shows R2 > R3 > R1, with increases due to R2 and R3 over R1 of 64.6% and 37.0% respectively. Superiority of R2 over R1 was most pronounced where compaction was done to the soil surface giving 71.4%, as compared with increases of 64.8% where bitumen was used, and 56.4% where no-surface treatment was done to the positive effect of compaction and bitumen treatment showed mean increases of 20.8% and 50.1 respectively. The increase by bitumen was greater under R2 (53.1%), than under R1 (45.2%) or R3 (50.0%).

Grewal *et al.*, (1982) showed that the grain yield values of wheat under the harvesting water with one and two supplemental irrigations were 0.28, 1.32 and 3.35t/ha respectively. **Salem *et al.* (1992)** found that the yield of wheat under the rain field condition do not increase above 14% from yield of wheat under irrigation conditions. **Abd El-Aleem *et al.* (1992)** found that the yields of wheat by different methods of water harvesting were 1303 kg/ha in the furrow system and 959 Kg/h in the contour system.

4.3.3. Yield of wheat straw:

Season 1 (Table 9):

Yield of wheat straw (kg/fed) ranged from 715 (R1O) to 1387 (R2B). The main effect of catchment ratios show R2 > R3 > R1. The magnitudes of increases of R2 and R3 over R1 was 38.5 and 19.4% respectively. The superiority of R2 over R3 was particularly considerable under conditions of bitumen application (45.5%) or soil compaction (34.8%).

The positive effect of compaction and bitumen application showed mean increases of 16.5% and 40.0% respectively. The increase by bitumen conditioning was greater under R2 (45.7%) than under R1 (33.3%) or R3 (40.4%).

Season 2 (Table 10):

The pattern of response in this season resembled that of season 1. Yield (kg/fed) ranged from 811 (R1O) to 1761 (R2B). The main effect of ratios shows R2 > R3 > R1 with increases for R2 and R3 of 50.3% and 32.7% respectively over R1. The increase due to R2 over R1 was particularly considerable under conditions of bitumen, being 58.6%, as compared with 43.8 and 46.9% under conditions of surface-compaction and non-treatment respectively.

Awni and Nabil (1997) pointed that production systems in rainfed areas can be broadly divided into two groups: those based on annual crops and those based on perenial crops. The main annual crops are wheat, barley, lentil and chickpea. They showed the wheat is main field crop in areas with more than 300 mm annual rainfall. Wheat straw is a valuable by-product that is used for feeding livestock. Average yield of wheat varied between 680 kg/ha to about 924 kg/ha because of shortages and erratic distribution of rainfall. Improved practices, including high yield varieties, seed drills, early planting, fertilizers and herbicides, have increased wheat yields.

4.3.4. Concentration of micronutrients in straw of wheat (Tables 11 and 12 and Fig. 11):

Concentrations values of the three micronutrients (Fe, Mn and Zn) in wheat plants show highly significant differences between the tested microcatchment ratios of water harvesting and the treatments of soil (control, compaction and bitumen).

The date presented in tables 11 and 12, and Fig. 11 show that concentration (μg g^{-1}) of micronutrients (Fe, Mn and Zn) in wheat plants under different catchment area (R_1, R_2 and R_3) and the soil treatments (control, compaction and bitumen) in the first season 2002/2003 and the second season 2003/2004.

4.3.4.1. Fe concentration in straw of wheat :

The results showed that the means of Fe ($\mu g\ g^{-1}$) contents in wheat plant varied from 183 (R1O) to 335 (R2B) $\mu g\ g^{-1}$ in the first season and 208 (R1O) to 375 (R2B) $\mu g\ g^{-1}$ in the second season. Means of plant content of Fe under the ratios of R_1, R_2 and R_3 were 225, 282 and 254 $\mu g\ g^{-1}$ respectively in the first season and 262, 353 and 310 $\mu g\ g^{-1}$ respectively in the second season.

The means of plant content of Fe for soil treatments; control, compaction and bitumen were 200, 258 and 302 $\mu g\ g^{-1}$ respectively in the first season; and 239, 312 and 374 $\mu g\ g^{-1}$ respectively in the second season. The results indicated significant differences for plant content of Fe between the ratios of R_1, R_2 and R_3 ; where there was more Fe under the ratio of R_2 than R_1 or R_3. The values of plant content of Fe for R_2 ratio increased by 25.3 and 11.0% respectively over R_1 and R_3 ratios in the first season, while they increased by 34.7 and 13.8% respectively over R_1 and R_3 ratios in the second season.

Therefore, the greatest values of plant content of Fe were found in the R_2 ratio in comparison with R_1 and R_3 ratios. The results show significant differences between soil treatments; control, compaction and bitumen. The bitumen treatment gave more Fe than the control and compaction treatments. The values of plant content of Fe for the bitumen treatment increased by 51.0 and 17.0%

respectively over the control and compaction treatments respectively in the first season, comparable increases were 56.4 and 19.8% respectively than the control and compaction treatments respectively in the second season. The greatest values of plant content of Fe were found in the bitumen treatment comparison with control and compaction treatments.

4.3.4.2. Mn concentration in straw wheat:

The results showed that means of concentration ($\mu g\ g^{-1}$) of Mn in the wheat plant varied from (R1O) 29.3 to 56.9 (R2B) $\mu g\ g^{-1}$ in the first season and 33 (R1O) to 73 (R2B) $\mu g\ g^{-1}$ in the second season.

Means of concentration of micronutrient Mn in wheat plants under the ratios of R_1, R_2 and R_3 were 36.8, 46.0 and 40.3 $\mu g\ g^{-1}$ respectively in the first season and 42.6, 58.0 and 49.3 $\mu g\ g^{-1}$ respectively in the second season. Means of concentration of Mn in wheat plant for treatments; control compaction and bitumen were 33.7, 40.0 and 48.8 $\mu g\ g^{-1}$ respectively in the first season and 40.3, 48.3 and 61.3 $\mu g\ g^{-1}$ respectively in the second season.

The results indicated significant differences among the concentration of micronutrient Mn in wheat plant between the R_1, R_2 and R_3. Contents of Mn for R2 were greater than R_1 and R_3 ratios. The content of Mn for R_2 ratio increased by 25.0 and 14.0% respectively over R_1 and R_3 ratios in the first season, while the increases were 36.1 and 17.6% respectively over R_2 and R_3 ratios in the second season. The greatest values of the concentration of Mn in the wheat plant were found under the R_2 ratio comparison with R_1 and R_3 ratios.

The results show significant differences between soil surface treatments of control, compaction and bitumen. The bitumen treatment showed more Mn than the control or the compaction treatments. Values of concentration of Mn for bitumen treatment increased by 44.8 and 22.0% over the control and compaction treatments respectively in the first season, while increased by 52.1 and 26.9% respectively in the second season. The greatest value of the concentration of Mn in the wheat plant were found in the bitumen treatment in comparison with the control and compaction treatments.

4.3.4.3. Zn concentrations in straw wheat:

The results showed the concentration ($\mu g\ g^{-1}$) of Zn in the wheat plant varied from 4.3 (R1O) to 19.3 (R1B) $\mu g\ g^{-1}$ in the first season and 4.8 (R1O) to 24.7 (R2B) $\mu g\ g^{-1}$ in the second season. Means of concentration of micronutrient Zn in wheat plant under the ratios of R_1, R_2 and R_3 were 8.2, 11.3 and 10.0 $\mu g\ g^{-1}$ respectively in the first season and 9.5, 14.2 and 12.3 $\mu g\ g^{-1}$ respectively in the second season. Means of concentration of Zn in wheat plants, for treatments of the control, compaction and bitumen were 4.6, 8.4 and 16.5 μgg^{-1} respectively in the first season and 5.4, 10.2 and 20.5 $\mu g\ g^{-1}$ respectively in the second season.

The results indicate significant differences among the concentration of micronutrient Zn in wheat plant between the ratio of R_1, R_2 and R_3. More Zn was found in R_2 ratio than R_1 and R_3 ratios. Values of concentration of Zn for R_2 ratio exceeded those of R1 and R3 by 37.8 and 13.0% respectively in the fist season, while and 49.4 and 15.4% respectively in the second season. Thus the greatest values of the concentration of Zn in the wheat plant were found in the R_2 ratio in comparison with the R_1 and R_3 ratios. The results show the significant differences between the soil treatments of control, compaction and bitumen. The bitumen treatment showed more Zn than control and compaction treatments. Values of concentration of Zn for bitumen treatment increased by about 2 to 2.5 times compared to that of control in the first season and about 1 to 2.7 times compared to that of control in the second season. Thus, the greatest values of the concentration of Zn in the wheat plants were found in the bitumen treatment comparison with control and compaction treatments.

4.3.5. Available micronutrients Fe, Mn and Zn in soil after crop harvest (Tables 13 and 14 and Fig. 12):

The transport of nutrients from solution to runoff occurs simultaneously with water movement in soils. Many factors, including rainfall intensity, volumes of runoff, water discharge, water storage capacity of soils, and agricultural practices, can affect nutrient transport in runoff. The data presented in tables 13 and 14 and Fig. 12 show the DTPA extractable contents of Fe, Mn and Zn micronutrients from the soil under different treatments i.e., control, compaction and bitumen in the first season (2002/2003) and the second season (2003/2004), as $mgkg^{-1}$.

4.3.5.1. Available Fe:

Results show that available soil Fe $mgkg^{-1}$ by DTPA extractable in soil varied from 17.7 (R1O) to 30.6 (R2B) $mgkg^{-1}$ in the first season and 20.2 (R1O) to 36.1 (R2B) mg kg^{-1} in the second season. Means of available soil Fe under R_1, R_2 and R_3 ratios were 19.9, 25.6 and

22.4 mgkg^{-1} respectively in the first season and 22.9, 30.4 and 25.9 mgkg^{-1} respectively in the second season. The means of available of Fe concentration in soil for treatments of control, compaction and bitumen were 19.3, 22.3 and 26.2 mgkg^{-1} respectively in the first season, and 30.0, 26.0 and 30.2 mgkg^{-1} respectively in the second season. These results indicate significant differences among the available soil Fe values under the ratios R_1, R_2 and R_3 under the R_2 ratio Fe was highest in soil. The contents under R_2 ratio were higher by 28.6 and 14.2% respectively over the R_1 and R_3 ratios in the first season, and by 32.7 and 17.3% respectively in the second season.

Thus, the greatest values of available amount of Fe were found under the R_2 ratio in comparison with the R_1 and R_3 ratios. The results show that the bitumen treatment was superior to the compaction treatment.

He *et al.* (2004) reported that the concentrations and loads of Cu, Fe, Zn and Mn in the runoff were correlated with amounts of 0.01 $MCaCl_2$- extractable Cu, Fe, Zn and Mn in the soils.

The nutrient contents in the study areas varied among treatments, and were probably positively affected by many factors, such as extent of greater accumulation in the soil and securing more rainfall volumes.

4.3.5.2. Available Mn :

The results showed that available DTPA extractable soil Mn varied from 10.9 (R1O) to 19.7 (R2B) mgkg^{-1} in the first season and 12.6 (R1O) to 22.6 (R2B) mgkg^{-1} in the second season. Means of available soil Mn under ratios of R_1, R_2 and R_3 were 12.9, 16.1 and 14.5 mgkg^{-1} respectively in the first season and 14.5, 18.4 and 16.7 mgkg^{-1} respectively in the second season. Means of available soil of Mn under the soil treatments of control, compaction and bitumen were 11.6, 14.5 and 17.4 mgkg^{-1} respectively in the first season and 13.4, 16.2 and 20.0 mgkg^{-1} respectively in the second season. The results indicate significant differences among ratios of R_1, R_2 and R_3. The ratios of R_2 showed greater Mn than R_1 and R_3. Available soil Mn under R_2 ratio increased by 24.8 and 11.0%, respectively over R_1 and R_3 in the first season, and by about 26.8 and 10.1% respectively than R_1 and R_3 in the second season.

Thus, the greatest values of soil available Mn were found under the R_2 ratio in comparison with R_1 and R_3 ratios. The results show significant differences between the soil treatments of control compaction and bitumen treatments. The bitumen treatment values were higher than those of the control or compaction treatment. Available soil of Mn under bitumen treatment increased by 50.0 and 20.0%, over control and compaction treatments respectively in the first season, and by 29.2 and 23.4%, respectively in the second season. Thus, the greatest values of available Mn were found under bitumen treatment in comparison with control and compaction ones.

4.3.5.3. Available Zn :

The results show that of DTPA- extractable nutrient Zn from the soil varied from 0.86 (R1O) to 2.8 (R2B) mgkg^{-1} in the first season, and 0.9 (R1B) to 3.3 (R2B) mgkg^{-1} in the second season. Means of available amount of Zn for the ratios of R_1, R_2 and R_3 were 1.40, 2.14 and 1.68 mgkg^{-1} respectively in the first season, and

1.63, 2.46 and 1.93 $mgkg^{-1}$, respectively in the second season. Means of available amount of Zn for soil-surface treatments of control, compaction and bitumen were 1.12, 1.74 and 2.36 $mgkg^{-1}$, respectively in the first season and 1.26, 2.0 and 2.76 $mgkg^{-1}$ respectively in the second season. The results showed significant differences among the available of Zn under the ratio of R_1, R_2 and R_3. Under the R_2 ratio there were greater available Zn as compared with R_1 and R_3 ratios. The values of available Zn under R_2 ratio were greater by 52.8 and 27.3%, over those R_1 and R_3 respectively in the first season and by 50.9 and 27.4%, respectively in the second season. The results of available soil Zn showed significant differences between the soil-surface treatments of control compaction and bitumen. The bitumen treatment significantly showed greater values than the control or the compaction treatment. The available soil Zn under bitumen treatment was greater by 110.7 and 35.6%, respectively over the control and compaction treatments respectively in the first season, and by 119.0 and 38.0% respectively in the second season. Thus, the greatest value of available soil Zn was found under the bitumen treatment in comparison with control and compaction treatments.

He *et al.* (2004) studied the transport of micronutrients and heavy metals in surface runoff from vegetable and citrus field and found variations in the concentrations of due to runoff discharge. Annual loads of dissolved nutrients in the runoff would vary widely. Treatments leading to increased water harvesting such as R2 and bitumen treatments would lead to increased soil fertility.