MAXIMIZING THE UTILIZATION OF RAINWATER FOR THE AGRICULTURAL USE

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ABSTRACT

In arid and semi-arid regions, where precipitation is low or infrequent during the dry season, it is necessary to store the maximum amount of rainwater during the wet season for use in the agriculture sector. Rainfall in the Kingdom of Saudi Arabia takes place primarily during winter and spring seasons. The amount of rainfall ranges from 0.1 to 0.2 m in the area extending from north of Riyadh to the vicinity of Hail. The shortage of rainfall, high soil water evaporation and deep-water percolation derived us to give great thought to the present study. One of the methods frequently used in rainwater harvesting is the storage of rainwater *in situ.* Mulching is the procedure usually used to reduce soil water evaporation. Soil compaction can lead to reduction for the deep-water percolation. Collecting the rainfall *in situ*, reducing the soil water evaporation and reducing the deep-water percolation simultaneously are our ultimate goals from this study. For achieving this study, several field plots in the Agriculture and Veterinary Faculty Farm- Al-Qassim, King Saud University were selected. The dimension of such a plot was 3x5m and 1 m apart. For harvesting the rainfall or the sprinkler irrigation water effectively, a big metal drum with a notch was designed to dig cone- holes in the soil surface to 0.1 m depth and 0.10 m I.D. The holes were 0.30 m apart. A single plant of faba bean was planted nearby the holes on 10 of October, 2003 in the winter season. Similarly, the corn and green bean were planted on 6 of April, 2004. To suppress water evaporation from the holes, three patterns were used. The first pattern was filling the hole with grass residue. In the second pattern, the holes were filled with rocks (5-20 mm diameter). The third pattern, the holes were covered with drilled black plastic (winter season) or white plastic (summer season) sheet. In addition to these treatments, planting nearby the holes and in flat plots were used too as treatments. Sprinkler irrigation system was used for irrigation when the rainfall was limited. Three replicates were assigned for each treatment. The growth and yield parameters were monitored during the growing season that lasted till 9th of March, 2004 during the winter season and 20 of July during the summer season. The growth rate of faba bean for the plastic treatment was 0.0095 m/day while it was 0.006 m/day for either the flat or grass residue treatments. The results of the final yield of faba bean followed the order: plastic> rock> grass> hole> flat treatments. The fresh weight of green bean followed the order: rock>plastic>hole>grass>flat treatments. In the corn experiment, all surface treatments gave greater ear yield than the yield of flat treatment. The results of this project validated soil surface management that positively

impact crop yield and water conservation. Therefore, using the designed machine can enhance the soil water storage that lead to great yield of a crop.

UTILIZATION

The Kingdom of Saudi Arabia is located in an arid region, which receives little amount of rainfall. This rainfall occurs usually during the winter and spring seasons. Adapting rainfall harvesting is usually a mandatory technique for utilizing the rainfall for the agricultural use. New technique is proposed for maximizing the use of collected water. The new technique based upon collecting and reducing both water evaporation and deep percolation through compaction the soil surface in forms of cone-hole. In addition, the cone-hole was filled using rock fragments or grass residues or coved using a plastic sheet. The new technique was conducted at the Agriculture and Veterinary Faculty Farm, Al-Qassim, King Saud University. Filed experiment (1000 m^2) was prepared for the study. Faba bean and green beans were sown and their growth and yield parameters were monitored during the growing season. So, the new technique can increase the rainfall or sprinkler irrigation efficiency under crops planted in rows.

INTRODUCTION

Rainfall in the kingdom of Saudi Arabia takes place primarily during winter and spring. Rainfall of 0.1 to 0.2 m occurs in an area extending from north of Riyadh to the vicinity of Hail (Ministry of Agriculture and Water, 1984). Maximizing the use of water resources is a mandatory goal in the Kingdom Saudi Arabia. Numerous techniques, modern and traditional, for augmenting the availability of water resources, have been developed and implemented in different parts of the world. These include, among others, rainwater harvesting. One of the methods frequently used in rainwater harvesting is the storage of rainwater *in situ.* Maximizing the use efficiency of rainfall depends on enhancing rainwater storage, reducing the water evaporation from a soil surface, and reducing the deep-water percolation. Furrows may be used as an *in situ* means of storing harvested rainwater (International Environmental Technology Center, 1997). They are built prior to or after planting to store water for future use by the plants. This method uses flattened trenches between the rows of crops to store water. Furrows may have mud dams or barriers every 2.0 m to 3.0 m along the row in order to retain water for longer periods of time and avoid excessive surface runoff and erosion. Raised beds may also be used to trap the water in the furrows, or uncultivated areas may be left between rows, spaced at 1.0 m apart, to assist in capturing rainwater falling on the land surface between furrows. However, tillage practices affect furrow systems by altering the infiltration characteristics of the soil and by altering crop residue in the furrow. Both of these factors affect the ability of the furrow to convey water down the field. As tillage practices become less intensive, infiltration rates often increase (Eisenhauer et al., 1984). Crop residue on the soil surface reduces evaporation. Most of the evaporation occurs when the soil is wet, within a few days after rain or irrigation. The residue insulates the wet soil from solar energy and reduces evaporation. When soil is wet more often as in the case of sprinkler irrigation, evaporation increases and crop residue contributes even more to evaporation reduction. Cumulative evaporation was studied experimentally in moist sandy soil columns by Al-Salamah and Nassar (2002). The municipal garbage was applied to the soil columns using four ways: zero g, 45 g at the top of soil column, 45 g was mixed in the upper 0.10-m layer of soil column and 45 g was placed as a layer at 0.1 m-depth. According to the result of cumulative evaporation, the four application ways were in the order: the bare soil > mixed layer> subsurface layer> top layer. Significant differences in the cumulative evaporation between the bare soil and either application ways were found. On the other hand, the difference between the subsurface layer and top layer in the cumulative evaporation was not significant. They recommended placing the garbage wastes either beneath the soil surface or on the top of soil surface.

Crop canopies also play a role in reducing evaporation by shading the soil surface. Crop residues are often left on the surface in dry and crop rotations. Weed-free wheat stubble in west central Nebraska can reduce evaporation by 0.05 m compared to a bare soil, from wheat harvest in July until row crop planting the following May. These water savings can contribute to yield increases of up to 10 bushels of corn per acre. Surface mulches have been used to improve soil water retention, reduce soil temperature, and reduce wind velocity at the soil surface and arid lands (Kay, 1978; Jalota and Prihar, 1998). Surface mulches can also improve water penetration by impeding runoff and protecting the soil from raindrop splash and reducing soil crusting (Munshower, 1994). Vertical mulches pushed or crimped into the ground can funnel precipitation to substrate soils (Bainbridge, 1996). An early demonstration plot at the mesquite mounds site showed much improved survival with early bark mulch, and similar results have been found in other arid sites (Zink and Allen, 1995).

The use of mulch to conserve moisture in very arid environments is not always successful. It appears that the use of mulch, like many other arid zones, is a gamble. Jalota and Prihar (1998) reviewed the effects of mulch on soil moisture content and found that mulch may be of little value or detrimental in low rainfall periods. The mulch can intercept moisture from light rains before it reaches the soil. Mulch can also absorb moisture from the soil into the air, increasing evaporation. In their experiments Jalota and Prihar determined that with evaporation rates of 0.0154 m/ day unmulched soil conserved more moisture than mulched soil (Jalota and Prihar, 1990). Burying the mulch 0.05 m deep appears to provide increased benefits (Minhas and Gill, 1985), while the benefit of surface mulch may be realized only with heavy rains or regular irrigation.

According to literature reviewed the rainwater harvesting is an essential practice to utilize the rainwater more effectively for plant consumption. The rainwater in the Saudi kingdom is limited and occurred during the winter and spring season. So, we propose this study to test a new technique of rainwater harvesting and maximize the water use efficiency of the harvested water. Reducing both water evaporation and deep-percolation can maximize the water use efficiency. The study took place at the Agriculture and

Veterinary Faculty Farm, Al-Qassim, King Saud University. The new technique of rainwater harvesting was applied in some plots in comparison with conventional rainwater harvesting (bare soil plots). Two growing plants were used in the study (green bean, faba bean).

MATERIALS AND METHODS

I- Rainfall harvesting machine:

For maximizing the water use of rainfall and sprinkler irrigation, a machine was designed for compaction the soil *in situ*. Compaction results in reducing the deep percolation of water especially in a high permeable soil. Figure (1) shows the designed machine. It is a 2-m length, 0.5-m diameter. It is made of steel with weight of 500 kg. The weight of machine can be increased using additional weight. So, if the soil is hard for compaction, one can add more weight on the machine. A tractor draws the machine for performing a cone-hole with 0.3-m apart. The height and the largest diameter of the cone is 0.1 m. Five rows of cone-holes can be achieved using the machine. Figure (2) shows the cone-holes achieved using the machine in a sandy loam soil.

II- Sprinkler irrigation system:

Since the rain is infrequent in Al-Qassim region, a sprinkler irrigation system was designed for watering an area of 1000 m^2. The system included 7 lateral lines 5-m apart. Each line included four sprinklers in each with 5-m apart. The system is used for irrigating the crops when the rainfall is limited.

III- Preparing the field experiments for faba bean and green bean plants:

For achieving this study, an area of 1000 m^2 in the Agriculture and Veterinary Faculty Farm, Al-Qassim, King Saud University was selected. The particle size distribution of the studied area is shown in Table (1). The sand percentage ranged from 84 to 91 %, the silt percentage ranged from 1.2 to 4.6 %, and the clay percentage ranged from 4.6 to 14.8 %. Figure (3) shows a map for the studied area. The area was divided into plots with dimension of 3x5 m and 1 m apart. The area was irrigated before performing the cone-hole. For harvesting the rainfall effectively, the rainfall harvesting machine cylindrical was used to dig cone-holes as described before. During augmenting the holes its circumference and bottom were compacted. This compaction process reduces the deep-water percolation throughout the holes. To suppress water evaporation from the cone-holes, three ways were used. In the first way, the holes were filled using grass residue. In the second way, the soil surface including the holes was covered with black drilled plastic sheet. This sheet has opens to allow water accumulating beneath the plastic in the cone-holes. In the third, rock fragments with diameter ranged from 0.005-0.020 m was used to fill the cone-hole. Faba bean or green beans were planted on the edge of the cone-hole. The seeds of faba bean and green beans were sown on 20 of October, 2003. Five treatments were assigned for each crop. Three replicates for each treatments. Each replicate was 5x3 m. The five treatments were: Flat area (control), cone-hole, cone-hole filled with fresh residue grass, cone-hole filled with fragments of rocks, and cone-hole covered with plastic. The five treatments will be referred as: flat, hole, grass, rocks and plastic, respectively. The plastic treatments started just after emergence of the shoot of a plant. Unfortunately, the flat treatments in the green bean did not germinate and it was sown again on 8 of November. The experiments were fertilized using urea on the third of December, 2003. Tensiometres were inserted at different locations at depth of 0.15 m in the plots for monitoring the matric potential. The irrigation water was added using the sprinkler system when the soil matric potential reachs –15 kPa. The sprinkler system was used in the absence of rainfall. Soil samples at depth of 0.10 m were collected on 10/2/2004 (112 days after planting) for determining the soil moisture contents in the plots. Three replicates were assigned for each treatment. The growth and yield parameter were monitored during the growing seasons. The growth parameters included the shoot height, weight, moisture content, dry matter, and the number of branches. These parameters were recorded on 19/12, 18/1 and 23/2/2003. The corresponding time of these dates is 60, 90, and 125 days after seed sowing. The yield parameters were collected on March 9th. 2004. They included the number of pods and their weights.

IV- Preparing the field experiments for corn and green bean plants:

Similar experiments were performed on 6/4/2004 for growing corn and green beans. The treatments of previous experiment were used. Irrigation of the pants using the sprinkler irrigation system was done twice a day. Each irrigation period lasted 10 minutes. The plants were fertilized using urea dose (5 g/plant) on 15 of May and 6th of June, 2004. The lengths of green beans were recorded on May 25th. Some growth parameters were obtained on 5th of June for the green beans. The length of corn shoot was recorded on 25/5, 5/6, 20/6 and 20/7/2004.

RESULTS AND DISCUSSION

I- Results of the faba bean experiment

Figure (4) shows effect of sampling time on the shoot length of faba bean under the five treatments. It obvious that the length increased as time increased till 90 days then it does change slowly by further increase in the time. The plastic treatment possessed the greatest shoot length while the flat possessed the lowest one. There are two reasons for the superiority of the plastic treatments over the other treatments. The first is due to the ability of plastic for storing the soil moisture and the second is increasing soil temperature. The black plastic absorbs the solar heat during the day time and these heat increases the soil temperature. Increasing the soil temperature increased the absorbing soil water and nutrient uptake by plants. Mahmoud (1996) reported that mulching of soil with single and double layers of polyethylene sheets for 10 weeks resulted in increasing soil temperature at 0.10 and 0.20 m depths, compared to the unmulched soil. Similarly, Mauromicala et al. (2001) reported that mulching increased mean daily maximum temperatures of the soil by 8.9 °C and 10.7 °C at 0.05 m depth and 11.5 °C and 11.3 °C at 0.15 m depth. Low soil temperatures can retard growth of some crops, such as corn (Tisdale and Nelson, 1975). A first-order polynomial was regressed with the collected data of shoot length. The determination coefficients (R^2) (Table 2) for the flat, hole, plastic, rock and grass treatments were 0.99, 0.96, 0.96, 0.89, and 0.99, respectively. It is obvious that polynomial described quit well the shoot length as a function of time. The slope of the polynomial represents the changes of shoot as a function of time. These changes were shown in Table (2). These changes followed the order: plastic> hole>rock>flat>grass. These changed ranged from 0.0059 to 0.0096 m/day for the grass to the plastic treatments, respectively.

The fresh weight of shoot as a function of time for the studied treatments is shown in Figure (5). The weight increased till 125 days for all treatments then decreased by further increase in the time. The plastic treatment gave the greatest weight while the flat gave the lowest after 125 days of growth. These results are in harmony with shoot length discussed above.

Figure (6) shows the dry weight of shoot as a function of time. The dry weight increased a time increased from day 60 to day 125 after planting for all treatments except the flat one. The plastic treatment possessed the greatest rate in comparison to the other treatments. This growth parameter is in agreement with the fresh weight of shoot.

Figures (7) and (8) show the number of pods per plant and their weight after 140 days of planting, respectively. The plastic treatment possessed the greatest number and weight for the pods while the flat treatment possessed the lowest. The weight of pods followed the order: plastic> rock> grass>hole>flat. Results of pods are in agreement with the aforementioned data of growth parameters. Similar studies were reported by Elias et al. (2004). In their studies, stubble cover was positively correlated with chickpea yield. The highest ground cover was estimated at 55%, the lowest being no ground cover, with an average of 15%.

Figure (9) shows the number of branches per plant. The rock treatment gave the greatest number in comparison to the other treatments.

Table (3) shows water content of the shoot at different dates (19/12, 18/1 and 23/2) that correspond to 60, 90, and 125 days after the experiment initiation. The water showed slight differences among the treatments studied. On the other hand, the water content decreased as time increased. This trend is in opposite to the dry matter content. The later increased with time which results decreases in the water content.

Table (4) shows the soil moisture content on 10/2/2004 under faba bean plants (112 days after the planting). The moisture contents were the greatest under the plastic and hole treatments in comparison to the other treatments. The high moisture contents might due to the variation in the soil texture in the area. The vegetative part under the plastic treatments was high that results high transpiration.

II- Results of the green bean and corn experiment

Figure (10) shows the shoot fresh weight of green bean under different treatments for soil surface. The flat surface gave the lowest fresh weight (0.00913 kg/plant) while the rock treatment gave the greatest weight (0.0187 kg/plant). It is obvious that rock treatment gave twice fresh weight as the flat treatment. The rock treatment enhances storing the water that drive greater growth for the green bean shoot. The difference between the rock treatment in the dry weight and either grass residue, plastic, or hole treatment was small.

The dry shoot weight of green bean is shown in Figure (11). The flat soil surface gave the lowest dry weight similar to the trend of fresh shoot weight. The plastic treatment possessed the greatest dry weight among all treatment.

Figure (12) shows the water content of green bean shoot. It is obvious that the plastic treatment possessed the lowest water content among all treatments. The difference in water content of shoot between the plastic treatment and rock or the grass residue treatments was significant at 5% level (Table 5).

Figure (13) shows the stem length of green bean under different surface treatments. The stem lengths ranged from 0.1742 to 0.2037 m. The lowest length was obtained under flat treatment and the tallest stem was obtained under rock treatment. The differences among the treatments in the stem length were not significant (Table 5).

The weights of corn ears per a plant are shown in Figure (14). The flat treatment possessed the lowest weight of ears (0.1646 kg/ plant). The hole treatment gave the greatest ears weight (0.2581 kg/plant). The plastic treatment gave 0.2537 kg/plant. The differences among the treatments were not significant at 5% level (Table 5).

Figure (15) shows effect of soil surface treatments on the number of ears per plant. The numbers of ears ranged from 1.5 to 2.5 ears per plant. The flat and rock treatments possessed the lowest number while the plastic treatment possessed the highest. The differences in ears numbers between the plastic and either the flat or the rock treatments were significant at 5 % level (Table 5). Using no-till with whole corn stalk mulching or incorporated straw reduce water loss, energy, soil erosion, increase corn yield and improve water use efficiency (Dianxiong et al., 1999). A field study in Alabama investigated newsprint and nitrogen source interactions and their effects on corn growth and grain yield (Lu *et al*., 1994). When the ground newsprint was applied to soil in combination with inorganic nitrogen sources (ammonium nitrate, urea, and anhydrous ammonia), corn seedlings were stunted during the first four to six weeks after emergence, compared to fields where poultry litter was used as the nitrogen source. The authors indicated that ground newsprint applied with poultry litter to balance the C:N ratio enhanced corn growth and grain yield.

Figure (16) shows effect of sampling time on the shoot length of corn under the five treatments. The data represents a period of growth from 49 to 105 days for the seedling time. It obvious that the length increased as time increased. The hole treatment possessed the greatest shoot length while the grass one possessed the lowest length. A first-order polynomial was regressed with the collected data of shoot length. The determination coefficients (R^2) for the flat, hole, plastic, rock and grass treatments were 0.96, 0.96, 0.92, 0.87, and 0.78, respectively. The polynomial described reasonably the shoot length as a function of time. The slope of the polynomial represents the changes of shoot as a function of time. These changes were 0.0132, 0.0082, 0.0125, 0.0132, and 0.0121 m/day for the flat, grass, rock, hole and plastic treatments, respectively.

CONCLUSION

A new machine was designed for achieving conical holes in the soil surface with 0.1 m-depth and 0.1 m diameter. The machine was under three different crops (corn, faba bean and green bean) for reducing water losses by evaporation and deep percolation. It is highly recommended using the machine for saving water under rainfall or sprinkler area with spaced-planted crops such as corn or faba bean. If some mulching materials is available, the machine will be more effective in enhancing water storage.

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Table (1): The particle size distributions for soil used in the experiment.

Soil texture	Particle size Distributions, %			No. of site shown on Figure 3
	Sand	Silt	Clay	
Sand	90.75	4.62	4.62	1
Sand	90.75	1.22	8.02	2
Loamy Sand	83.95	4.62	11.42	3
Sandy loam	83.95	1.22	14.82	4

Table (2): The change of shoot length of faba bean (m/day) as a function of time to the treatments.

Treatments	Change of shoot (m/day)x100	R^2 for linear regression
Flat	0.625	0.999
Hole	0.916	0.964
Plastic	0.955	0.965
Rock	0.836	0.896
Grass	0.586	0.986

Table (3): The water contents (kg/kg) of the faba bean (shoot) at three different time under the studied treatments.

Date	Flat	Hole	Plastic	Rock	Grass
19/12/2003	0.85	0.84	0.86	0.85	0.85
18/1/2004	0.80	0.79	0.84	0.80	NA
23/2/2004	0.81	0.81	0.83	0.76	0.81

Table (4): The soil water contents (kg/kg) under the studied treatments in the upper 0.1 m layer.

Date	Flat	Hole	Plastic	Rock	Grass
10/2/2004	0.0527	0.0744	0.0747	0.0385	0.0504

Table 5: Effect of soil surface management on the growth of corn and green beans in rainfall harvesting exp.

plant	parameter	flat	grass	rock	hole	plastic	$LSD_{(0.05)}$
Green bean	Water content, kg/kg	0.809	0.816	0.816	0.812	0.798	0.016
	Dry weight, kg/plant	0.00174	0.00277	0.00343	0.00327	0.00360	0.00151
	Fresh weight, kg/plant	0.0091	0.0152	0.0188	0.0174	0.0179	0.0083
	Length, m	0.1742	0.1994	0.2037	0.199	0.1991	0.0323
Corn	Weight of Ears kg/plant	0.1646	0.2104	0.1767	0.2581	0.2537	0.1024
	# ears/plant	1.5	1.94	1.5	2.17	2.5	0.7

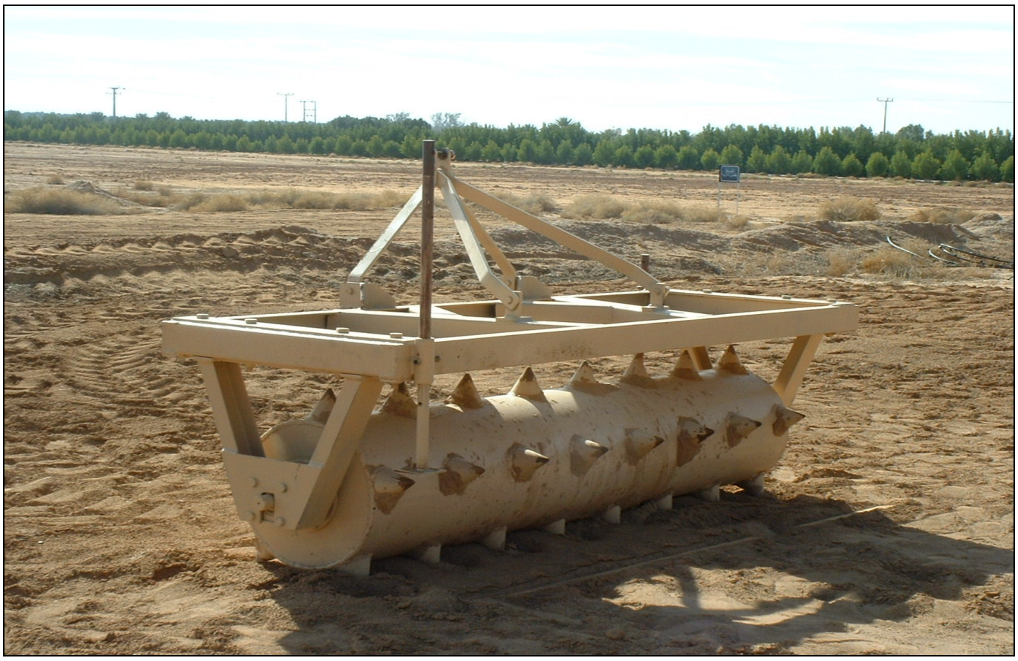

Fig. 1: The new designed equipment for making hole in soil surface.

Fig. 2: Holes achieved using the new equipment

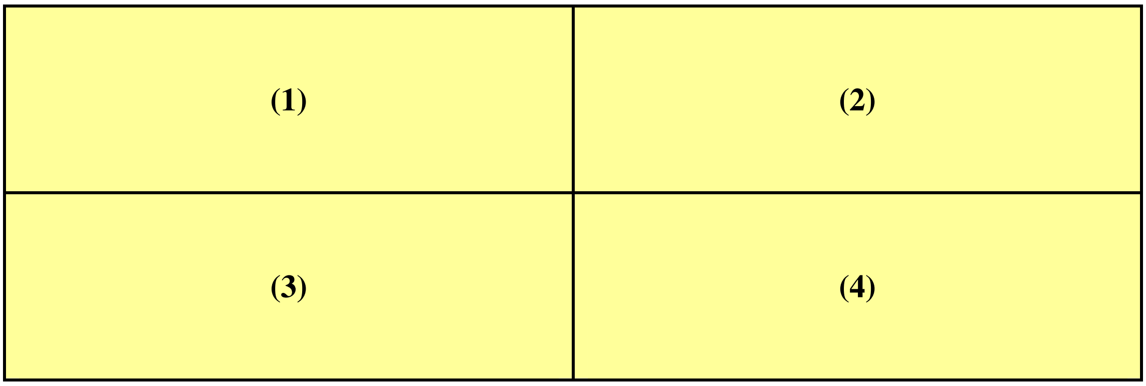

Fig. 3: A map for the studied area.

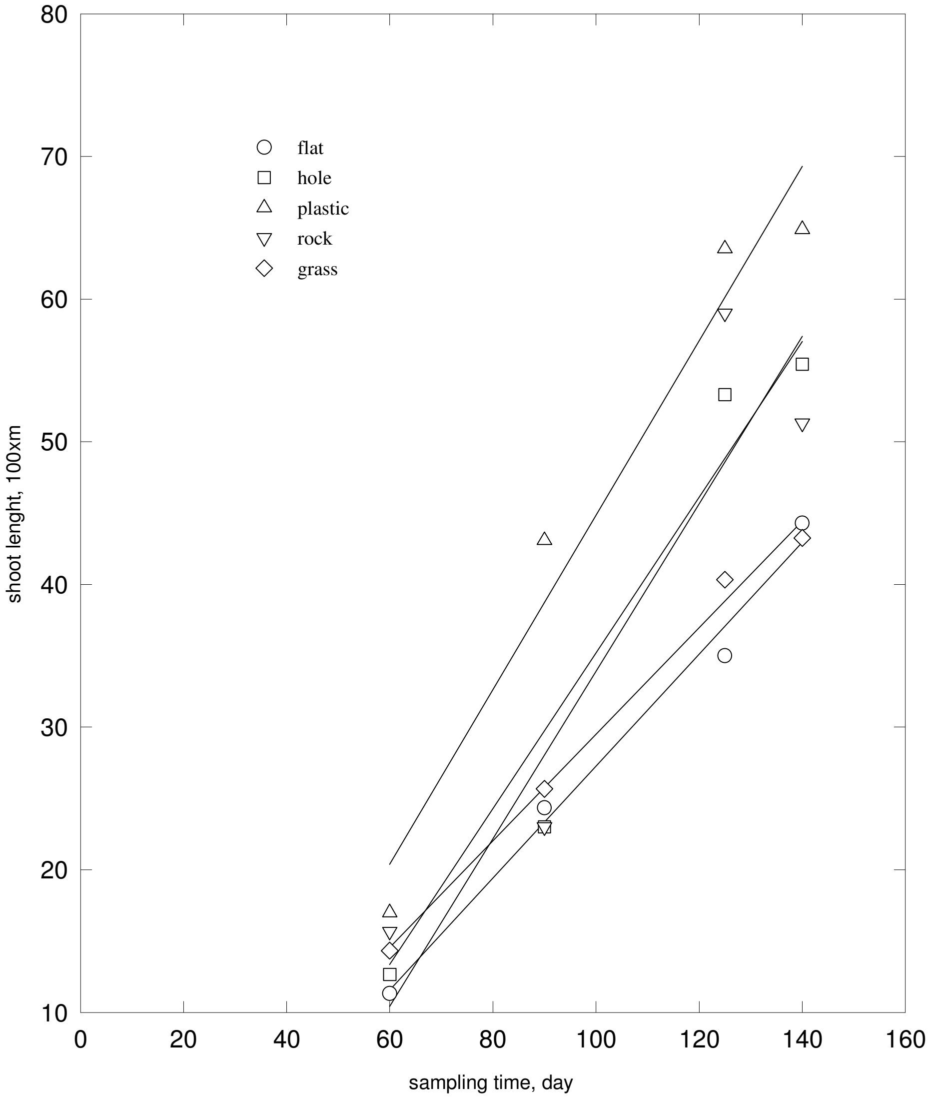

Fig.4:Effect of time on the shoot growth of faba bean.

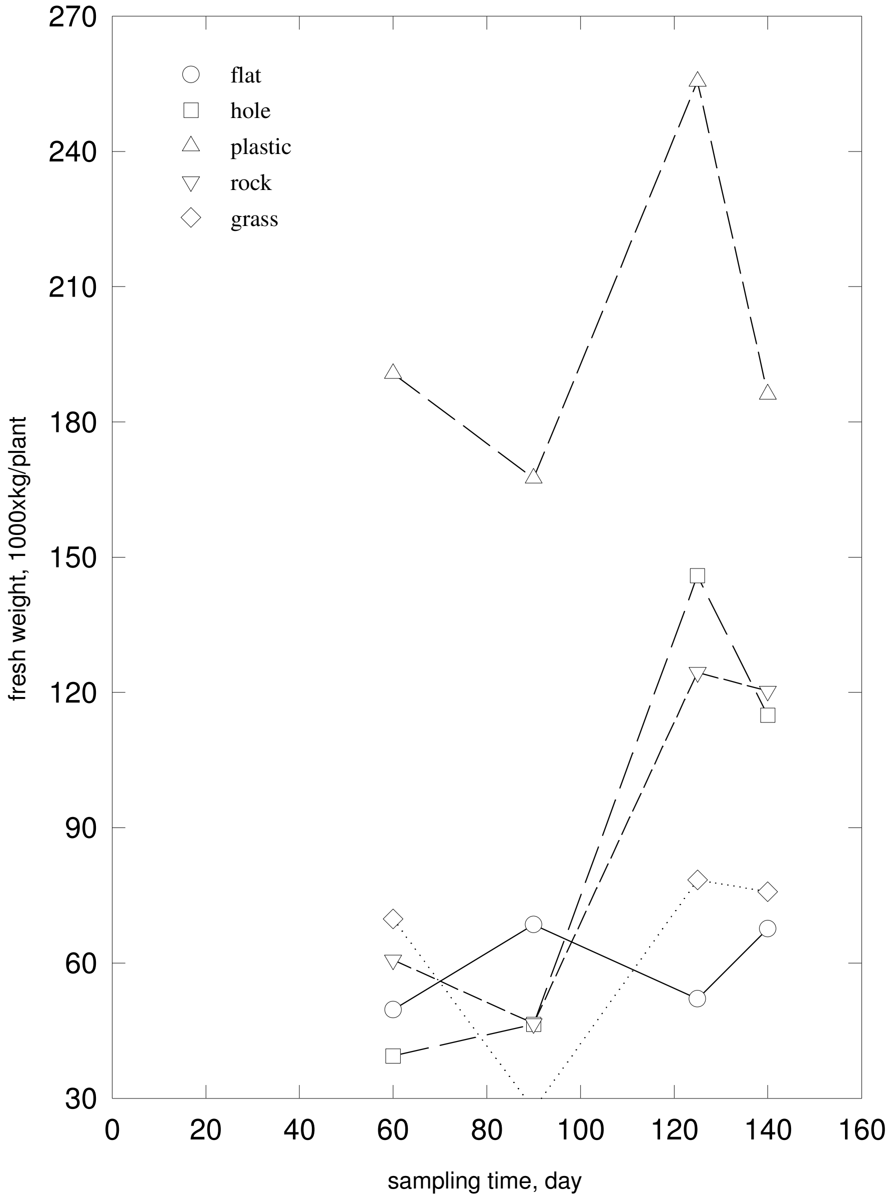

Fig. 5: Effect of time on the fresh weight of shoot of faba bean.

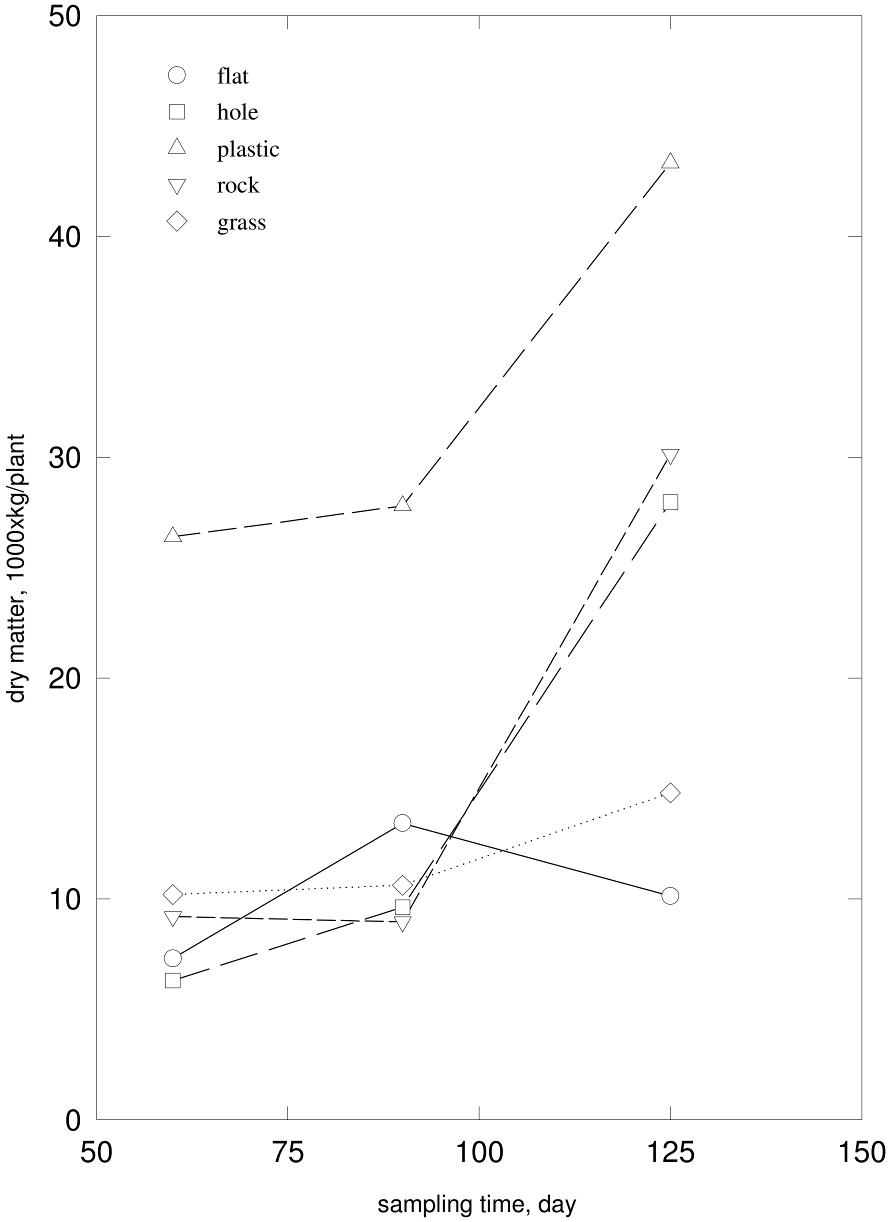

Fig.6: Effect of time on the dry weight of shoot of faba bean.

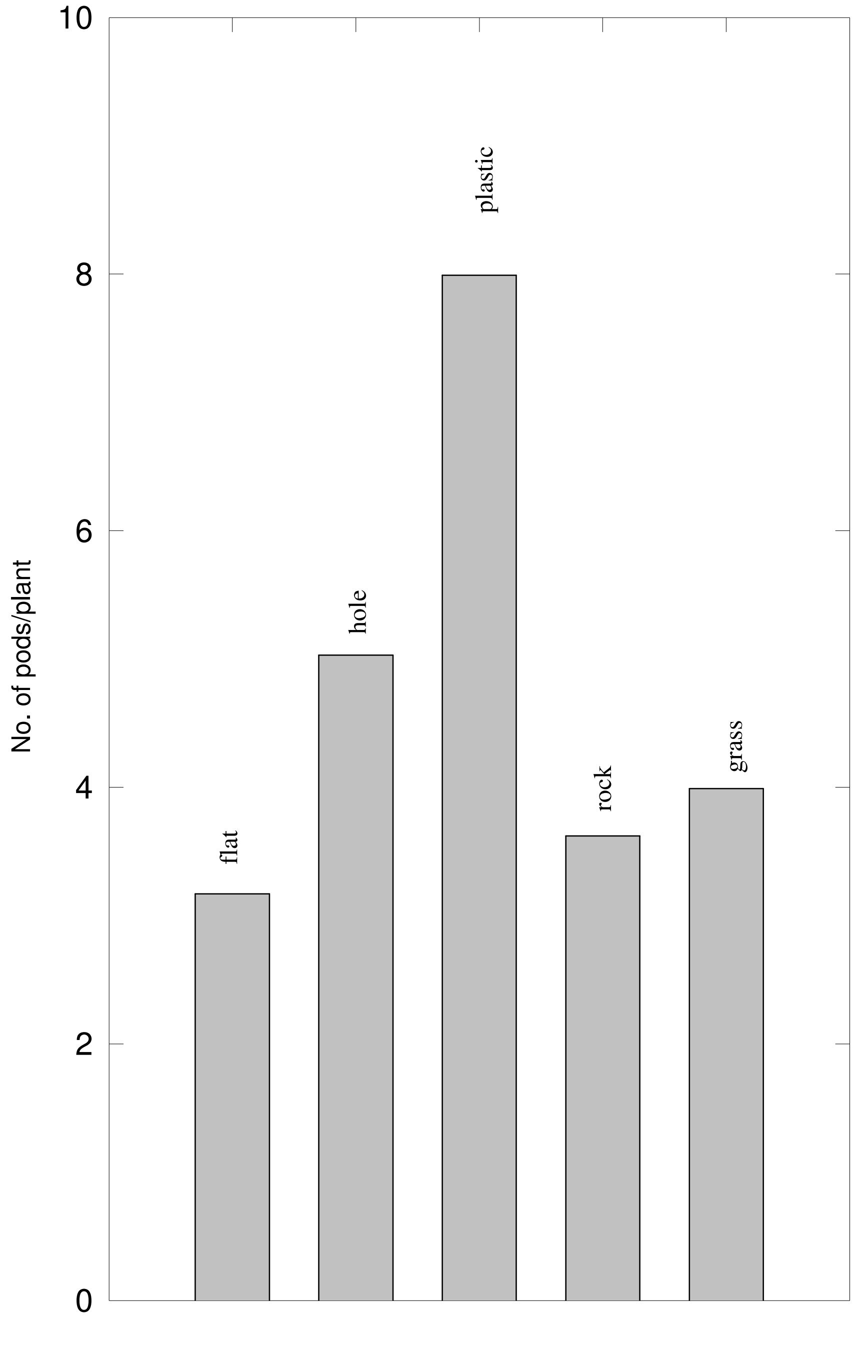

Fig 7: number of pods per plant for the faba bean.

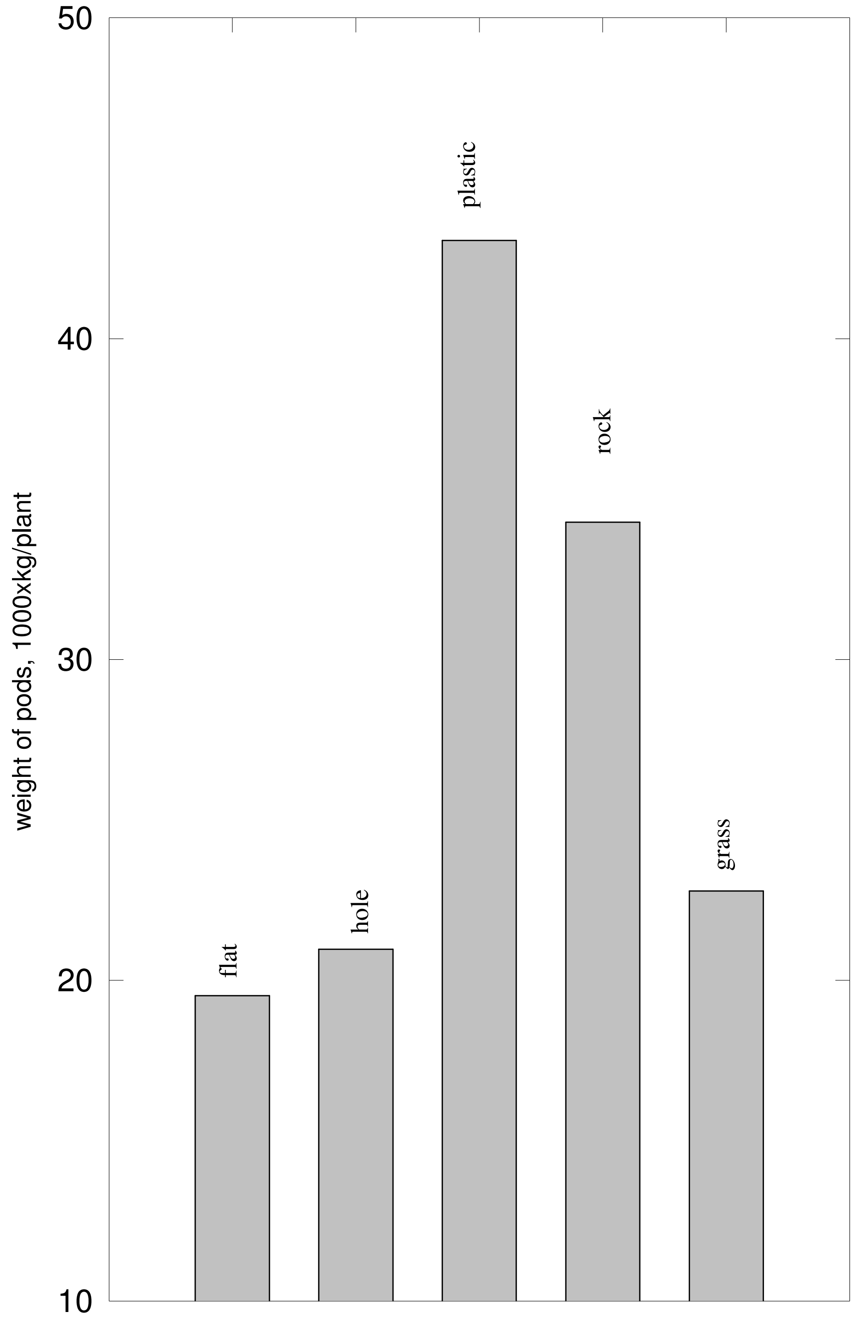

Fig 8: Weight of pods per plant for faba bean.

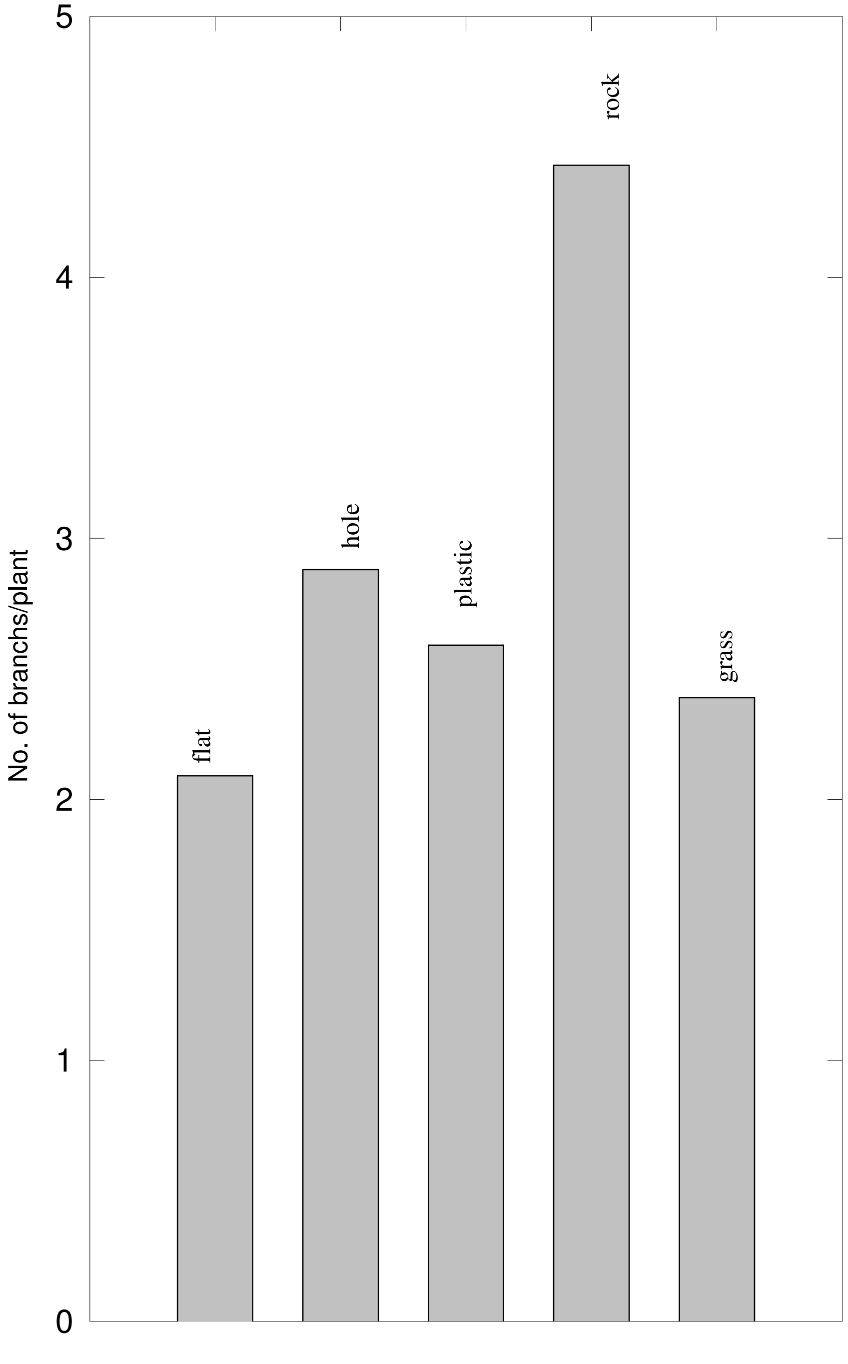

Fig.9: Number of branches per plant for faba bean.

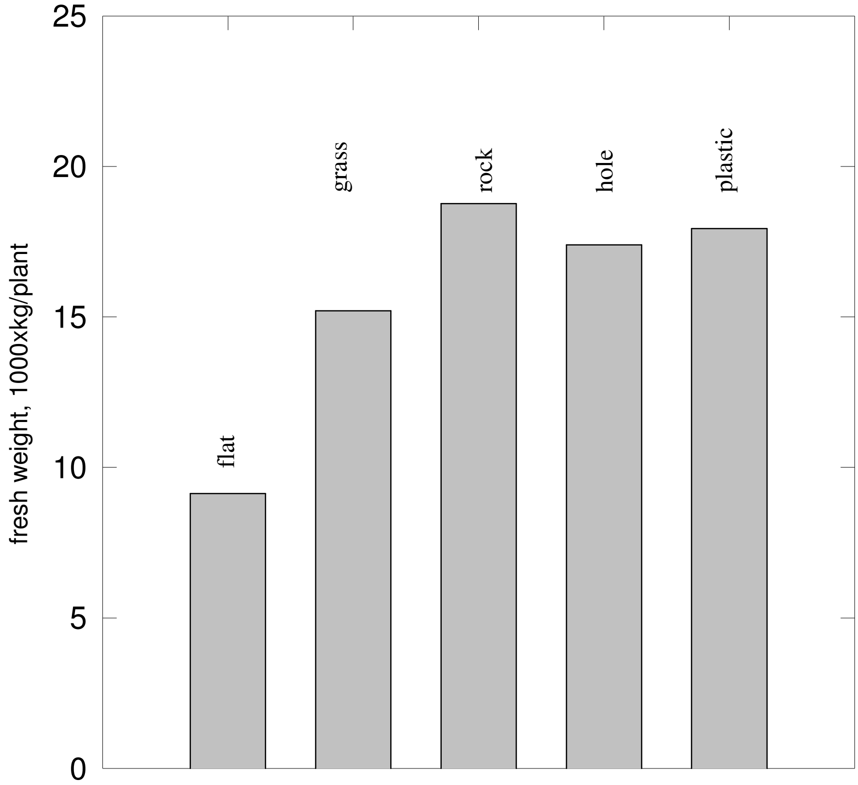

Fig 10: Effect of soil sufrace treatments on the fresh weight of green bean.

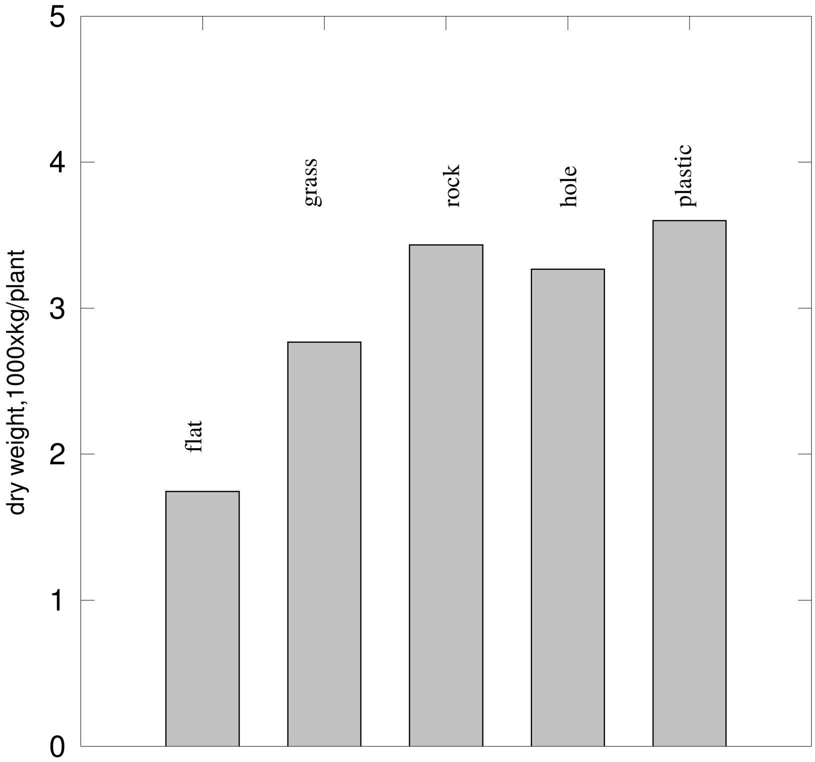

Fig 11: Effect of soil sufrace treatments on the dry weight of green bean.

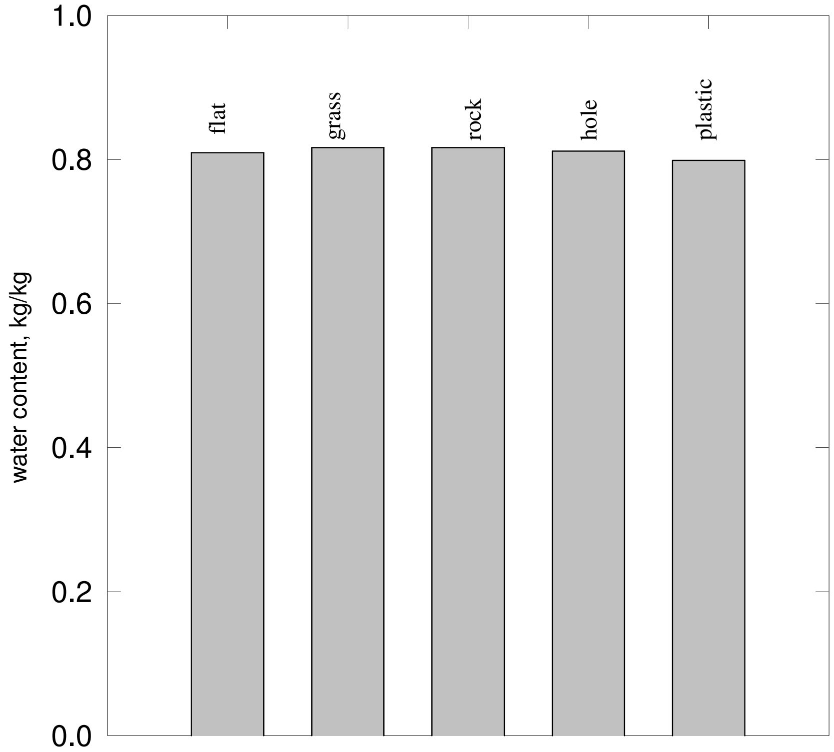

Fig 12: Effect of soil sufrace treatments on the water content of vegetative part of green beans.

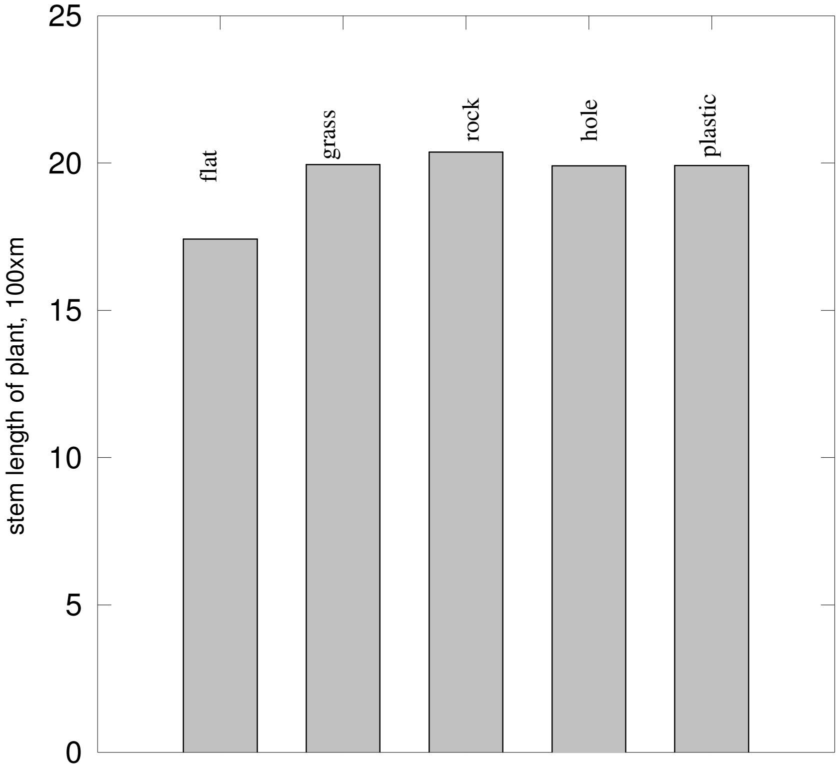

Fig 13: Effect of soil sufrace treatments on the stem length of green bean.

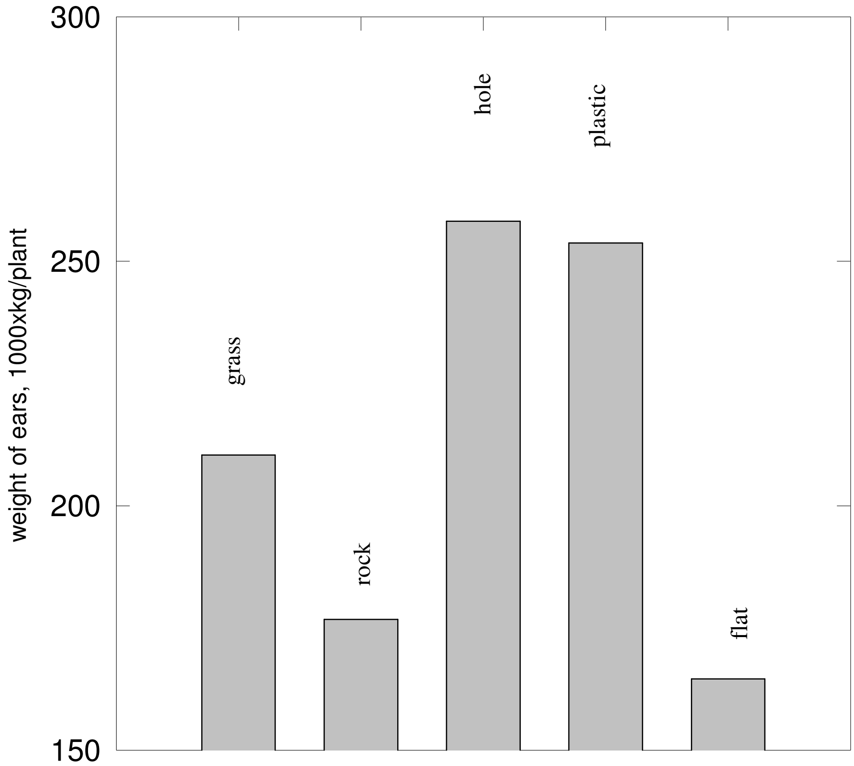

Fig 14: Effect of soil sufrace treatments on the ears fresh weight of corn ears.

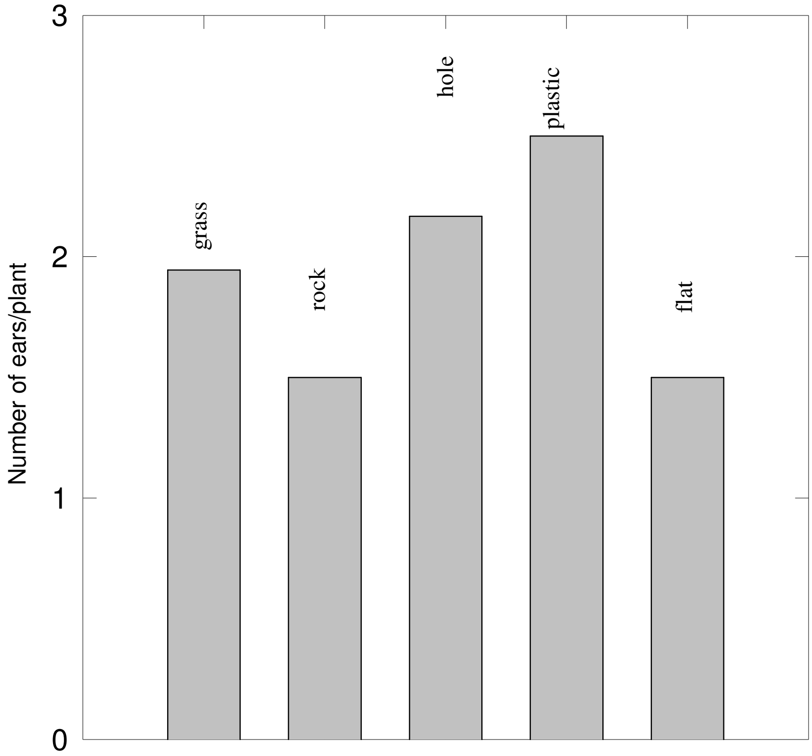

Fig 15: Effect of soil sufrace treatments on the ears numbers of corn.

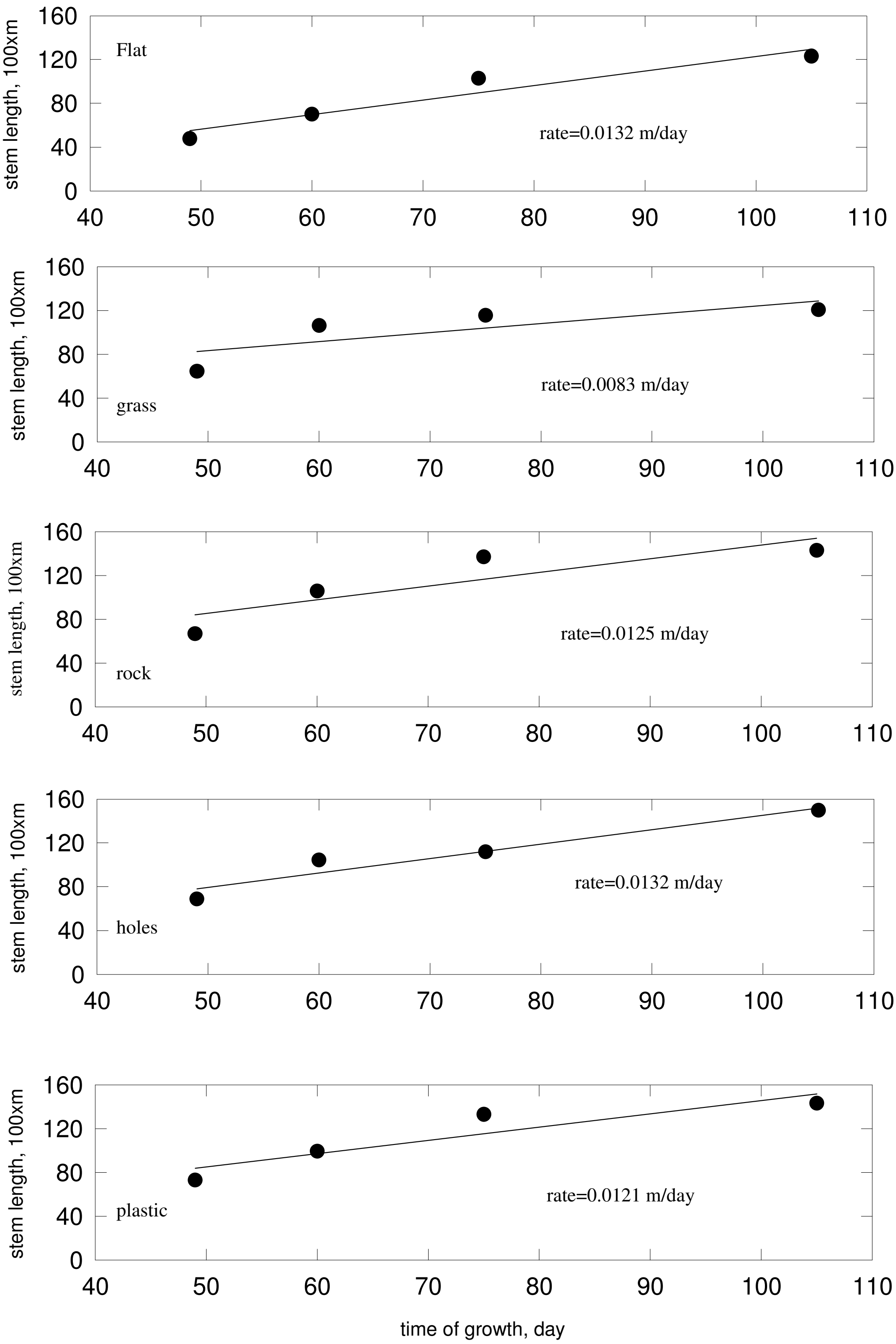

Fig 16: Effect of soil sufrace treatments on stem growth rate of corn.