समर्पण

माझ्या जीवनरूपी रोपट्याचे सर्वगुणसंपन्न व सुसंस्कृत अशा वृक्षात रूपांतर करण्याची जिद्द बाळगणारे माझे वडिल ति. आबांस व वात्सल्यपूर्ती आई सौ. आक्का तसेच आत्मविश्वासाने व स्वाभिमानाने जगण्यास शिकवणा-या माझ्या आजी व आजोबा

यांना सस्नेहसमर्पित

... जितेंद्रकुमार

SCREENING OF GRAPE ROOTSTOCKS FOR DROUGHT TOLERANCE

By

JITENDRAKUMAR HANAMANT KADAM
(Reg. No. 99139)

A thesis submitted to the

**MAHATMA PHULE KRISHI VIDYAPEETH,
RAHURI – 413 722, AHMEDNAGAR,
MAHARASHTRA, INDIA**

in partial fulfilment of the requirements for the degree
of

MASTER OF SCIENCE (AGRICULTURE)
in

HORTICULTURE

Approved by

Dr. T. B. Tambe
(Chairman and Research Guide)

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2001

CANDIDATE'S DECLARATION

I hereby declare that this thesis or a part

thereof has not been submitted by me

or any other person to any other

University or Institute

for Degree or

Diploma

Place : M. P. K. V., Rahuri

Dated : 30 / 06 / 2001

Kadam

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CERTIFICATE

This is to certify that the thesis entitled, "**SCREENING OF GRAPE ROOTSTOCKS FOR DROUGHT TOLERANCE**" submitted to the Faculty of Agriculture, Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist. Ahmednagar, Maharashtra State, India in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE (AGRICULTURE)** in **HORTICULTURE**, embodies the results of piece of *bona fide* research work carried out by ***Shri. JITENDRAKUMAR HANAMANT KADAM,*** under my guidance and supervision and that no part of the thesis has been submitted to any other University for degree or diploma or publication in other form.

The assistance and help received during the course of this investigation and sources of references has been duly acknowledged.

Place: M.P.K.V., Rahuri
Dated: 30/06/2001

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Dated: 13/06/2001

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Place : M.P.K.V., Rahuri

Date : 30/06/2001

(J.H. Kadam)

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LIST OF ABBREVIATIONS

ABA	:	Abscisic acid
C.D.	:	Critical Difference
°C	:	Degree Celsius
cm	:	Centimeter
cm^2	:	Centimeter square
C.S.I.	:	Chlorophyll Stability Index
cv.	:	Cultivar
D.F.	:	Degree of freedom
DTPA	:	Diethylene Triamine Pentacetic Acid
etc.	:	Et cetera
et al.	:	et alli
FYM	:	Farm yard manure
Fig.	:	Figure
g	:	Gram
ha	:	Hectare
hrs.	:	Hours
i.e.	:	id est
K	:	Potassium
Kg	:	Kilogram
lits.	:	Liters
mg	:	Milligram
mg g^{-1} FW	:	Milligram per gram of fresh weight
ml	:	Milliliter
mm	:	Millimeter

List of Abbreviations contd...

mm^2	:	Millimeter square
M Pa	:	Mega pascal
N	:	Nitrogen
NS	:	Non significant
P	:	Phosphorous
PEG	:	Polyethylene glycol
ppm	:	Parts per million
RLWC	:	Relative leaf water content
SE±	:	Standard error
TSS	:	Total soluble solids
viz.,	:	Videlicet (namely)
V/V	:	Volume by volume
WSD	:	Water saturation deficit
/	:	Per
%	:	Per cent

ABSTRACT

SCREENING OF GRAPE ROOTSTOCKS FOR DROUGHT TOLERANCE

By

J.H. Kadam

For the degree

of

MASTER OF SCIENCE (AGRICULTURE)

in

HORTICULTURE

MAHATMA PHULE KRISHI VIDYAPEETH, RAHURI

2001

Research Guide	:	**Dr. T.B. Tambe**
Department	:	**Horticulture**

The investigation on "Screening of grape rootstocks for drought tolerance" was conducted in pot culture under glasshouse conditions in the Department of Horticulture, Mahatma Phule Krishi Vidyapeeth, Rahuri (M.S.) to study the morphological, physiological and biochemical characters during the year 2000-2001.

The experiment was laid out in Factorial Completely Randomised Design (F.C.R.D.) with two replications. Six grape genotypes *viz.*, Dogridge (*Vitis champini*), Salt Creek (*Vitis champini*), 1613-C (*V. othello* x *V. riparia*), 1616-C (*V. othello* x *V. solonis*), 1103-P (*V. berlandiri* x *V. rupestris*) and SO4 (*V. berlandiri* x *V. riparia*) with three levels of irrigation regimes 0.3 bar, 0.5 bar and 0.7 bar were undertaken. Total thirty irrigations of water of different irrigation regimes (0.3 bar eleven irrigations, 0.5 bar ten irrigations and at 0.7 bar nine irrigations) were given. The observations on morphological parameters *viz.* growth, leaf, root attributes and days to appearance of stress, physiological parameters *viz.*, Relative leaf water content, shoot and root fresh weight, shoot and root dry weight, stomatal frequency and biochemical parameters *viz.*, chlorophyll 'a', 'b' and total chlorophyll content in leaf, chlorophyll stability index were recorded. The reduction in height of shoot, diameter of shoot, number of shoots per vine, length of internode, total number of leaves per vine, length of main root, number of primary and secondary roots, days to rolling, shrivelling and drying of leaves, relative leaf water content, fresh and dry weight of root and shoot, chlorophyll stability index and highest reduction in stomatal frequency and leaf area and highest content of chlorophyll 'a', 'b' and total chlorophyll were considered as the criteria for relative drought tolerance in grape rootstock. Based on these criteria the maximum height of shoot (61.33 cm) at 0.5 bar and (57.81cm) at 0.7 bar recorded by 1103-P while highest diameter of shoot by Dogridge (3.38mm). The maximum number of shoots by 1103-P (14.67) and also highest length of internode (6.85cm). The maximum total number of leaves were observed by 1103-P (98.83). The maximum leaf area was observed by Salt Creek (82.89cm^2) while lowest by 1103-P (51.35cm^2) because of its genetical character. The maximum length of main root was observed by 1103-P (56.03cm) followed by Dogridge (50.67cm). The maximum number of primary root per vine (21.08) and secondary roots per vine (36.83) were also observed by 1103-P followed by Dogridge (19.75 and 32.67, respectively). The maximum days were required by 1103-P for days to appearance of stress followed by Dogridge and Salt Creek.

Abstract contd... **J.H. Kadam**

The highest relative water content was recorded by 1103-P (79.68 %) followed by Dogridge (76.58%). The lowest reduction in shoot and root weight was observed by 1103-P followed by Dogridge and Salt Creek. The maximum shoot : root ratio on fresh weight basis was observed by 1103-P (1.401) and on dry weight basis also by 1103-P (1.696) which was followed by Dogridge (1.213 and 1.303, respectively). The rootstock SO4 recorded the maximum stomatal frequency (214.91 per mm^2) while lowest by 1103-P (96.69 per mm^2).

The lowest chlorophyll stability index was recorded by 1103-P (0.328) followed by Dogridge (0.504) while the rootstock Salt Creek and SO4 recorded the highest CSI (0.688 and 0.689, respectively).

The maximum chlorophyll 'a' content (1.638 mg g^{-1} FW), chlorophyll 'b' content (0.608 mg g^{-1} FW) and total chlorophyll content (2.246 mg g^{-1} FW) were observed by 1103-P followed by Dogridge (1.403 mg g^{-1} FW, 0.577 mg g^{-1} FW and 1.982 mg g^{-1} FW, respectively).

It is inferred that 1103-P, Dogridge and Salt Creek rootstocks of grapes are relatively drought tolerant.

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INTRODUCTION

1. INTRODUCTION

Grape (*Vitis vinifera* L.) is an important fruit crop of the world. It is one of the delicious, refreshing and nourishing fruit crop. The crop is native of Sub Tropical zone between 34° North and 40° South latitude and their culture is almost successful there. The crop is mainly grown mostly for wine making, to a limited extent for preparation of raisins and to a certain extent for table purpose. However, grape growing in India mostly for table purpose.

India is fast emerging as one of the major grape growing countries in the world. It is an important commercial crop of India earning sizable foreign exchange. Grape cultivation is located in semi-arid regions of Maharashtra, Andhra Pradesh, Karnataka and Punjab. The area under grapes in India is about 40,000 ha with annual production of 9 to 10 *lakh* tonnes, while in Maharashtra the area is 28,400 ha with 5 to 6 *lakh* tonnes production (Yadav, 1999). The area under grapes is increasing steadily in different parts of the state. The increase in area is more conspicuous in the scarcity zone of Maharashtra comprising districts of Solapur, Ahmednagar, Sangli, Pune and Nasik. Nearly 65-70 per cent of the total grape is located in the Western and Southern states of the country. Maharashtra alone accounting for about 55 per cent area under grape cultivation. The state was leading in India in area and productivity of grape. However, the productivity has come down to 17.60 tonnes/ha as against the national average of 22.50 tonnes/ha and the productivity of Punjab 27.00 tonnes/ha

(Anonymous, 1997-98). But the productivity of grape is restrained by scarcity of water, limited rainfall and detrimental effects associated with the excess salts and drought.

Drought, permanent or temporary, limits the growth and distribution of natural vegetation and the yield of cultivated plants more than any other earth's surface is classified as arid or semi-arid because it is subject to permanent drought. Equally important is the fact that most of the humid temperate regions, where much of the world's food is produced, are often subjected to periods of severe drought. As a result, investigators all over the world have been and are concerned with the improvement of drought tolerance and increase in the efficiency of water use by plants. Water is a main factor, limiting the quality and yield of fruits in arid zones. (Fanizza and Riccardi, 1990).

In India irrigation is a limiting factor, out of the total cultivable land only 35.00 per cent of area under irrigation while that of in Maharashtra at present 15.41 per cent area is under irrigation. Even after completion of all the major and minor irrigation projects, only about 31.00 per cent of the cultivable area can be brought under irrigation. Even with this limited area, the irrigation interval will be quite prolonged one. Grapes are heavily affected not only yield but also the regular maintenance of the vineyards. Hence it is on urgent need to select resistant rootstocks for such drought prone conditions (Patil *et al.*, 1994).

Drought is accompanied by relatively high temperatures, which promote the losses of moisture particularly due to evapotranspiration and hence could accentuate the effects of drought and there by further reduce the crop yields. These events occur more frequently in tropical and semi-tropical regions where most of the developing countries are situated. These developing countries are deprived of harvesting satisfactory yields of the fruit crops. Therefore, raising of drought tolerant rootstocks for the fruit crops is the only resort to the possibility of self sufficiency in foods. Blum *et al.* (1981) reported that the total drought resistance of a genotype can not be defined physiologically, since most probably it does not exist as unique plant trait. According to Passioura (1981), drought resistance is a nebulous term that appears to become more nebulous the more closely we look at it.

The term drought is used as a meteorological event a period without rain long enough to deplete soil moisture and injure plants. The length of the period without rain that must elapse to constitute a drought depends on the kind of plant, the water storage capacity of the soil in the root zone and the atmospheric conditions affecting the rates of evaporation and transpiration. Plants show varying degrees of tolerance, either because they possess adoptions such as deep roots or good control of transpiration that postpones dehydration or because of adaptations that increase tolerance to dehydration.

Drought tolerance refers to the ability of plant tissue to withstand water stress. It is a complex of many morphological, physiological and bio-chemical characteristics and it is doubtful, if any one criterion will be adequate for the selection of drought resistant genotype. Hence a combination of desirable factors must be selected.

Besides the increasing need for drought tolerance under severe water stress conditions it is obviously of prime importance. Rootstocks of *Vitis* species used in grape cultivation since the early 1880's were introduced to counter the effect of phylloxera and nematode resistance. Other attributes of rootstocks such as tolerance to drought and salt are also considered (Hardie and Cirami, 1988). A number of different rootstocks are used in various grape growing parts of the world to improve yield potential which is declining due to the physical variations in soil types, environment, water relationship, nutrition and disease complexes.

Rootstocks are known to impart marked effects on the physico-chemical productivity, longevity of trees, disease resistance and also an adaptability to the soil and climatic conditions. The association of stock and scion can function well and satisfy the requirements of aerial system of the scion. Rootstocks can bring about an ideal equilibrium between available soil moisture and water status in vines as rootstocks provide a different root systems to the scion (Yadav, 1999). In Southern part of India grapes continue their growth throughout the year while in Northern India grapes go in dormant conditions. Fimber and Lagarda (1988) reported that most critical stage for water applications were during formation of future canes (41-60 days of the bud sprouting) and during fruit development (61-126 days of the bud sprouting). Hence in Southern India grapes are pruned twice, once in the month of April called April pruning or foundation pruning and another is in the month of October. The aim of April pruning is for fruit bud differentiation (FBD). FBD takes place at 45 to 60 days after April pruning at which due to high temperature and scarcity of water affects FBD and naturally occurs barrenness in grapes (Tambe, 1998).

As temperature increases with the progress of growing season, large quantities of water are transpired through the leaves and the requirement of water from the soil is largely increased. Without additional moisture, the leaves will curl and drop, young fruit bunch will abscise and bunches may not attain proper size and quality, thus contributing to decline in yield in one or many ways.

It necessitates investigation of superior rootstock that have efficient mechanism to tolerate prolonged periods of dry spells. The rootstocks can contribute to the modification of the potential soil. The aptitude of a root system to develop and absorb mineral and water largely affects the growth and vigour of the scion especially in difficult/scarcity situations (Rives, 1971). Interest in grape rootstocks has recently intensified, particularly since the twin problems of water shortage and salinity has been noticed in vine yards. Due to several restrictions on availability of good quality water for irrigation and uncertainty of rains, rootstocks could provide an attractive and environmentally sound alternative to these twin problems (Prakash, 1998).

However, information on the effects of rootstock on growth, drought tolerance and water relations of *Vitis vinifera* L. leaves are largely incomplete. Simultaneously, there are also very few field experiments involving different rootstocks to conclusively show the utility of certain rootstocks in difficult situations. In the light of the above, the aim of the present experiment was to screen the grapes rootstock which is drought tolerant.

This will enable the growers to bring some additional area under the grape cultivation. Number of attempts were made to screen the varieties/rootstocks for drought tolerance in grapes by various scientists, however, more intensive efforts in this direction are still needed. Before this a better understanding of the various morphological, physiological and bio-chemical attributes will be helpful as indicators of drought tolerance or susceptibility. Attempt, therefore are made here after reviewing the literature available in this respect, to select the most drought tolerant grape rootstock among the existing ones. The main objectives of the present investigations are:

1. To study important morphological, physiological and biochemical characters of various grape rootstocks.
2. To screen the grape rootstock for drought tolerance.

This investigation, therefore, was accordingly planned and executed and the results there of are presented.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Drought is a serious problem for fruit crops in India from last few decades due to erratic rains or continuous dry spell. Amongst the several environmental stresses to crop plants, water stress condition is of increasing importance in agriculture, because it affects almost all the functions of cell (Levitt, 1980).

Drought resistance is a complex of many morphological, physiological and biochemical characteristics and therefore, it is doubtful if any one criterion will be adequate for selection of drought resistance genotypes.

Grape is commercially important fruit crop of India, mostly grown under limited water resources. Hence use of drought resistant cultivars or rootstocks have special significance in grape cultivation (Chadha, 1984). Quantitative information on physiological and biochemical changes associated with moisture stress has been obtained and proximal causes of stress injury have been carefully analysed in some cases. However, very meagre information is available on the changes in various enzymes and metabolites in grape rootstock species differing in drought tolerance.

Hence an attempt has been made to review the work done on various species and rootstock response to drought tolerance.

2.1 Morphological characters

2.1.1 Effect of water stress on growth attributes

May and Mitthorpe (1962) reported that water deficit caused a loss of turgor. The expansion of cells and cell division are reduced resulting in a decrease in growth of stem, leaves and fruits.

According to Hsiao (1973) the inhibitory effect of water stress on plant growth may be explained to some degree because cell growth depends on cell turgor pressure as its driving force. The degree of cell turgidity of a plant is based on relative rates of root absorption and of stomatal water loss. Turgor pressure can be affected by atmospheric, soil and plant factors that modify the rates of absorption and transpiration.

Rao *et al.* (1975) showed that in grapes irrigation water is considered most important input influencing the vine growth, fruit bud differentiation, productivity and quality. Inadequate soil moisture leads to weak growth, delayed maturity and less fruitfulness for optimum growth and productivity of vines it is imperative to schedule the irrigation to meet the evapotranspiration demands of the crop.

El-Barkouki *et al.* (1979) studied the performance of the two varieties (in pots) under shade house. They found that reduction in the available water resulted in a reduction of shoot's length of grapevine. The depression of growth of shoot may be a direct adaptation to the high stress of water. Similar result was obtained by Chaponan (1973) working on apple and Smart (1974) working on grapevine. Inadequate soil moisture availability leads to weak growth, delayed maturity of wood and poor crop production (Rao *et al.* 1975).

Eibach and Alleweldt (1985) studied the influence of water supply on growth of the grapevines. Dry matter production is significantly reduced by soil drought. Root growth being less influenced than shoot growth. The shoot growth was reduced under the soil drought.

Miah *et al.* (1988) exposed 30 days old sunflower plants to water stress and observed that internode production and stem elongation were reduced during seven and nine days stress and were still retarded upto 21 days of rewatering.

Rosario and Fajardo (1988) subjected pot cultured groundnut cultivars to water stress and reported that cvs. ACC-847, SS-437 and GNP-1157 tended to have the tallest plants even under stress conditions.

Thakur (1989) studied out door grown plants of eight tomato cultivars (in pots) by subjecting them to water stress and revealed that resumption of growth in terms of length of shoots and roots was exhibited by all cultivars, although recovery was never complete. Least recovery was observed for shoot and root elongation. The differences in relation to growth characteristics were marked during the recovery period.

Salleo and Gullo (1989) was recorded xylem cavitation in one year old internodes and nodes of young potted grapevines subjected to increasing water stress. Xylem conduits of the internodes under went cavitation to a significantly higher extent than those of the nodal regions (between 50 and 600 per cent more). The non conduction xylem cross-sectional area increased by up to 56 per cent in the internodes and to about 25 per cent in the nodes of the most severely stressed plants. Both cavitation and anatomical data suggested that nodes are more resistant to cavitation, than internodes and further support and hypothesis of a plant segmentation.

Fanizza and Ricciardi (1990) compared the growth of wine grape genotypes under stress and non-stress condition. The weekly rate of elongation of shoot increases in the first period of stress and then it decreases while under non stress condition it increases. They explained that morphological characters are better parameters to discriminate varieties under water stress condition.

Rao and Padma (1991) studied the effect of moisture stress at different phenological stages of growth of tomato cultivars and reported that, in general, the stress induced at all the stages of the crop growth, reduced the plant height significantly in all the cultivars compared to non-stressed plots

Chandel and Chauhan (1992) studied the drought resistance of starking delicious apple plants on different rootstocks. They grafted starking delicious on eleven rootstocks and subjected to soil moisture tension. He observed the reduction in plant growth and vigour *viz.* annual shoot growth and trunk girth.

Fanizza and Castrignano (1993) grown two year old rooted cuttings of 14 wine – grape cultivars (*V. vinifera*) to a single shoot under stressed and non stressed conditions. The cultivars adapted to the drought environments had the highest shoot growth values.

During *et al.* (1995) studied under conditions of soil water deficiency, under a high leaf water status they observed that shoot growth was significantly reduced.

Patil *et al.* (1995) measured the length of the shoot of rootstocks of grapevine and number of internodes under water stressed condition in pot culture experiment to calculate the growth rate percentage. They found that length of the shoot is relatively more in control than the water stressed rootstocks of grapevine. Vigorous growth was observed in Digraset followed by *Riparia* x *Rupestris*. Growth of the shoot is maximum in *Solonis* x *Riparia*.

Shikhamany and Prakash (1995) noticed that the localities where drought prevails during the growth phase, shoot growth gets arrested resulted into immature causes.

Ramteke *et al.* (1999) studied the response of Tas-A-Ganesh vines on Dogridge rootstock to imposed water stress. He observed that withholding irrigation during the fruiting season has reduced significantly the shoot length and internodal length.

2.1.2 Effect of water stress on leaf attributes

Kozlowski (1976) reported that leaf shedding and reduction in leaf area are recognized as important adaptive features for drought tolerance in arid regions. Hanson *et al.* (1977) stated that the second leaf blades of Excelsior plant to prolonged PEG stress and reported that the leaf area was decreased and this decline was due to the narrowing of the desiccating leaf blade.

El-Barkouki *et al.* (1979) showed that total number of leaves per plant had significantly decreased after reduction of the available water upto 25 per cent or 12.5 per cent compared with that of plants grown under

50 per cent and 100 per cent available water. Number of leaves are less affected of Cultivar Romi Red by reduction of available water in comparison to that of Banaty cultivar. Hence, it might be suggested that Banaty cultivar was more sensitive to high water stress than Romi Red cultivar.

Davies and Johnson (1982) determined one year old plants of *V. ashei* cv. Bluegem to stomatal conductance. Both moderate and severe water stresses significantly reduced leaf area and plant weight.

Clarke (1984) reported that leaf area reduction is a common drought avoidance mechanism; indeed controlled environmental studies with wheat show that leaf removal can reduce the amount of water required for grain production.

Carbonneau (1985) studied the plants of one year old of Cabernet. Sauvignon which are grafted on the twenty different rootstocks are grown inside greenhouse and subjected to different water regimes. At the end of the experiment the total active leaf area of the plant (F) and the mean leaf stomatal conductance (l/rs) is measured to calculate the mean plant transpiration index (F/rd) which is expressed in percentage. He make five classes of grapevine rootstocks on the basis of the transpiration index.

Kuhad and Sheoran (1986) reported that as a result of water stress, the leaf area decreased to a lesser extent in Durgajay variety of cluster bean compared to its other four varieties.

Pire *et al.* (1988) showed that eight year old vines of the white table cv. Italia grafted on the local rootstock Criolla Negra. The vines were irrigated (2, 4, 7-8 or 11-14 irrigation / growth cycle) and only matured leaves were sampled. Vines growing in the driest soil showed an increase in leaf temperature, a decrease in leaf water potential due to which leaf area was reduced.

Nevryanskaya (1989) studied the four varieties of grapevine in pot culture experiment under soil moisture regimes of 70 per cent and 35 per cent of field capacity. Moisture stress reduced photosynthetic rate, specific leaf weight, leaf area and dry matter accumulation in the leaves.

Sweet *et al.* (1990) reported that the rate of leaf expansion was monitored as plant water status was manipulated by modulating the supply of irrigation water to potted grape cv. Thompson seedless plants over several days. The results indicate a high sensitivity of wall polysaccharides (particularly cellulose) synthesis to growth inhibiting water deficits.

Winkel and Rambal (1993) reported that the cultivars of grapevine which are resistant to the drought, apparently adjusted to water stress by reducing leaf area.

During *et al.* (1995) observed under conditions of soil water deficiency, plant water relations and chemical signals affect the stomatal conductance of grapevine leaves. Under a high leaf water status shoot growth, leaf number and leaf area is significantly reduced increasing the fruit to pruning weight ratio. A model integrating hydraulic and chemical signaling in water stressed plants is presented to interpret results obtained with grapevines. It is concluded that chemical root to shoot communication is an integral part of adaptation process leading to reduction of water loss before the water status in plant declines.

Patil *et al.* (1999) reported most of the leaves in *Vitis* species and their cultivars are simple or with 3-5 lobes. Smaller leaf size, more leaf thickness, minimum leaf area, short petioles, less number of teeth and veins are the important characters of plant types having resistance to drought leaf area was less in *V. berlandiri, V. champini* cv. Digraset and Dogridge, *V. tiliefolia* and *Berlandiri* x *Riparia.*

2.1.3 Effect of water stress on Root attributes

Stocker and Schmidt (1943) commented that drought resistant variety owed its resistance to a larger root system, higher osmotic potential and other similar factors. A deep and extensive root system may be an useful criterion for drought resistance of plant species; especially for those growing under extremely xeric conditions.

Newman (1974) reported that next to root depth, extensive root branching is often the most important characteristic of root system which favours the uptake of water. If there is an ample supply of water throughout the rooting zone, the size of root systems may be more than ample to meet the needs of plants and the removal of an appreciable part of the root system can have little effect on the total water uptake (Andrews and Newman, 1968).

Mayaki *et al.* (1976) reported a decrease in both shoot and root dry matter accumulation in field grown soybean in response to drought. Although there was no difference in the rooting depth between irrigated and non-irrigated soybean, they reported a relative increase in dry matter for the deepest roots of non-irrigated plants.

Fregoni (1977) reported that there appears to be no consistant relationship between root shoot vigour and drought tolerance and further claimed that drought tolerant rootstock varieties of grapevine usually have extensive and deep root systems.

Davies and Albrigo (1983) reported that cultivar differences in root : shoot ratio or rooting depth also may influence drought tolerance in Rabbit Eye blue berry. The cultivar Triblue had a greater canopy volume, but comparable rooting of Bluegem and Woodard. Rooting depth of *V. arboreum* and root distribution in *V. darrowi* may account for the greater drought tolerance of these species relative to shallower rooted *Vaccinium* species.

Miller (1986) studied the root characteristics that affect the area of absorbing surface are important that is root length, density, number and type of root hairs and mycorrhizal relations. The functions like absorption and translocation of water and nutrients, synthesize and transport organic compounds, a sink for carbohydrates and support the plant are affected when subjected to inadequate or excess water. Higher plants have mechanisms to cope with the various stresses. These mechanisms include such things as an expanding root system, change in root : shoot ratio development of advential adventitious roots and internal pore space, stomata opening control, adjustment to low osmotic potential and changes in morphology.

Chandel and Chauhan (1992) showed that the root length was reduced under soil moisture stress conditions, while studying the drought resistance of starking delicious apple plants on different rootstocks.

Yadav (1999) studied the rootstock and their rooting habit under drought. It is clear that the rootstock is capable of exploring large volumes of soil horizon by producing both active feeder root in the top 15-20 cm layer of soil an also thick tap anchor roots penetrating to deep layers of the soil. It can be postulated that the rootstock is not only capable of harvesting moisture at deeper layers but also is capable of absorbing very thin film of water adhered to the small soil particle.

2.1.4 Days to appearance of stress

Chang *et al.* (1974) reported a mass screening technique where leaf rolling, tissue death, stunted growth under drought stress and recovery upon stress were the criteria for drought tolerance during the vegetative stage.

Begg and Turner (1976) observed rolling of crop leaves under stress. According to them, this passive movement reduces the interception of radiation which increases the temperature of leaves due to closing of stomata and thus prevents further leaf water deficits in the plant.

O'Toole and Chang (1979) reported that leaf rolling of rice is perhaps the most universally obvious symptom of drought. Rolling of leaves indicates a decrease in turgor or pressure potential of the specialise tissue giving the leaf lamina its lateral hydraulic extensibility.

During (1985) suggested that in grapevine the leaf wilting test based on water holding capacity of leaves is a very good test for selection of drought tolerant types.

Matthews *et al.* (1990) selected four sorghum lines on the basis of leaf desiccation for resistance and susceptibility to mid-season drought and reported that resistant lines showed more leaf rolling than the susceptible ones. They attributed it to the reduction in the effective area of the uppermost part of the leaf upto 75 per cent. Further, they reported that leaf rolling in resistant lines occurred in a narrow range of leaf water potential (-2.0 to 2.2 mPa) which suggests leaf rolling alters the micro-climate so that the stomata may remain open and growth may continue without association of high rates of water loss.

Mhetre (1999) showed that grapevines experiencing moisture stress may exhibit one or more symptoms depending upon the degree and duration of water stress. Succulent young shoots experiencing sudden water reduction may wilt and drop their basal leaves. If stress prolonged, shoot tips die back and leaves and shoots dry up. Stunted growth of shoots and a shorter internodes near the tip, a change from normal green appearance, loss of turgidity and flagging of leaves.

2.2 Physiological parameters

2.2.1 Effect of water stress on Relative leaf water content

Slatyer (1960) observed that there is a relatively smaller decrease in relative water content per unit decrease in water potential in drought resistant species than in the drought susceptible ones.

Barrs (1968) suggested that relative water content (RWC) under stress could be used as a measure of tolerance to stress and could be used in screening programme.

El-Barkouki *et al.* (1979) reported that the relative water content (RWC) in the leaves of grapevine was positively correlated with the available soil moisture present and could be used as a indication of water stress.

Freeman and Turkington (1979) xylem water potential can give a physical measure of water stress in grapevine.

Allweldt and Ruw (1982) showed in own rooted and grafted grapevine varieties, that in most of the genotypes where the plants grown under drought conditions, the specific leaf weight (SLW) and Relative water content (RWC) reduced except in Dogridge, suggesting that it could withstand stress without loss in dry matter or water content in leaves.

Hulamani and Kalkundrikar (1982) conducted pot culture experiments with eight cvs. of citrus rootstocks and stress was created by withholding irrigation for 48 hours. They reported that, Sohmyndong a Rough lemon cultivar was the most drought tolerant rootstock with maximum of 94.71 per cent RWC.

According to During (1985) the stomatal size or frequency is not directly correlated with drought resistance, but leaf wilting test based on water holding capacity of leaves is a very good test for selection of drought resistant types.

Lee and Asahira (1983) evaluated cultivars of capsicum species for drought resistance as measured by water saturation and classified them into drought resistant (WSD $\leq$ 20 %), intermediate (WSD 20-40 %) or susceptible ($\geq$ 40 %). They reported a highly significant correlation between leaf water potential and WSD values ($r = -0.908$).

Patil *et al.* (1984) reported that with the advance in stress RWC decreased, while the free proline increased. Further, out of all the plant parts of maize, leaf sheath had higher RWC at all the stress treatments and no relationship between RWC and free proline content could be noticed. After re-irrigation of stressed plants, the RWC, in general was nearly restored to the original value.

Thakur (1989) reported that, recovery in relation to relative water content (RWC) was significant for all tomato cultivars at all levels of stress. Further, it was noticed that after the long term stress (10 days) the value of RWC was significantly lower than those of plants subjected to short-term (4 and 7 days) water stresses and that of unstressed control plants.

Rodrigues *et al.* (1993) studied the osmotic adjustment in water stressed grapevine leaves in relation to carbon assimilation. The leaves under water stressed was reached at lower water potential and relative water content values than the leaves in the control.

Patil *et al.* (1994) evaluated sixty five grape varieties for their drought tolerance. Observations recorded for fresh weight, turgid weight and dry weight were used for calculation of water deficit and relative turgidity. Range of relative turgidity was recorded from 47.81 to 84.52 per cent. Maximum turgidity was recorded in rootstock *Berlandiri* x *Riparia*, while it was minimum in *Solanis* x *Othello*.

Prakash and Bhatt (1999) measured the RWC of different rootstocks of grapevine by taking leaf discs. The imposition of water stress strongly decreased the relative water content of leaves in all the rootstocks by the end of stress cycle. The reduction was as steep as 27 per cent in Salt Creek to 6 per cent in R x R, next only Dogridge where it was 12 per cent suggesting that these rootstocks are able to maintain the water levels in their leaves during water stress.

Ramteke *et al.* (1999) showed that soil moisture content at various stages during the fruiting season was significantly reduced in unirrigated vines. The physiological indicators of stress namely relative water content of leaves were also influenced significantly by the water stress.

2.2.2 Effect of water stress on fresh and dry weight of root and shoot

Hanson *et al.* (1977) studied second leaf blade of Excelsior cv. for prolonged PEG stress and observed that in the first four days, fresh weight steadily fell to less than half of the initial value and dry weight also declined, particularly during the first day of stress.

Perry *et al.* (1983) in a field study where they found that out of the four *Vitis* cultivars at one location in Texas cv. Dogridge maintained the greatest above ground canopy and the most intensive root system. They reported highest number of roots in Dogridge under thicker category than under feeder or finer root category.

Miah *et al.* (1988) exposed 30 days old sunflower plants to water stress and observed that the differences between the fresh weights of stressed and unstressed plants gradually decreased. During the recovery period, however, the dry weight gradually recovered after rewatering, but it never reached that of the control.

Rosario and Fajardo (1988) reported significant interaction between peanut cultivars and water stress on root dry weight basis. Further, the cvs. *viz.* ACC-847, SS-437 and GNP-1157 had shown a tendency towards tallness and maximum shoot dry matter under stress conditions.

Thakur (1989) reported that the resumption of growth in terms of fresh and dry weights of shoots and roots, respectively were exhibited by all the tomato cultivars, although recovery was never complete.

Ashraf and Mehmood (1990) studied four species of *Brassica* and reported that during drought stress, the drought tolerant species *B. napus* produced relatively greater fresh weight and dry weight, while drought susceptible species *B. carinata* produced significantly lower fresh weight and dry weight.

Goodwin and Macrae (1990) studied that in a trickle irrigated vineyard of Cabernet Sauvignon vines spaced at 1.5 x 3.0 m and trained the canes in a vertical trellis. Each vine is irrigated when the soil water tension approached 100 centibars, the aim to being to wet to a depth of 40 cm (Normal treatment) or were irrigated for 1/5 of the run time of the normal treatment. Water deficits causes decrease in fresh weight and dry weight of vines.

Poni *et al.* (1992) showed that the shoot growth and root growth of the stressed plants was generally less than in control which is about 25 per cent on average.

Prakash (1999) studied six cultivars/rootstocks in pot culture. The total shoot length recorded at the time of uprooting the plants from the pot showed highest growth in Dogridge with highest shoot weight followed by Salt Creek. The lowest shoot length was recorded with Arka Neelamani and R x R. The root weights on dry weight basis in different category of roots shows that, in all the categories Dogridge had maximum root weight, while lowest in Arka Neelamani. These results suggest that the vigour as observed by shoot growth also manifested itself by producing maximum number of roots.

2.2.3 Effect of water stress on root : shoot ratio

Sandhu and Laude (1958) reported that the drought tolerant varieties of wheat and greater root : top ratio at all the stages of growth, as compared to susceptible ones.

Begg and Turner (1976) reported that the root to shoot ratio of plants increased with the increase in the water stress.

During (1979) reported that compared with grapevine cv. Muller-Thurgau, Riesling was more drought tolerant, had a higher root : shoot ratio, lower stomatal resistance and produced more fresh and dry weights of shoots and leaves.

Kummerow (1980) reported that root : shoot ratios are generally increased by water stress, although the absolute weight of roots usually decreases. Also, the root : shoot ratio is generally supposed to be larger for plants of drier regions than for plants of humid regions.

Eibach and Alleweldt (1985) studied the influence of water supply on growth, gas exchange and substance production of fruit bearing grapevines. The different effect of drought and fruit production on shoot and root growth caused a pronounced alteration of the shoot to root ratio. This ratio being low at a low water supply and high in fruit bearing plants.

Matthews *et al.* (1990) reported that the resistant *Sorghum bicolour* lines had a higher root : shoot ratio than those of the susceptible ones, which might have been responsible for their higher leaf water potential under stress conditions.

2.2.4 Effect of water stress on stomatal frequency

The stomata on the leaf area capable of influencing many aspects of plant metabolism. They are, therefore of considerable importance to the vital functions of energy storage and its utilization. The stomata further act as plant protective mechanisms by decreasing water loss through their closure during periods of plant water deficits and light intensity.

Raschke (1975) found that water stressed leaves had higher endogenous Abscisic Acid (ABA) concentrated and that exogenous ABA cause stomata to close. The higher concentration of ABA in various rootstocks shows tolerance to drought condition. Fregoni *et al.* (1978) found that drought tolerant rootstocks namely 402-A, 99-R and 1103-P had higher level of ABA.

The number of stomata per unit leaf area has been shown to vary among genotypes within a species and to be under genetic control Dobrenz *et al.* (1969) reported that low stomatal frequency was associated with greater drought tolerance in blue panic grass (*Panicum antidotale*, Retz.).

Liu *et al.* (1978) observed 356 stomata/mm^2 in *Vitis labrusca* cv. Concord, which differs from the present count of 162 stomata/mm^2. The same was reported by Meider and Mansfield (1968) and Turner (1979).

Dernoeden and Butler (1979) reported that stomatal density of leaves was much greater on the adaxial surface as compared to the abaxial surface. Most of the stomata on the upper leaf surface were in a central depression adjacent to the mid-vein. Further, greater stomatal densities on the adaxial surface, coupled with leaf folding during drought stress, appeared to be a water conserving feature.

During (1980) observed variation in stomatal frequency in five *Vitis* species to the range of 177 to 276/mm^2. In *Vitis rupestris*, he observed the stomatal frequency of 177/mm^2 i.e. lowest among the *Vitis* species studied.

Scienza and Boselli (1981) reported that both genotype and leaf position on the shoot markedly affected the frequency and morphological characteristics of stomata. Further, the drought resistant vine rootstocks had significantly fewer stomata than the susceptible ones.

Patil and Patil (1983) showed that stomata plays an important role in photosynthesis and respiration process as the exchange of gases take place through their pores. Similarly they are responsible for the evaporation of water from the mesophyll tissue of leaves. Stomatal frequency and stomatal index have great significance in the physiological process of plants, where stomatal frequency and index is less, water loss may be very less.

Rutland *et al.* (1987) studied 10 heat resistant cultivars of *Antirrhinum mayus* L. (Snapdragon) under summer green house conditions. They measured transpiration in relation to leaf area and stomatal density and reported that the total leaf area and the total number of stomata per plant did not correlate with daily transpiration. The abaxial leaf surface had higher stomatal density than that of adaxial one. Stomatal densities were consistently the lowest on leaves near the apex of stems and the highest on leaves near the base.

Aravindan *et al.* (1989) observed greater number of stomata in the lower epidermis than the upper epidermis. Stomatal frequency has direct relations with transpiration loss and a lower frequency is considered ideal for tolerating drought.

Patil and Patil (1994) also recorded the highest stomatal frequency in *V. assamica* ($333/mm^2$) and lowest in *Vitis mollis* ($70/mm^2$).

Patil *et al.* (1999) showed that stomatal frequency and index were significantly very less in *V. champani* cv. Digraset, *V. tiliefolia* and *Berlandiri* x *Riparia*. However, all these characters exhibit their tolerance to drought. Stomatal frequency was maximum in *Vitis paniflora* ($322/mm^2$), while minimum in *Berlandiri* x *Riparia* ($91/mm^2$).

2.3 Biochemical parameters

2.3.1 Effect of water stress on chlorophyll content in leaves

Chloroplast is an important photosynthetic unit of the plant cells. The major damages to the chloroplast caused by water stress are the structural changes due to excessive swelling, distortion of lamellae, vesiculation and the appearance of lipid droplets (Paleg and Aspinall, 1981).

Drought stress reduced the rate of net and gross photosynthesis and decreased chlorophyll content in some plants (Boyer, 1976; Gupta, 1978).

Dwivedi *et al.* (1979) reported more rapid changes in the chlorophyll content of the water stressed leaves than that of turgid ones. Further, the decrease in chlorophyll was still faster with concomitant increase in the level of α-amino nitrogen during the senescence of turgid leaves.

Guralnick and Ting (1987) reported that the chlorophyll levels decreased with preferential loss of chlorophyll 'a' over chlorophyll 'b' over the whole course of drought period in *Portulacaria afra* (L.) Jacg.

Gummuluru *et al.* (1989) reported that the tolerant types of wheat genotypes had higher chlorophyll content than the susceptible ones and maintained the chlorophyll content to a greater level of stress. After rewatering, the tolerant genotypes recovered more chlorophyll content than the susceptible ones.

Asharf and Mehmood (1990) in their greenhouse studies with four *Brassica* species in relation to drought stress and reported that *B. napus* was the most drought tolerant having the highest chlorophyll content.

Sharma *et al.* (1990) reported that both the photosynthesis and chlorophyll content decreased with increasing drought stress. Drought stress induced a gradual shift of carbon flow from the C_4 carbon fixation pathway to an alternate (Glycollate) pathway in maize.

Doroftei *et al.* (1993) studied the photosynthetic pigments in the leaves of grape under different soil moisture conditions. They reported that soil moisture stress reduces the production of green pigment.

Ramteke *et al.* (1999) studied the response of Tas-A-Ganesh vines on Dogridge rootstock to imposed water stress. They observed that chlorophyll content in leaf reduced significantly by 15.1 per cent under the soil moisture stress than the irrigated vines.

2.3.2 Effect of water stress on Chlorophyll stability index (CSI)

Koleyoseas (1958) stated that chlorophyll stability index is the difference between the absorbance of chlorophyll extract from heated and unheated leaf samples and correlated with drought resistance. It is very less in *Vitis berlandiri, V. champini* cv. Digraset, *V. longi, V. tiliefolia* and *Berlandiri* x *Riparia*. Hence, these types are significantly superior for drought resistant than other types studied.

Chlorophyll stability index (CSI) values of two well known drought susceptible clones of two drought resistant hybrid varieties of sugarcane *S. officinarum* were determined. It was reported that the lower the index, the higher was the drought resistance (Anonymous, 1962).

Murthy and Mujumdar (1962) determined the CSI values of two wet land varieties *viz.* Co-13 and Adt-19 and two well known drought resistant varieties of rice for assessing the differences between these two sets of varieties. They reported that the wet land varieties had relatively higher CSI values than the drought resistant types.

Matthew and Ramadasan (1973) determined the CSI of 5 coconut genotypes. The mean CSI was found to be significantly higher in the West Coast Tall (20.7) compared it that in the T x D (13.2), D x T (13.2), Dwarf Green (13.7) and Dwarf Orange (10.6). The high yielding hybrids recorded lower CSI values, indicating perhaps their superiority in drought tolerance over the West Coast Tall, which is a common and widely cultivated variety. The lowest mean CSI value was recorded for the Dwarf Orange variety.

Chhabra *et al.* (1981) tested 20 genotypes of Indian mustard for their drought resistance by chlorophyll stability index method. In highly drought resistant group, the CSI values varied from 0.012 to 0.316. In moderately drought resistant group, the values ranged from 0.426 to 0.810 and in drought susceptible group, they ranged from 0.908 to 2.392. They suggested that this method could successfully be exploited for screening Indian mustard varieties for drought resistance.

Sharma and Gill (1981) reported that the heat stability of the total leaf chlorophyll was closely related to the varietal characteristics under drought conditions and the chlorophyll stability index (CSI) ranged from 1.0 to 18.6 units among the different cultivars of sugarcane. The CSI values were 75-92 per cent lower in drought tolerant cvs. than those in drought susceptible ones. This was noticeable particularly during tillering stage. The most drought resistant cv. was Co-312 followed by Co.L-29 and Co-1148.

Patil *et al.* (1999) showed that wide variations in stomatal frequency and index, leaf water potential and chlorophyll stability index of grape cultivars *Vitis* species and rootstocks. In grape cultivars of *Vitis vinifera* cv. Gulabi, *V. labrusca* cv. Concord and *V. rotundifolia* cv. James have better drought resistance. Likewise, *V. arizonica, V. berlandiri, V. candicans* and *V. tiliefolia* and rootstocks – *Berlandiri* x *Riparia* and Digraset confirms their drought resistance.

MATERIAL AND METHODS

3. MATERIAL AND METHODS

The studies on grape rootstocks were undertaken with a view i) to study important morphological, physiological and biochemical characteristics of various grape rootstocks and ii) to screen the grape rootstocks for drought tolerance at the Post Graduate Institute glass house, block of the Department of Horticulture, Mahatma Phule Krishi Vidyapeeth, Rahuri (M.S.) during the year 2000-2001.

Rahuri is situated in the semi-arid zone at 20°10N latitude and 74°29E longitude and at an altitude of 675 meters above the Mean Sea Level; the average rainfall is 400-520 mm received during June to October. The range of minimum and maximum temperatures is between 7.3 and 39.3°C, respectively. The mean relative humidity is of 65 per cent and average day length is of 8 hours and 28 minutes.

3.1 Experimental materials

3.1.1 Rooted cuttings

Six month old uniform rooted cuttings of rootstocks *viz.* Dogridge, Salt Creek, 1613-C, 1616-C, 1103-P and SO4 were obtained from All India Co-ordinated Research Project on Sub Tropical Fruits-Grapes, Department of Horticulture, M.P.K.V., Rahuri.

The soil was also collected from orchard of All India Co-ordinated Research Project on Sub Tropical Fruits-Grapes, Department of Horticulture, M.P.K.V., Rahuri. The chemical analysis of the soil was carried out as per the standard methods in Table 1.

Plate 1. **A view of representative pots of experiment on drought tolerance under study.**

Pot No.	Rootstocks
1.	Dogridge
2.	Salt Creek
3.	1613-C
4.	1616-C
5.	1103-P
6.	SO4

3.1.2 Earthen pot

Earthen pots each of 30 cm diameter and 30 cm in height was filled with 10 kg of soil and FYM in 3:1 proportion was used for the experiment.

3.1.3 Black polythene sheets

To prevent the absorption of water at inner side of the pot were lined with 400 guage (100 cm x 75 cm size) black polythene sheets.

3.1.4 Tensiometers

The tensiometers are commonly used to measure soil water suction developed due to unsaturated soil. The measurement of capillary pressure or moisture tension can be used to determine moisture deficiencies and irrigation requirement after suitable calibration (Moisture tension Vs water content). The tensiometer consists of porous ceramic cup with an airtight connecting tube that leads to measuring device, vacuum guage. The connecting tube and ceramic cup is filled with water and saturated properly and placed in soil at 15 cm depth. The saturated porous cup is installed in soil, water from cup move through the tip until pressure inside and outside the ceramic cup is equal. As the soil dries, water moves out of tensiometers in response to the increasing soil water capillary pressure. The pressure developed in complete system is measured with the help of vacuum guage. At this particular pressure, water content is measured only by calibration and irrigation is practiced at pre-decided depletion of available water at depth of 15 cm.

3.2 Methods

3.2.1 Standard methods of soil and plant analysis

The soil and plant analysis was done by adopting the following standard methods.

Table 1. Standard methods of soil and plant analysis

Sr. No.	Property	Standard methods	Reference
A)	**Standard method of soil analysis**		
a)	Major nutrients		
1.	Available N	Alkaline permagnate method	Shahrawat and Budford (1982)
2.	Available P	Olsen method (spectrophotometry)	Watanabe and Olsen (1965)
3.	Available K	Flame photometric	Jackson (1973)
b)	Minor nutrients		
1.	Iron (Fe)	DTPA method	Lindsay and Novell (1978)
2.	Manganese (Mn)	DTPA method	Lindsay and Novell (1978)
3.	Zinc (Zn)	DTPA method	Lindsay and Novell (1978)
4.	Copper (Cu)	DTPA method	Lindsay and Novell (1978)
5.	F.C. and P.W.P.	Pressure plate apparatus	Richard (1947)
6.	Bulk density	Core sampler method	Dastane (1972)
B)	**Standard method of plant analysis**		
1.	Chlorophyll stability index (CSI)	Calorimetric method	Mackinney G. (1941)
2.	Chlorophyll content	Spectrophotometric method	Arnon (1949)
3.	Relative water content	Dry weight method	Barrs and Weatherly (1962)

3.2.2 Statistical analysis

The results were tabulated in Factorial Completely Randomised Design (FCRD) and the statistical analysis was done as per method given by Panse and Sukhatme (1967).

3.3 Experimental details

3.3.1 Treatment details

The drought tolerance studies in grape were conducted to screen the grape rootstocks for drought tolerance at various levels of water regimes. The details of genotypes selected for study are as given below (Table 2).

Table 2. Source of grape genotypes used for the investigation

Sr. No.	Genotype	Botanical name	Breeder
1.	Dogridge	*Vitis champini*	Munson selection ≈ (1900)
2.	Salt Creek	*Vitis champini*	Species selection (Munson) ≈ (1900)
3.	1613-C	*Vitis othello* x *Vitis riparia*	Couderc (1881)
4.	1616-C	*Vitis othello* x *Vitis solonis*	Couderc (1881)
5.	1103-P	*Vitis berlandiri* x *Vitis rupestris*	Paulsen (1895)
6.	SO4	*Vitis berlandiri* x *Vitis riparia*	Teleki group 4A (1896)

The experiment was carried out in F.C.R.D. with two replications and three levels of irrigation regimes as given below.

Rootstocks

1. Dogridge
2. Salt Creek
3. 1613-C
4. 1616-C
5. 1103-P
6. SO4

Irrigation regimes

1. 0.3 Bar
2. 0.5 Bar
3. 0.7 Bar

3.3.2 Transplanting of rooted cuttings of rootstocks

The rooted cuttings of grape rootstocks were pruned to retain 2 to 3 matured buds and the excess roots were also pruned. The pruned rooted cuttings were dipped in 0.1 per cent bavistin solution to avoid any fungal infection. Two rooted cuttings were planted in each pot on 6th August, 2000 and in each replication two pots were maintained. The subsequent irrigation with equal volume in each pot was done through measuring cylinder to maintain soil below the field capacity. The transplanted rooted cuttings sprouted and shoots were allowed to grow upto 5th February, 2001. The recut of sprouted shoots was undertaken on

6^{th} February, 2001 retaining 2 to 3 matured buds on shoot. The recut was taken for uniform shoot growth and equal foliage density. After having 5 to 6 leaves on a shoot of each rootstock treatment application was started, on the basis of the standard curve moisture tension Vs water content was prepared.

3.3.3 Preparation of standard curve

The standard curve was prepared as tensiometer reading i.e. matric suction in bar on x-axis and moisture present in soil in per cent on y-axis (Fig. 1). For this, the earthen pot filled with representative soil was taken, then the pot is saturated with water and tensiometer was installed in the pot. Then at each 0.05 bar tensiometer reading soil sample was drawn with screw auger and moist weight of the soil sample was recorded. Then the soil is kept in oven at 105°C till constant weight was obtained. Then the oven dry weight was recorded. The percentage of moisture present in soil was calculated by following equation

$$\text{Moisture content (per cent)} = \frac{\text{Weight of moist soil} - \text{Weight of oven dry soil}}{\text{Weight of oven dry soil}} \times 100$$

Table 3. Tensiometer readings (matric suction) in bars and per cent moisture present in soil

Matric suction in bars	% moisture
0.05	41.60
0.10	39.86
0.15	38.01
0.20	36.09
0.25	34.30
0.30	33.00
0.35	32.20
0.40	31.90
0.45	31.55
0.50	31.25
0.55	30.95
0.60	30.60
0.65	30.30
0.70	30.00
0.75	29.70
0.80	29.35
0.85	29.05

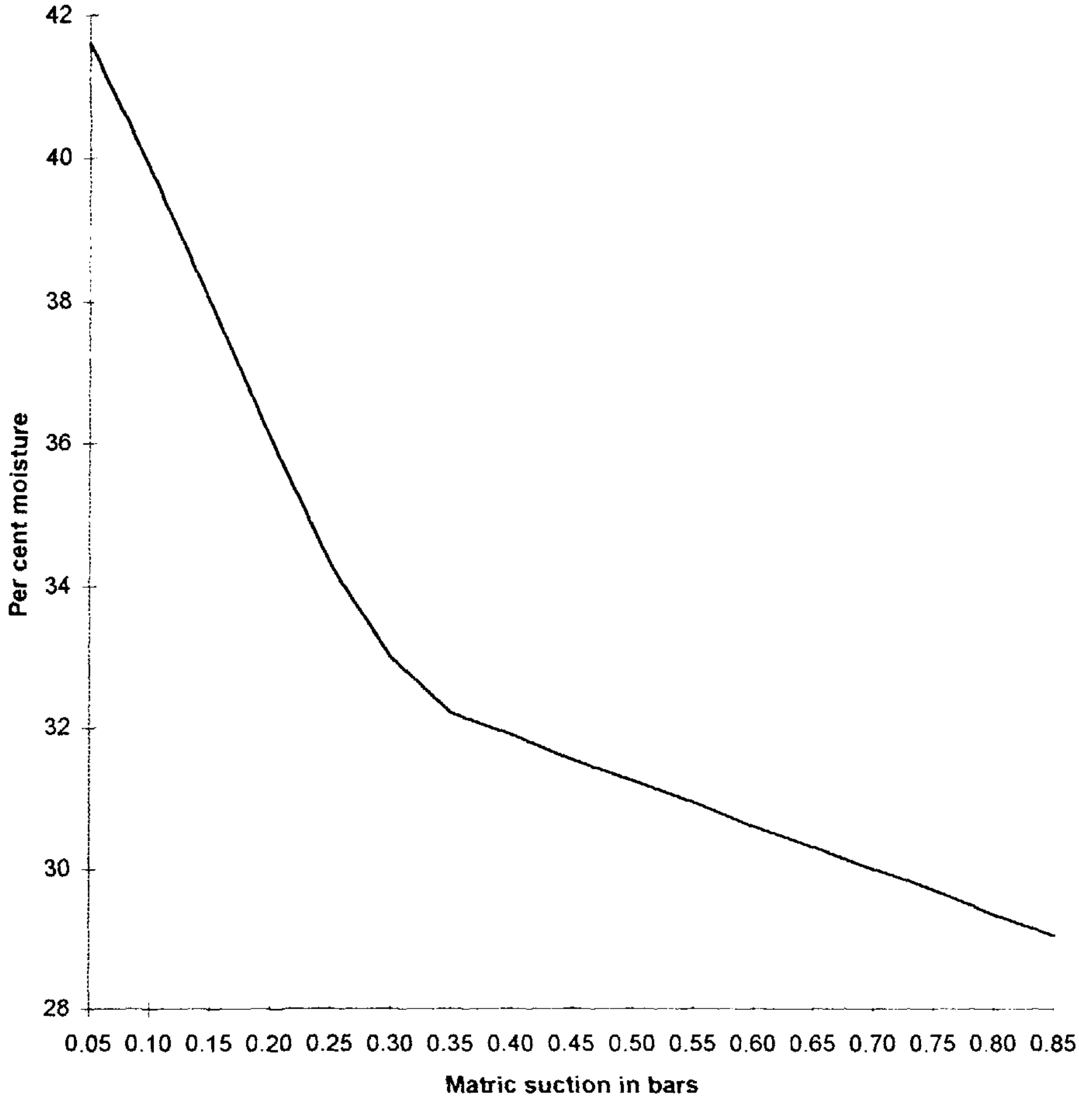

Fig. 1. Standard curve of matric suction Vs water content

3.3.4 Quantity of water according to irrigation regimes

After attaining shoot growth at 5 to 6 leaf stage all the pots were saturated on 1st March, 2001 and tensiometers were installed. The quantity of water required for saturation was calculated by following equation (Richard, 1947)

$$d = \frac{F.C. - P.W.P.}{100} \times B.D. \times D.$$

Where,

d	=	Available water holding capacity in %
F.C.	=	Field capacity in %
P.W.P.	=	Permanent wilting point in %
B.D.	=	Bulk density in gm/cm^3
D	=	Depth of pot upto which soil was filled in cm.

2.54 lits. of water was required for saturation of the pot.

The water was applied by measuring cylinder when the tensiometer shows the required reading of water regimes, scheduling of the irrigation was done by keeping the five days interval. The water that must be depleted from soil was applied by calculating the amount of water from standard curve. This procedure was followed for all treatments.

Table 4. Total number of irrigations and average tensiometer reading

Irrigation regimes (bar)	Total No. of irrigations	Average Tensiometer Reading (bar)	
		Before irrigation	12 hours after irrigation
0.3	11	0.562	0.299
0.5	10	0.697	0.498
0.7	9	0.840	0.704

3.4 Observations recorded
(2½ month after treatment)

3.4.1 Morphological characters

3.4.1.1 Growth attributes

3.4.1.1a Height of shoot (cm)

The height of shoot of each rootstock was measured from the base of main shoot to growing tip with the help of flexible tape. The average of four rootstock cuttings were computed and presented. Care was taken to measure it accurately upto 0.1 cm.

3.4.1.1b Diameter of shoot (mm)

The diameter at middle part of the second internode of the main shoot was measured with the help of vernier calliper. The average for four rootstock cuttings were computed for all the treatments. Care was taken to measure it accurately upto 0.01 cm.

3.4.1.1c Number of shoots per vine

The number of shoots sprouted on each vine of rootstock was counted and average of four vines were computed.

3.4.1.1d Length of internode (cm)

Length of each internode was measured with the help of flexible tape from base of main shoot to the growing tip. The average number of four vines were calculated.

3.4.1.2 Leaf attributes

3.4.1.2a Number of leaves per vine

The number of leaves per vine were counted and the average for four vines were computed.

3.4.1.2b Leaf area (cm^2)

The leaf area was measured by graph method.

3.4.1.3 Root attributes

The roots of each rootstock per vine were removed carefully from the earthen pots at the end of experiment along with adhering soil and washed by pressure water pump to clean the roots. After repeated washing with water the vines were spread over the filter paper. The shoot and root portion was separated with the help of secator at the collar region and following observations of roots were recorded.

3.4.1.3a Length of main root (cm)

The maximum length of root was measured with the help of measuring tape and average from four vines were computed.

3.4.1.3b Number of primary roots per vine

The number of primary roots per vine were counted and average for four vines were computed.

3.4.1.3c Number of secondary roots per vine

The number of secondary roots per vine that arises from primary roots were counted and average for four vines were computed.

3.4.1.4 Days to appearance of stress

The following observations were recorded to express the appearance of stress.

3.4.1.4a Leaf rolling

The number of days required for 50 and 100 per cent rolling of the leaves at various stages were recorded on the basis rating of rolled leaf lamina.

3.4.1.4b Leaf shrivelling

a) Days to initiation of shrivelling were recorded on the basis of rating of shrivelling of leaves of rootstock cuttings.

b) Days to more than 50 per cent shrivelling were recorded on the basis of rating of shrivelling of leaves of rootstock cuttings.

3.4.1.4c Days to dryness of leaf

Days to dryness of complete leaves were counted. The average of four vines were computed.

3.4.2 Physiological parameters

3.4.2.1 Relative leaf water content (RLWC)

A technique as suggested by Barrs and Weatherly (1962) was used for this purpose. Accordingly, both the sixth and seventh leaf of each vine which was physiologically functional was collected with its petiole during early in the morning. The leaf samples were brought to the lab after careful sealing in double walled thermocole chamber in order to prevent from water loss. Twenty five discs of 1 cm diameter were taken with the help of cork borer. The similar number of the discs were also obtained from the leaves of vines under treatment. Immediately fresh weight (FW) of the leaf discs were recorded. Then all of them were allowed to float on distilled water for 6 hours until they attain equilibrium. Then all these turgid leaf discs were removed from water and wiped dry using a new clean blotting paper. They were weighed and their weights was taken as the weight of turgid leaf tissue (TW). Then the same discs were kept in a clean moisture can and dried in hot air oven at 85°C for 24 hours to reach a constant weight. This weight was taken as dry weight (DW) of the dry leaf tissue. The relative water content (RWC) was then computed by using the following equation

$$RLWC = \frac{FW - DW}{TW - DW} \times 100$$

Where,

RLWC	=	Relative leaf water content (%)
FW	=	Fresh weight of leaf discs (mg)
TW	=	Turgid weight of leaf discs (mg)
DW	=	Dry weight of leaf discs (mg)

3.4.2.2 Fresh weight of root and shoot system (g)

The separated root and shoot of each vine was used for fresh root and shoot observation. The portion from where the roots emerged was included in the root system, while the portion above that level (collar regions) including leaves were taken as the shoot system. The weights for shoot and root systems were recorded accurately separately for each vine. The averages separately for the root and shoot systems for the four vines were computed and presented.

3.4.2.3 Dry weight of root and shoot system (g)

All the root and shoot of each vine used for determining the fresh weight were separately cut into small pieces and were separately filled in the brown paper bags. They were dried in a hot air oven at 70°C temperature, till the two consecutive weights obtained were constant. The averages separately for the shoot and root systems for the four vines were computed and presented.

3.4.2.4 Root : shoot ratio on fresh weight basis

This was computed by dividing the fresh weight of the root system of each vine by the fresh weight of its shoot system. The average for the four vines were computed and presented.

3.4.2.5 Root : shoot ratio on dry weight basis

The dry weight of root system of each vine was divided by the dry weight of its shoot system. The average for the four vines were computed and presented.

3.4.2.6 Stomatal frequency

Sampson's (1961) technique was used for this purpose. Accordingly, a freshly prepared paste of thermocole and chloroform (1:1 V/V) was used for obtaining transparent replicas of stomatal impressions for microscopic studies.

This paste was gently smeared over a small part of the lower leaf surface of the sixth leaf of each of the four vines in a treatment of each rootstock and left to polymerise over there exactly for a period of 2 minutes. It was then gently lifted away with the help of a pair of forceps and placed flat on a glass slide leaving its impressed surface upwards. It was covered with a thin, clean, dry glass cover slip and examined microscopically under high power (40 X) of the microscope. A total of 5 microscopic fields of each leaf print were read. The total number of stomata from each such microscopic field was counted and the average number of stomata per mm^2 of leaf surface for each rootstock cuttings was counted. The average for the four vines in a treatment was computed and it was expressed as number of stomata per mm^2 using the following equation.

$$\text{Stomatal frequency} = \frac{1 \times A}{0.0068 \times 100}$$

Where,

A = Number of stomata per microscopic field

0.0068 = Area of the microscopic field under 40 X magnification (cm^2)

3.4.3 Biochemical parameters

3.4.3.1 Determination of chlorophyll content (mg g^{-1} FW)

Chlorophyll pigments were extracted with cold 80 per cent acetone (V/V) and estimated spectrophotometrically as suggested by Arnon (1949). The 7^{th} leaf from the top of the growing shoot from each vine under treatment was collected between 7.00 to 7.30 a.m. They were cleaned and rinsed with distilled water and wiped off with a clean absorbent paper.

250 mg of fresh leaf material was accurately weighed excluding mid ribs on electronic balance and transferred to mortar and pestle for grinding. 10 ml of 80 per cent acetone was mixed in it and leaves were thoroughly macerated. A homogenous paste was made. Chlorophyll extract was poured in a funnel having Whatman filter paper No. 1 and collected in 50 ml volumetric flask. The green extract was gradually obtained by adding 5 ml of acetone (80 %) every time. Three to four washings were given and extraction continued until leachate becomes colourless. Volume should not exceed 50 ml eventually. Make the volume to 50 ml with 80 per cent acetone. Since, the extract was subject to photo-oxidation, it was kept away from direct sunlight and stored in refrigerator. The absorbance was recorded on spectrophotometer at 645 and 663 nm wavelengths.

3.4.3.2 Estimation of chlorophyll stability index (CSI)

The method for determination of chlorophyll stability index was standardised, by Mackinney (1941). This involved determination of critical temperature and time for effecting the pigment change and adopting uniform procedure for chlorophyll extraction. For this, 7^{th} leaf from the top of growing shoot of each rootstock was collected between 7.00 to 7.30 a.m. They were cleaned and rinsed with distilled water and wiped off with clean absorbent paper.

Two clean glass tubes were taken and five grams of representative leaf sample was placed in them with 50 ml of distilled water. One tube was then subjected to heat in water bath at 56°C ± 1°C for exactly 30 minutes. Other tube was kept as control. The leaves were then ground in a mortar for five minutes with 100 ml of 80 per cent acetone. The slurry was then filtered with Whatman No. 1 filter paper. This chlorophyll extract was further examined immediately for light absorption. The absorbance value for each such extract was recorded at 652 nm wavelength on the spectrophotometer. The absorbance value for the respective unheated 5 gm leaf shreads was also recorded. The chlorophyll stability index was obtained as the difference between the readings of chlorophyll extracts of heated and unheated leaf shreads.

EXPERIMENTAL RESULTS

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Plate 2. Relative water stress tolerance based on irrigation regimes of grapevines.

Table 5. Effect of water stress on height of shoot of grapevine rootstocks

Rootstocks / Irrigation regimes (bar)	Height of shoot (cm)						Mean
	Dogridge	Salt Creek	1613-C	1616-C	1103-P	SO4	
0.3 bar	66.500	64.663	64.175	64.150	66.238	62.625	64.725
0.5 bar	59.475 (10.56)	52.713 (18.48)	48.300 (24.73)	46.788 (27.06)	61.325 (7.41)	40.050 (36.04)	51.442
0.7 bar	53.775 (19.13)	41.550 (35.74)	36.425 (43.24)	32.550 (49.25)	57.813 (12.71)	22.488 (64.09)	40.767
Mean	59.917	52.975	49.633	47.829	61.792	41.721	52.311

	S.E.±	C.D. at 5 %
Rootstocks (A)	0.127	0.378
Irrigation regimes (B)	0.090	0.267
Interaction (AB)	0.220	0.656

(Figures in parentheses indicate percentage reduction).

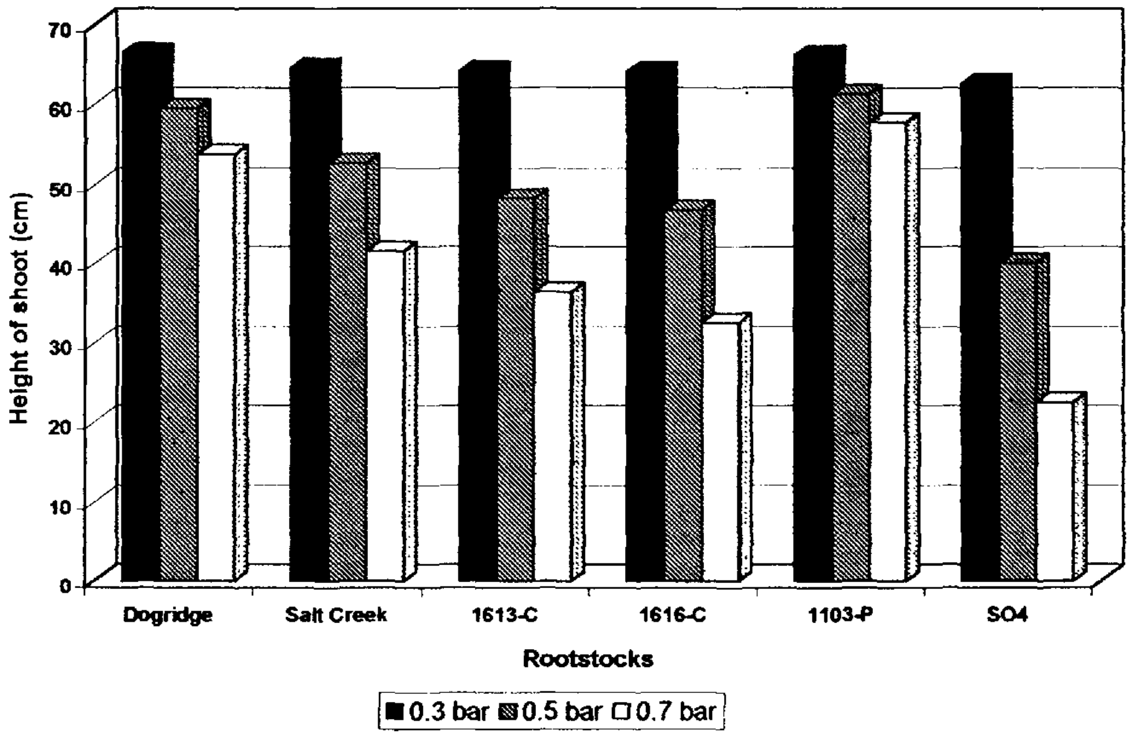


Fig. 2: Effect of water stress on height of shoot of grapevine rootstocks

Effect of irrigation regimes

The height of shoot was also significantly influenced by various irrigation regimes. The vines receiving level 0.3 bar i. e. at field capacity recorded significantly maximum height of shoot (64.73 cm) followed by (51.44 cm) when scheduling of irrigation at 0.5 bar. The height of shoot was decreased with increase in water stress. The lowest height of shoot (40.77cm) was recorded with scheduling of irrigation at 0.7 bar.

Effect of interaction

The interaction effect between irrigation regimes and different grape rootstocks was also significant. Among the different levels of irrigations, the maximum height of shoot (66.50 cm) was observed by Dogridge with scheduling of irrigation at 0.3 bar, however 1103-P attained the maximum height of shoot (61.32 cm) with scheduling of irrigation at 0.5 bar and 57.81cm at 0.7 bar. The lowest height of shoot (22.49 cm) was recorded by SO4. The minimum reduction in height of shoot was noticed by 1103-P at scheduling of irrigation at 0.5 bar (7.41 %) and at 0.7 bar (12.71 %), however, it was followed by Dogridge (10.56 % and 19.13 %, respectively) and Salt Creek (18.48 % and 35.74 %, respectively). The maximum reduction in height of shoot was recorded by SO4 (64.09 %) at 0.7 bar irrigation. Based on reduction percentage in height of shoot was indicated that 1103-P rootstock was found to be more drought tolerant followed by Dogridge and Salt Creek.

4.1.1b Effect of water stress on diameter of shoot (mm)

The data pertaining to the diameter of shoot as influenced by various levels of irrigation are presented in Table 6 and graphically depicted in Fig. 3.

Effect of rootstocks

The results showed that there was significant effect of different irrigation regimes of irrigation scheduling and various rootstocks on diameter of shoot. In all the rootstocks of grapes, the maximum diameter of shoot (3.38 mm) was noticed in Dogridge followed by 1613-C (3.23 mm), 1103-P (3.01 mm), 1616-C (2.88 mm) and Salt Creek (2.78 mm). The lowest diameter (2.36 mm) was observed by SO_4.

Effect of irrigation regimes

The diameter of shoot was also significantly influenced by various levels of irrigations. The maximum diameter of shoot (3.67 mm) was recorded when irrigation was scheduled at 0.3 bar which was followed by 0.5 bar (2.88 mm). As there was increase in the water stress the diameter of shoot was decreased. The minimum diameter of shoot (2.28 mm) was observed with scheduling of irrigation at 0.7 bar.

Effect of interaction

The interaction effect between different rootstocks and irrigation regimes was also significant. Among the different irrigation regimes the maximum diameter of shoot (4.20 mm) was observed by 1613-C with scheduling of irrigation at 0.3 bar whereas the Dogridge attained the highest diameter with scheduling of irrigation at 0.3 bar

Table 6. Effect of water stress on diameter of shoot of grapevine rootstocks

Rootstocks / Irrigation regimes (bar)	Diameter of shoot (mm)						Mean
	Dogridge	Salt Creek	1613-C	1616-C	1103-P	SO4	
0.3 bar	3.713	3.338	4.200	3.938	3.238	3.563	3.665
0.5 bar	3.350 (9.77)	2.763 (17.22)	3.175 (24.40)	2.738 (30.47)	2.988 (7.72)	2.263 (36.48)	2.879
0.7 bar	3.088 (16.83)	2.225 (33.34)	2.325 (44.64)	1.950 (50.48)	2.813 (13.12)	1.263 (64.55)	2.277
Mean	3.383	2.775	3.233	2.875	3.013	2.363	2.940

	S.E.±	C.D. at 5 %
Rootstocks (A)	0.010	0.031
Irrigation regimes (B)	0.007	0.022
Interaction (AB)	0.018	0.055

(Figures in parentheses indicate percentage reduction).

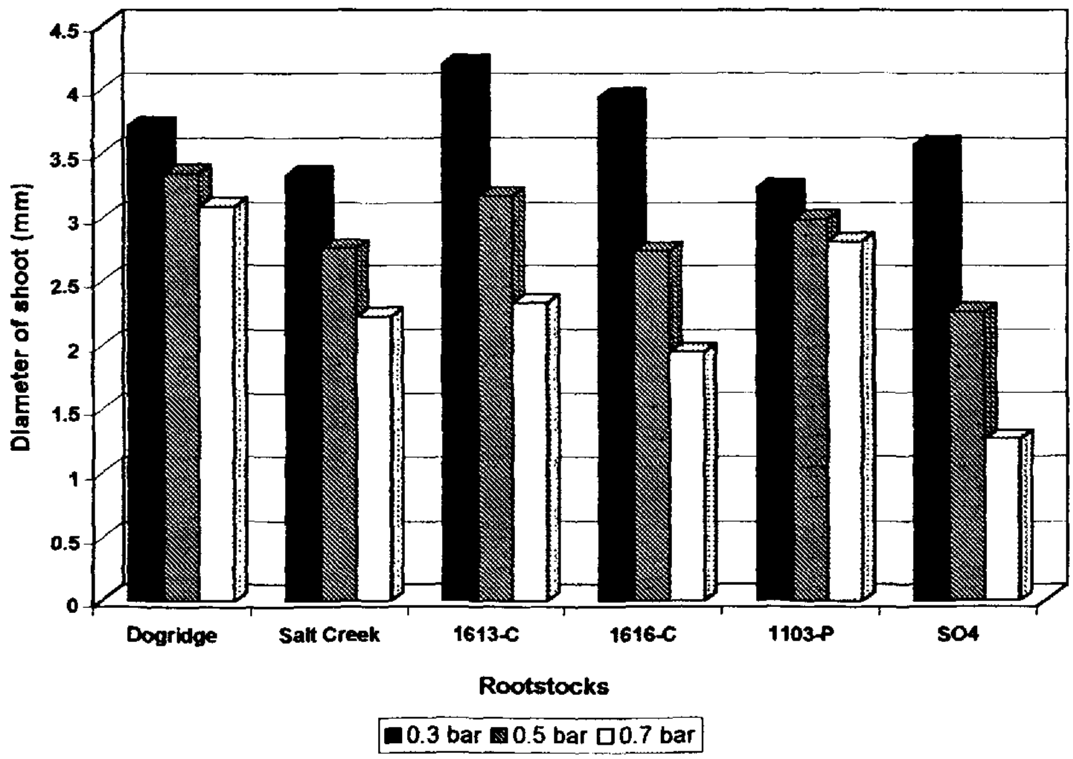


Fig. 3: Effect of water stress on diameter of shoot of grapevine rootstocks

(3.71 mm) as well as at 0.7 bar (3.09 mm). The lowest diameter of shoot (1.26 mm) was found by SO4. The minimum reduction of 7.72 per cent and 13.12 per cent in diameter of shoot was recorded by 1103-P with irrigation level at 0.5 bar and 0.7 bar, respectively which was followed by Dogridge (9.77 % and 16.83 %, respectively) and Salt Creek (17.22 % and 33.34 %, respectively). As the reduction percentage in diameter of shoot was recorded by 1103-P indicated that 1103-P was relatively more drought tolerant followed by Dogridge and Salt Creek.

4.1.1c Effect of water stress on number of shoots per vine

The relevant data on the number of shoots per vine affected by different irrigation regimes are presented in Table 7 and graphically shown in Fig. 4.

Effect of rootstocks

The data revealed that there was significant influence of different levels of irrigation regimes and various rootstocks on number of shoots per vine. In all the rootstocks the maximum number of shoots were recorded by 1103-P (14.67) followed by 1613-C (14.33), Dogridge (12.42), 1616-C (10.63) and Salt Creek (10.13). The lowest number of shoots per vine (8.83) was recorded by SO4.

Effect of irrigation regimes

The number of shoots per vine also significantly influenced by various irrigation regimes. The scheduling of irrigation at 0.3 bar i.e. at field capacity recorded significantly maximum number of shoots per vine (15.23). The number of shoots was decreased with increase in water stress.

Table 7. Effect of water stress on number of shoots of grapevine rootstocks

Rootstocks / Irrigation regimes (bar)	Number of shoots per vine						Mean
	Dogridge	Salt Creek	1613-C	1616-C	1103-P	SO4	
0.3 bar	14.875	12.875	19.125	15.125	16.125	13.250	15.229
0.5 bar	12.250 (17.64)	10.125 (21.35)	13.875 (27.45)	10.375 (31.40)	14.500 (10.07)	8.625 (34.90)	11.625
0.7 bar	10.125 (31.93)	8.000 (37.86)	10.000 (47.71)	6.375 (57.85)	13.375 (17.05)	4.625 (65.09)	8.750
Mean	12.417	10.333	14.333	10.625	14.667	8.833	11.668

	S.E.±	C.D. at 5 %
Rootstocks (A)	0.061	0.182
Irrigation regimes (B)	0.043	0.128
Interaction (AB)	0.106	0.315

(Figures in parentheses indicate percentage reduction).

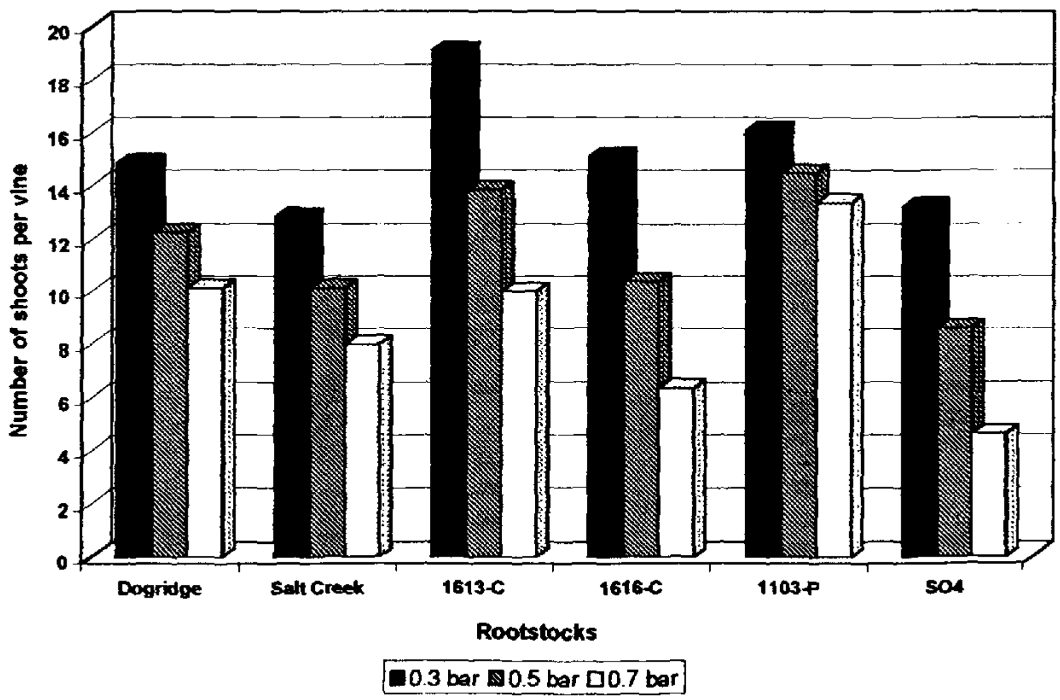


Fig. 4: Effect of water stress on number of shoots of grapevine rootstocks

The number of shoots per vine were observed while scheduling of irrigation at 0.5 bar (11.63), while lowest number of shoots per vine were recorded during scheduling of irrigation at 0.7 bar (8.75).

Effect of interaction

The interaction effect between irrigation regimes and different grape rootstocks were also significant. Among the different irrigation regimes the maximum number of shoots per vine (19.13) were observed in 1613-C followed by 1103-P (16.12), 1616-C (15.13), however, it was at par with Dogridge (14.88) with scheduling of irrigation at 0.3 bar. The 1103-P observed the maximum number of shoots per vine with scheduling of irrigation at 0.5 bar (14.50) and at 0.7 bar (13.38). The minimum number of shoots per vine was recorded by SO4 (4.63). The lowest reduction percentage in number of shoots per vine with irrigation regimes at 0.5 bar (10.07%) and also at 0.7 bar (17.05 %) was noticed by 1103-P which was followed by Dogridge (17.64 % and 31.93 %) and Salt Creek (21.35% and 37.86 %), respectively. In view the lowest reduction percentage in number of shoots per vine as observed by 1103-P it indicated that 1103-P was found more drought tolerant followed by Dogridge and Salt Creek.

4.1.1d Effect of water stress on length of internode (cm)

The effect of irrigation regimes on length of internode of different rootstocks are displayed in Table 8 and graphically depicted in Fig.5.

Table 8. Effect of water stress on length of internode of grapevine rootstocks

Rootstocks / Irrigation regimes (bar)	Length of internode (cm)						Mean
	Dogridge	Salt Creek	1613-C	1616-C	1103-P	SO4	
0.3 bar	6.813	6.588	6.338	6.425	7.275	6.000	6.573
0.5 bar	6.250 (8.26)	5.475 (16.89)	5.000 (21.11)	4.788 (25.47)	6.813 (6.35)	4.137 (31.05)	5.410
0.7 bar	5.788 (15.04)	4.538 (31.11)	3.900 (38.46)	3.363 (47.65)	6.450 (11.34)	2.525 (57.91)	4.427
Mean	6.283	5.533	5.079	4.858	6.846	4.221	5.470

	S.E.±	C.D. at 5 %
Rootstocks (A)	0.020	0.059
Irrigation regimes (B)	0.014	0.042
Interaction (AB)	0.034	0.103

(Figures in parentheses indicate percentage reduction).

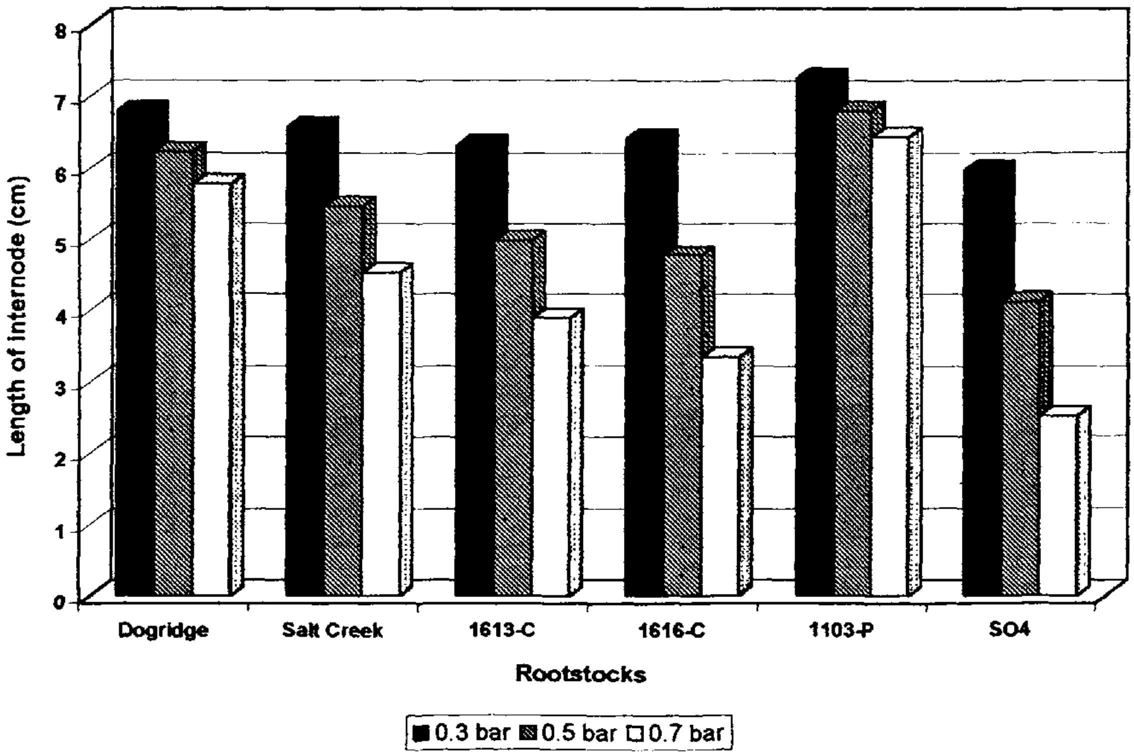


Fig. 5: Effect of water stress on length of internode of grapevine rootstocks

Effect of rootstocks

The data revealed that there was significant effect of different levels of irrigation regimes and various rootstocks on length of internode. Among the different rootstock of grapes, the maximum length of internode was noticed by 1103-P (6.85cm) which was followed by Dogridge (6.28cm), Salt Creek (5.53 cm), 1613-C (5.08cm) and 1616-C (4.86cm). The lowest length of internode was recorded in SO4 (4.22 cm).

Effect of irrigation regimes

The length of internode was also significantly influenced by various levels of irrigation. Significantly maximum length of internode was recorded with scheduling of irrigation at 0.3 bar (6.57 cm) i.e. field capacity which was followed by 0.5 bar (5.41 cm) whereas lowest length of internode was recorded with scheduling of irrigation at 0.7 bar (4.43 cm).

Effect of interaction

The interaction effect between irrigation regimes and different grape rootstocks were significant. Among the different levels of irrigations the maximum length of internode was observed 1103-P (7.28 cm) with scheduling of irrigation at 0.3 bar whereas in the scheduling of irrigation at 0.5 bar and 0.7 bar the same rootstock had attained the maximum length of internode (6.81 cm and 6.45 cm, respectively). The lowest length of internode was noticed by SO4 (2.53 cm). The minimum reduction at scheduling of irrigation at 0.5 bar (6.35 %) and 0.7 bar (11.34 %) was recorded by 1103-P, however, it was followed by Dogridge (8.26 % and 15.04 %, respectively) and Salt Creek (16.89 % and 31.11 %, respectively).

Based on reduction percentage in length of internode it was indicated that 1103-P rootstock was found to be relatively more drought tolerant followed by Dogridge and Salt Creek.

4.1.2 Effect of water stress on leaf attributes

4.1.2a Effect of water stress on total number of leaves per vine

The data in respect of total number of leaves per vine as influenced by various irrigation regimes are presented in Table 9 and graphically depicted in Fig. 6.

Effect of rootstocks

The results showed that there was significant effect of different irrigation regimes of irrigation scheduling and various rootstocks on total number of leaves per vine. In all the rootstock of grapes, the maximum total number of leaves per vine were noticed in 1103-P (98.83) which was followed by Dorgridge (78.00), 1613-C (75.33), Salt Creek (61.08) and 1616-C (53.08). The lowest total number of leaves per vine were observed in SO4 (35.96).

Effect of irrigation regimes

The total number of leaves per vine were also significantly influenced by various levels of irrigations. The maximum total number of leaves per vine were recorded when irrigation was scheduled at 0.3 bar (80.94) which was followed by 0.5 bar (65.69). As the water stress increases the total number of leaves per vine were decreased. The minimum total number of leaves per vine were observed with scheduling of irrigation at 0.7 bar (54.52).

Table 9. Effect of water stress on total number of leaves of grapevine rootstocks

Rootstocks / Irrigatioan regimes (bar)	Total number of leaves per vine						Mean
	Dogridge	Salt Creek	1613-C	1616-C	1103-P	SO4	
0.3 bar	85.750	72.250	94.750	70.750	104.500	57.625	80.938
0.5 bar	76.875 (10.34)	60.125 (16.78)	73.125 (22.82)	51.625 (27.03)	98.375 (5.86)	34.000 (40.99)	65.688
0.7 bar	71.375 (16.76)	50.875 (29.58)	58.125 (38.65)	36.875 (47.87)	93.625 (10.40)	16.250 (71.80)	54.521
Mean	78.000	61.083	75.333	53.083	98.833	35.958	67.049

	S.E.±	C.D. at 5 %
Rootstocks (A)	0.586	1.740
Irrigation regimes (B)	0.414	1.230
Interaction (AB)	1.015	3.014

(Figures in parentheses indicate percentage reduction).

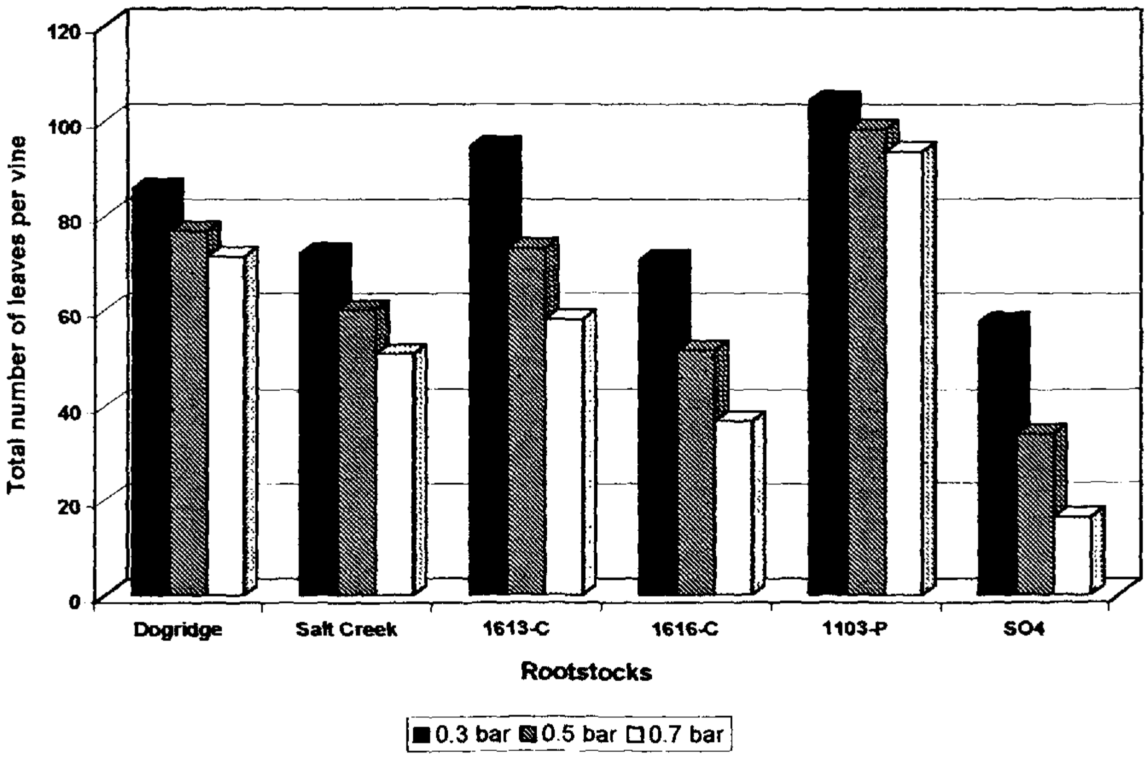


Fig. 6: Effect of water stress on total number of leaves grapevine rootstocks

Effect of interaction

The interaction effect between different rootstocks and irrigation regimes were significant. Among the different irrigation regimes the maximum total number of leaves per vine were observed by 1103-P with scheduling of irrigation at 0.3 bar (104.50) whereas maximum number of leaves per vine were recorded with scheduling of irrigation at 0.5 bar (98.38) and 0.7 bar (93.63), respectively. The minimum total number of leaves per vine was found by SO4 (16.25). The lowest reduction in total number of leaves per vine were recorded in 1103-P with irrigation level at 0.5 bar (5.86 %) and at 0.7 bar (10.40 %), respectively which was followed by Dogridge (10.34 % and 16.76 %, respectively.) and Salt Creek (16.78 % and 29.58 %, respectively). While considering the reduction percentage in total number of leaves per vine 1103-P was observed more drought tolerant followed by Dogridge and Salt Creek.

4.1.2b Effect of water stress on leaf area (cm^2)

The data pertaining to the leaf area as influenced by various levels of irrigation are presented in Table 10 and graphically depicted in Fig.7.

Effect of rootstocks

The results showed that there was significant effect of different irrigation regimes of irrigation scheduling and various rootstocks on leaf area. In all the rootstocks the maximum leaf area was observed by Salt Creek (82.88 cm^2) followed by 1613-C (80.30 cm^2), Dogridge (63.73 cm^2), 1616-C (61.34 cm^2) and SO4 (59.00 cm^2). The minimum leaf area (51.35 cm^2) was observed in 1103-P.

Table 10. Effect of water stress on leaf area grapevine rootstocks

Rootstocks / Irrigation regimes (bar)	Leaf area (cm^2)						Mean
	Dogridge	Salt Creek	1613-C	1616-C	1103-P	SO4	
0.3 bar	84.938	101.625	87.063	63.688	71.313	60.531	78.193
0.5 bar	62.719 (26.15)	81.406 (19.89)	79.000 (9.26)	59.000 (7.36)	50.500 (29.18)	57.469 (5.05)	65.016
0.7 bar	43.531 (48.74)	65.625 (35.42)	74.844 (14.03)	*	32.250 (54.77)	*	54.063
Mean	63.729	82.885	80.302	61.344	51.354	59.000	65.757

	S.E.±	C.D. at 5 %
Rootstocks (A)	0.261	0.776
Irrigation regimes (B)	0.184	0.548
Interaction (AB)	0.452	1.344

(Figures in parentheses indicate percentage reduction).
* Sample was not available.

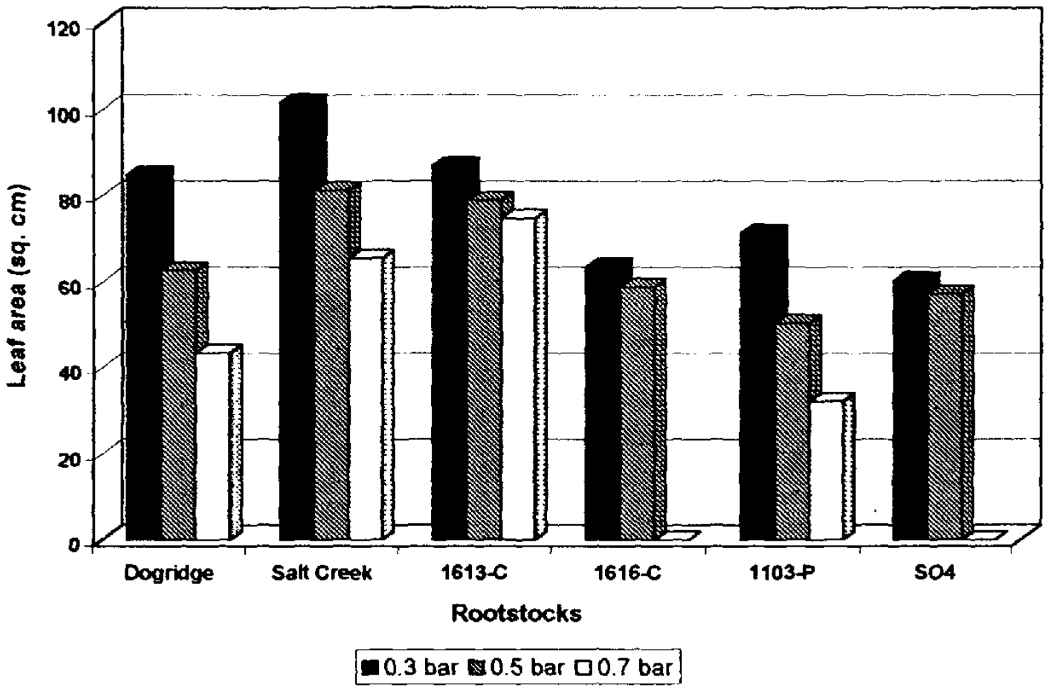


Fig. 7: Effect of water stress on leaf area of grapevine rootstocks

Effect of irrigation regimes

The leaf area was also significantly influenced by various levels of irrigations. The maximum leaf area was recorded when irrigation was scheduled at 0.3 bar (78.19 cm^2) which was followed by 0.5 bar (65.02 cm^2). As the water stress increased the leaf area in all the grape rootstocks were also decreased. The minimum leaf area was observed with scheduling of irrigation at 0.7 bar (54.06 cm^2).

Effect of interaction

The interaction effect between different rootstocks and irrigation regimes were significant. Among the different irrigation regimes the maximum leaf area was observed by Salt Creek with scheduling of irrigation at 0.3 bar (101.63 cm^2) and at 0.5 bar (81.41 cm^2) whereas 1613-C recorded the maximum leaf area with scheduling of irrigation at 0.7 bar (74.84 cm^2). The lowest leaf area was recorded by 1103-P (32.25 cm^2). The maximum reduction of leaf area was recorded by 1103-P with irrigation level at 0.5 bar (29.18 %) and 0.7 bar (54.77 %) it was followed by Dogridge (26.15 % and 48.74 %, respectively) and Salt Creek (19.89 % and 35.42 %, respectively). It was indicated that, 1103-P rootstock was found to be better for water stress as the reduction in percentage leaf area was highest as compared to Dogridge and Salt Creek.

4.1.3 Effect of water stress on root attributes

4.1.3a Effect of water stress on length of main root (cm)

The data regarding the length of main root as influenced by different irrigation regimes on various rootstocks are presented in Table 11 and graphically depicted in Fig. 8.

Effect of rootstocks

The data revealed that there was significant influence of different levels of irrigation regimes and various rootstocks on length of main root. Among the different rootstocks of grapes the maximum length of main root was noticed by 1103-P (56.03 cm) followed by Dogridge (50.67 cm) and 1616-C (43.78 cm), Salt Creek (41.65 cm) and 1616-C (39.70 cm). The lowest length of main root was recorded in SO4 (29.20 cm).

Effect of irrigation regimes

The length of main root was also significantly influenced by various levels of irrigations. Significantly maximum length of main root was recorded with scheduling of irrigation at 0.3 bar (54.00 cm) i.e. at field capacity which was followed by 0.5 bar (42.49 cm). The lowest length of main root was recorded with scheduling of irrigation at 0.7 bar (34.03 cm).

Effect of interaction

The interaction effect between irrigation regimes and different grape rootstocks was also significant. Among the different levels of irrigations the maximum length of main root was observed by 1103-P (61.33 cm) with irrigation scheduling at 0.3 bar. The 1103-P also attained

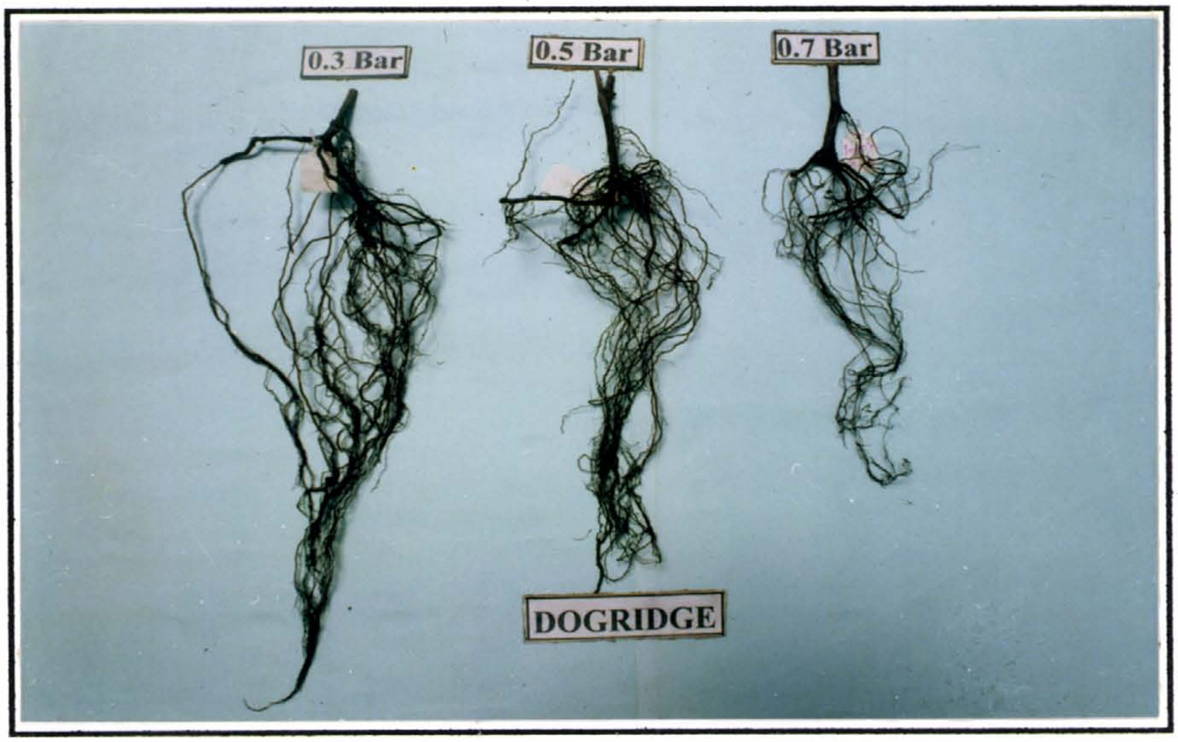


Plate 3. Relative water stress tolerance based on irrigation regimes on roots of Dogridge.

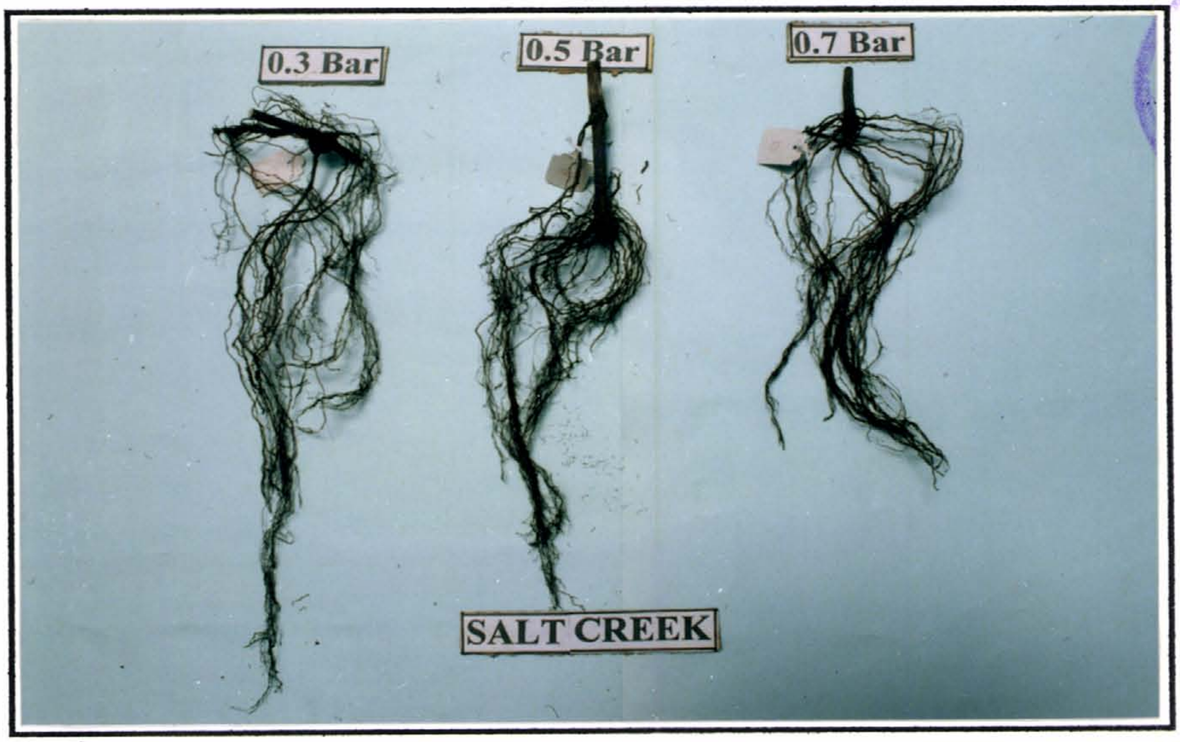


Plate 4. Relative water stress tolerance based on irrigation regimes on roots of Salt Creek.

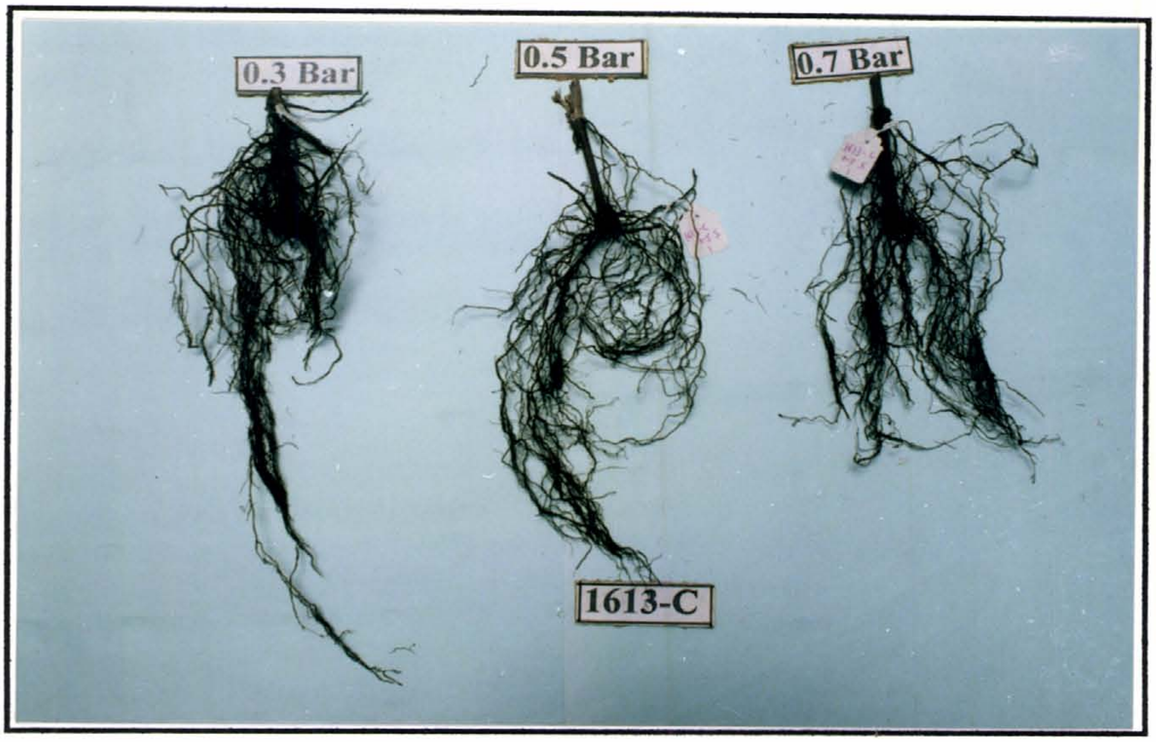


Plate 5. Relative water stress tolerance based on irrigation regimes on roots of 1613-C.

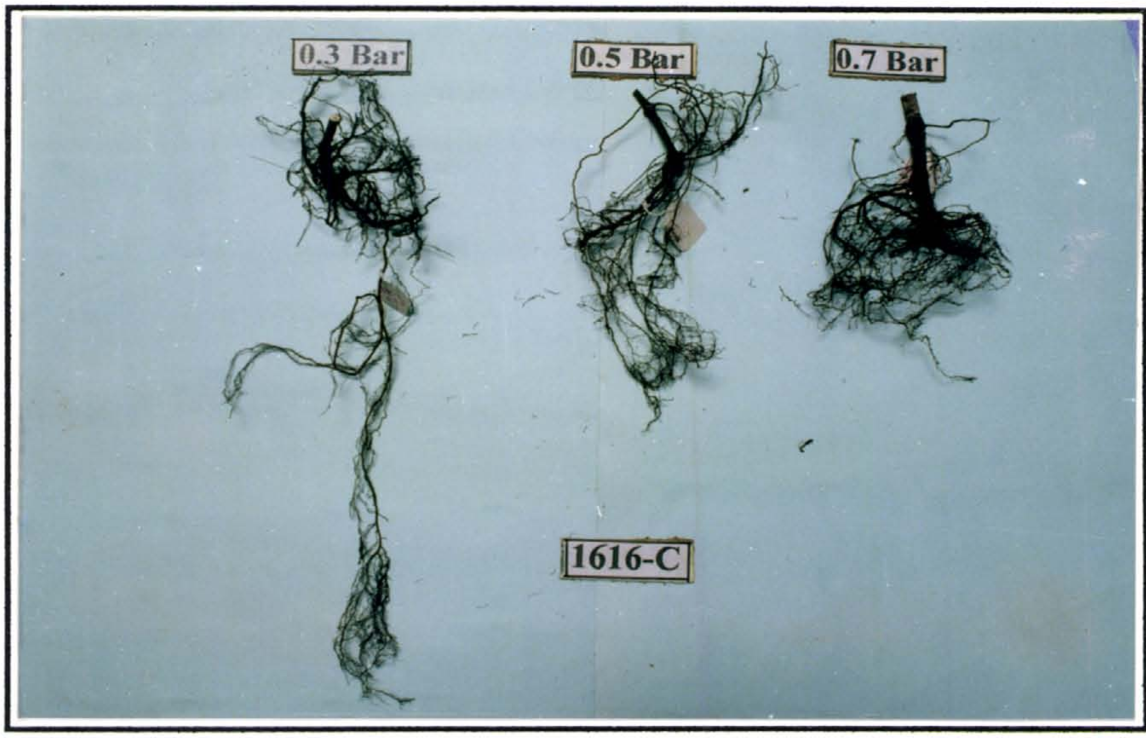


Plate 6. Relative water stress tolerance based on irrigation regimes on roots of 1616-C.

62C

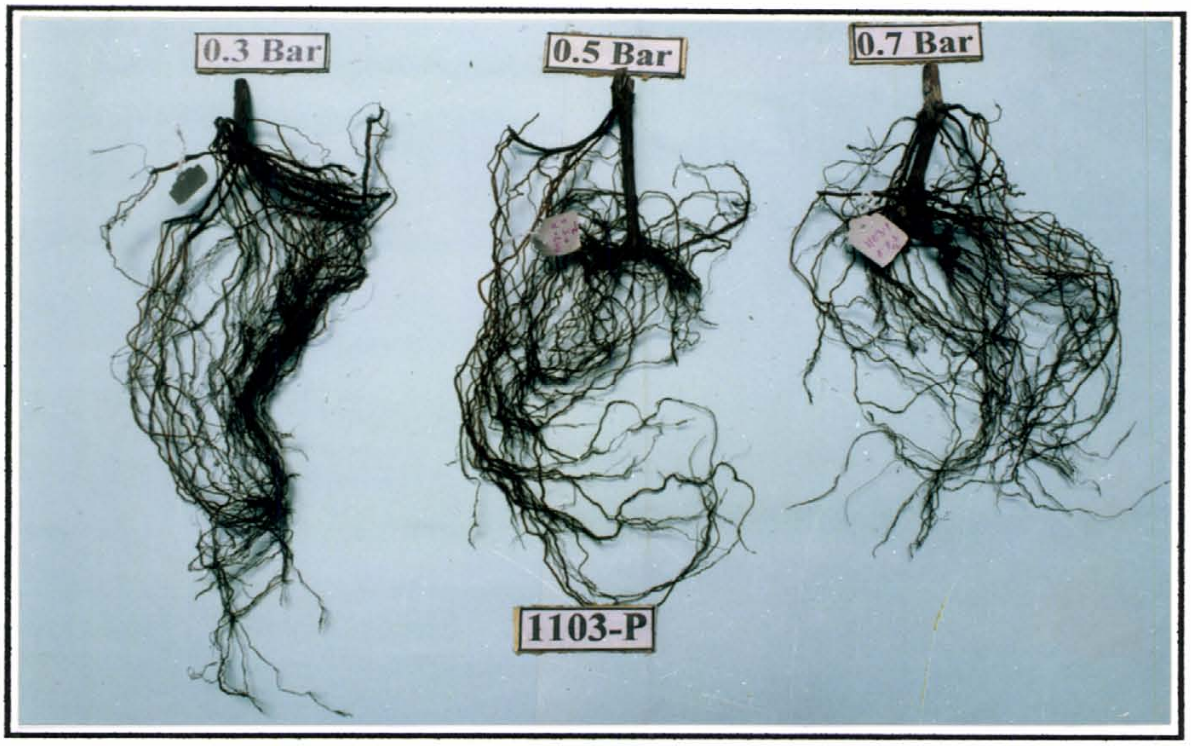


Plate 7. **Relative water stress tolerance based on irrigation regimes on roots of 1103-P.**

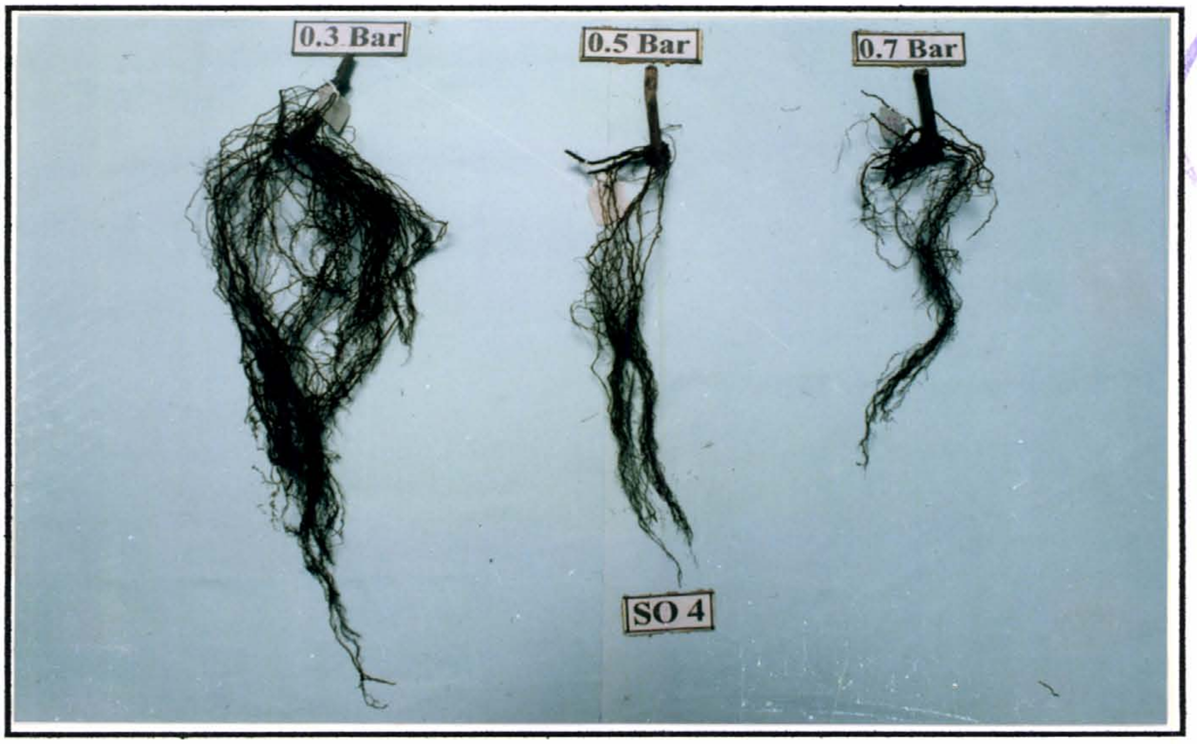


Plate 8. **Relative water stress tolerance based on irrigation regimes on roots of SO4.**

the highest length of main root with scheduling of irrigation at 0.5 bar (55.54 cm) and also at 0.7 bar (51.23 cm). The lowest length of main root was noticed by SO4 (15.79 cm). The minimum reduction in length of main root was recorded by 1103-P when scheduling of irrigation was done at 0.5 bar (9.43 %) and 0.7 bar (16.46 %) which was followed by Dogridge with scheduling of irrigations at 0.5 bar (13.76%) and at 0.7 bar (21.74 %) and Salt Creek with irrigation scheduling at 0.5 bar (20.34%) and at 0.7 bar (34.35%), respectively. Based on reduction percentage in length of main root it was indicated that 1103-P rootstock was found to be more drought tolerant then rest of the rootstocks except Dogridge and Salt Creek.

4.1.3b Effect of water stress on number of primary roots per vine

The data regarding the number of primary roots as influenced by various irrigation regimes are presented in Table 12 and graphically depicted in Fig.9.

Effect of rootstocks

The results showed that there was significant effect of different irrigation regimes of irrigation scheduling and various rootstocks on number of primary roots per vine. The maximum number of primary roots per vine was noticed by 1103-P (21.08) which was followed by Dogridge (19.75) and 1616-C (11.13). The number of primary roots per vine possessed by the rootstock 1613-C (16.13) which was at par with Salt Creek (15.50). The lowest number of primary roots per vine was observed by SO4 (9.21).

Table 12. Effect of water stress on number of primary roots of grapevine rootstocks

Rootstocks / Irrigation regimes (bar)	Number of primary roots per vine						Mean
	Dogridge	Salt Creek	1613-C	1616-C	1103-P	SO4	
0.3 bar	22.000	18.875	20.750	15.500	23.000	13.625	18.958
0.5 bar	19.625 (10.79)	15.250 (19.20)	15.750 (24.09)	10.750 (30.64)	20.875 (9.23)	9.000 (33.94)	15.208
0.7 bar	17.625 (19.88)	12.375 (34.43)	11.875 (42.77)	7.125 (54.03)	19.375 (15.76)	5.000 (63.30)	12.229
Mean	19.750	15.500	16.125	11.125	21.083	9.208	15.465

	S.E.±	C.D. at 5 %
Rootstocks (A)	0.250	0.744
Irrigation regimes (B)	0.177	0.526
Interaction (AB)	0.434	1.289

(Figures in parentheses indicate percentage reduction).

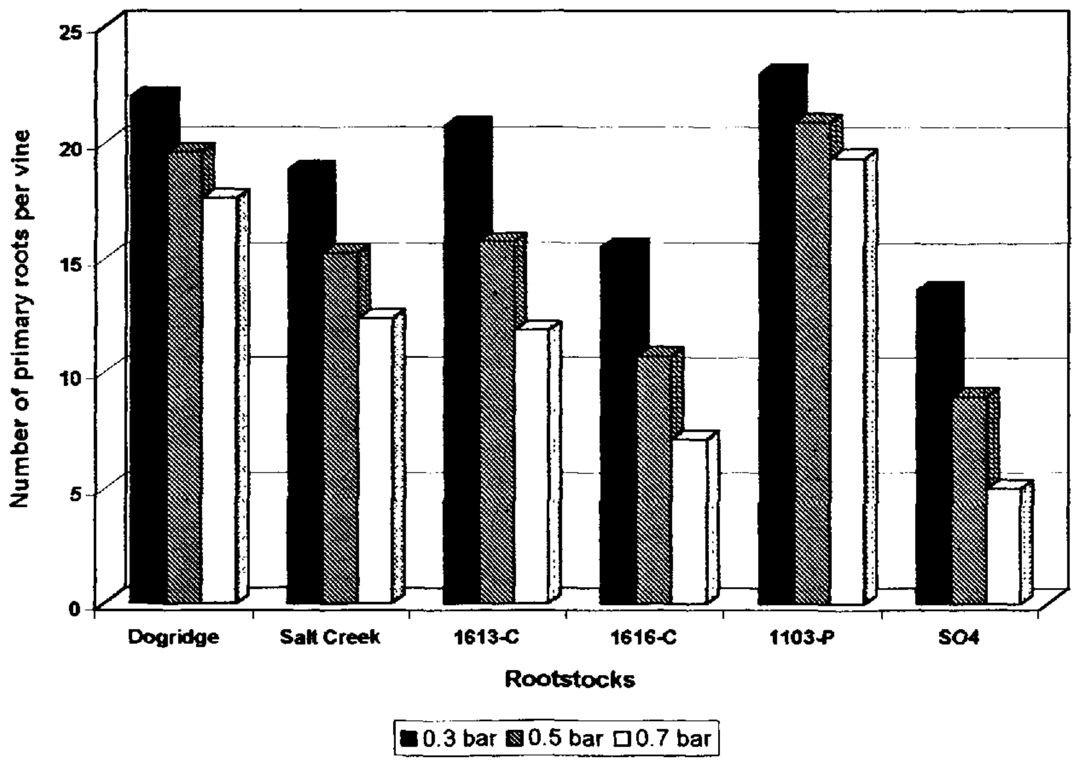


Fig. 9: Effect of water stress on number of primary roots of grapevine rootstocks

Effect of irrigation regimes

The number of primary roots per vine were also significantly influenced by various levels of irrigations. The maximum number of primary roots per vine were recorded when irrigation was scheduled at 0.3 bar (18.96) which was followed by 0.5 bar (15.21). As there was increase in the water stress the number of primary roots per vine were decreased. The minimum number of primary roots per vine were observed with scheduling of irrigation of 0.7 bar (12.23).

Effect of interaction

The interaction effect of irrigation regimes and different rootstocks were found to be significant. Among the different irrigation regimes the maximum number of primary roots were observed by 1103-P (23.00) however, it was at par with Dogridge (22.00) and 1613-C (20.75) with scheduling of irrigation at 0.3 bar. The maximum number of primary roots per vine were also recorded by 1103-P (20.88) however, it was at par with Dogridge (19.63) with scheduling of irrigation at 0.5 bar and 0.7 bar (19.38 and 17.63, respectively). The minimum number of primary roots were found by SO4 (5.0). The lowest reduction in number of primary roots per vine was recorded by 1103-P with irrigation level of 0.5 bar (9.23 %) and 0.7 bar (15.76 %) followed by Dogridge (10.79 % and 19.88 %, respectively) and Salt Creek (19.20% and 34.43 %, respectively). On the basis of reduction in percentage of number of leaves per vine was observed by 1103-P, it was indicated that 1103-P rootstocks was relatively more drought tolerant.

4.1.3c Effect of water stress on number of secondary roots per vine

The results on number of secondary roots as influenced by different levels of irrigations on various rootstocks are presented in Table13 and graphically depicted in Fig. 10.

Effect of rootstocks

The data revealed that there was significant effect of different levels of irrigation schedules and various rootstocks on number of secondary roots per vine. Among the different rootstocks of grapes, the maximum number of secondary roots per vine were recorded in 1103-P (36.83) followed by Dogridge (32.67), Salt Creek (26.71) however, it was at par with 1613-C (26.33) and 1616-C (21.58). The lowest number of secondary roots per vine was observed by SO4 (14.71).

Effect of irrigation regimes

The number of secondary roots per vine were also significantly influenced by various irrigation regimes. The vines receiving irrigation level of 0.3 bar i.e. at field capacity recorded significantly maximum number of secondary roots per vine (32.83) followed by when scheduling of irrigation at 0.5 bar (25.79). The number of secondary roots per vine were decreased with increase in water stress. The lowest number of secondary root per vine were recorded with scheduling of irrigation at 0.7 bar (20.79).

Table 13. Effect of water stress on number of secondary roots of grapevine rootstocks

Rootstocks / Irrigation regimes (bar)	Number of secondary roots per vine						Mean
	Dogridge	Salt Creek	1613-C	1616-C	1103-P	SO4	
0.3 bar	37.000	32.750	34.000	31.500	40.125	21.625	32.833
0.5 bar	32.250 (12.83)	26.250 (19.84)	25.625 (24.63)	19.875 (36.90)	36.500 (9.03)	14.250 (34.10)	25.792
0.7 bar	28.750 (22.29)	21.125 (35.49)	19.375 (43.01)	13.375 (57.53)	33.875 (15.57)	8.250 (61.84)	20.792
Mean	32.667	26.708	26.333	21.583	36.833	14.708	26.472

	S.E.±	C.D. at 5 %
Rootstocks (A)	0.446	1.325
Irrigation regimes (B)	0.315	0.936
Interaction (AB)	0.772	2.295

(Figures in parentheses indicate percentage reduction).

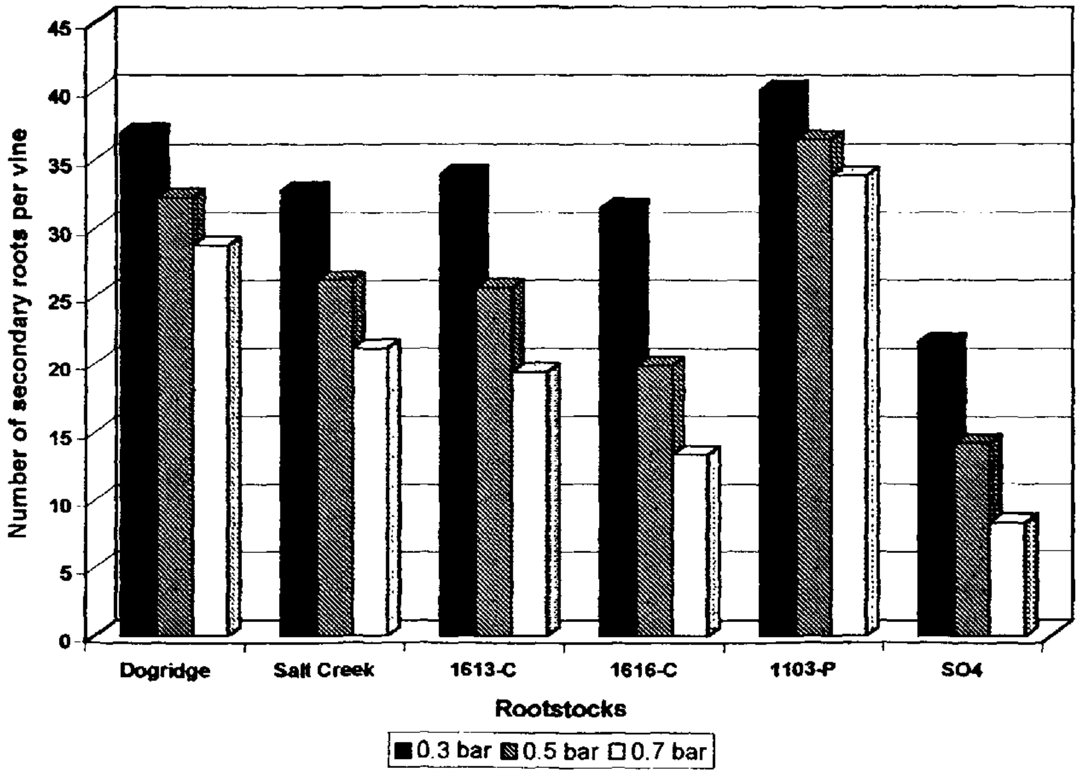


Fig. 10: Effect of water stress on number of secondary roots of grapevine rootstocks

Effect of interaction

The interaction effect between irrigation regimes and different grape rootstocks were significant. Among the various levels of irrigations, the maximum number of primary roots per vine were observed by 1103-P (40.13) with scheduling of irrigation at 0.3 bar. The maximum number of secondary roots per vine with the scheduling of irrigation at 0.5 bar (36.50) and 0.7 bar (33.88) were also recorded by 1103-P. The lowest number of secondary roots per vine were recorded by SO4 (8.25) with scheduling of irrigation at 0.7 bar. The minimum percentage reduction in number of secondary roots per vine was noticed by 1103-P when scheduling of irrigation was done at 0.5 bar (9.03 %) and 0.7 bar (15.57%) which was followed by Dogridge (12.83 % and 22.29 %, respectively) and Salt Creek (19.84 % and 35.49 %, respectively). On the basis of reduction percentage in number of secondary roots per vine it was indicated that 1103-P rootstock was found to be more tolerant to water stress followed by Dogridge and Salt Creek.

4.1.4 Effect of water stress on days to appearance of stress

4.1.4a Effect of water stress on leaf rolling

4.1.4a_1 Effect of water stress on days to 50 per cent leaf rolling

The data pertaining to the days to fifty per cent leaf rolling as influenced by various levels of irrigation are presented in Table 14 and graphically depicted in Fig.11.

Table 14. Effect of water stress on days to 50 per cent leaf rolling of grapevine rootstocks

Rootstocks / Irrigation regimes (bar)	Days to 50 per cent leaf rolling						Mean
	Dogridge	Salt Creek	1613-C	1616-C	1103-P	SO4	
0.3 bar	35.125	32.375	30.125	26.250	40.750	23.500	31.354
0.5 bar	32.000 (8.89)	28.875 (10.81)	26.375 (12.44)	21.875 (16.66)	37.625 (7.66)	19.250 (18.08)	27.667
0.7 bar	29.000 (17.43)	25.875 (20.07)	23.125 (23.23)	18.000 (31.42)	35.000 (14.11)	15.250 (35.10)	24.375
Mean	32.042	29.042	26.542	22.042	37.792	19.333	27.799

	S.E.±	C.D. at 5 %
Rootstocks (A)	0.141	0.419
Irrigation regimes (B)	0.099	0.296
Interaction (AB)	0.244	0.726

(Figures in parentheses indicate percentage reduction).

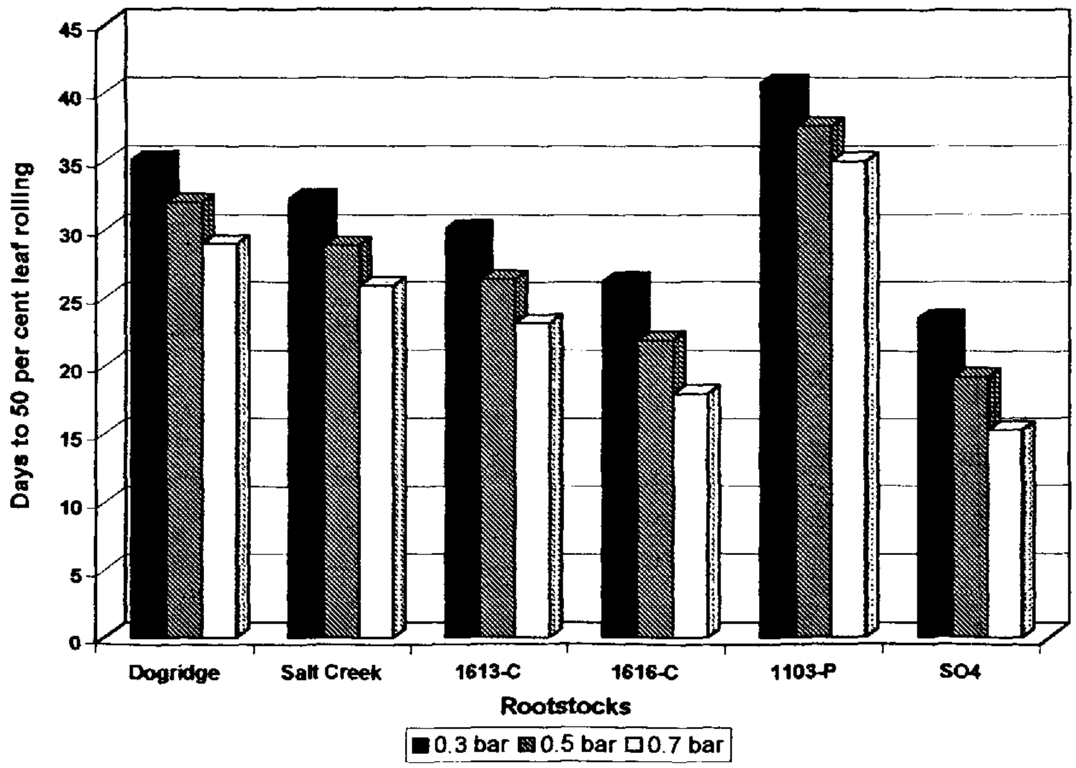


Fig. 11: Effect of water stress on days to 50 per cent leaf rolling of grapevine rootstocks

Effect of rootstocks

The results showed that there was significant effect of different irrigation regimes of irrigation scheduling and various rootstocks on days to 50 per cent leaf rolling. Among the rootstocks of grapes the maximum days required to 50 per cent rolling were noticed by 1103-P (37.79) followed by Dogridge (32.04), Salt Creek (29.04), 1613-C (26.54) and 1616-C (22.04). The minimum days required for 50 per cent leaf rolling were observed by SO4 (19.33).

Effect of irrigation regimes

The interaction between days to 50 per cent leaf rolling and various levels of irrigation was also significant. The maximum days required for 50 per cent leaf rolling were recorded when irrigation was scheduled at 0.3 bar (31.35) which was followed by 0.5 bar (27.67). As there was increase in the water stress the days required for 50 per cent leaf rolling was decreased. The minimum days required for 50 per cent leaf rolling were observed with scheduling of irrigation at 0.7 bar (24.38).

Effect of interaction

The interaction effect between different rootstocks and irrigation regimes was also significant. Among the various irrigation regimes the maximum days required to 50 per cent leaf rolling were observed by 1103-P (40.75) with scheduling of irrigation at 0.3 bar whereas 1103-P had also observed the maximum days required to 50 per cent leaf rolling (37.63 days) with scheduling of irrigation at 0.5 bar (37.63) at 0.7 bar (35.00). The minimum days required for 50 per cent leaf rolling were found by SO4 (15.25). The lowest reduction in days required for 50 per cent leaf rolling were recorded by 1103-P with irrigation level at 0.5 bar (7.66 %) and 0.7 bar (14.11 %), respectively which was followed by Dogridge (8.89 % and 17.43 %, respectively) and Salt Creek (10.81 % and 20.07 %, respectively). In view of above result the reduction percentage in respect of days required for 50 per cent leaf rolling was recorded by 1103-P. It was indicated that 1103-P more water stress tolerant followed by Dogridge and Salt Creek.

4.1.4a$_2$ Effect of water stress on days to 100 per cent leaf rolling

The relevant data on the days required to 100 percent leaf rolling affected by different irrigation regimes are presented in Table 15 and graphically shown in Fig. 12.

Effect of rootstocks

The data revealed that there was significant effect of different levels of irrigations regimes and various rootstocks on days to 100 per cent leaf rolling. In all the rootstocks the maximum days required for 100 per cent leaf rolling were observed by 1103-P (52.33) followed by Dogridge (42.08), Salt Creek (37.92), 1613-C (34.38) and 1616-C (28.54). The minimum days required to 100 per cent leaf rolling were recorded by SO4 (23.83).

Effect of irrigation regimes

The days required to 100 per cent leaf rolling were also significantly influenced by various irrigation regimes. The rootstocks were applied irrigation at 0.3 bar i.e. at field capacity recorded significantly

Table 15. Effect of water stress on days to 100 per cent leaf rolling of grapevine rootstocks

Rootstocks / Irrigation regimes (bar)	Dogridge	Salt Creek	1613-C	1616-C	1103-P	SO4	Mean
0.3 bar	45.750	42.125	39.125	34.125	55.875	29.375	41.063
0.5 bar	41.875 (8.46)	37.750 (10.38)	34.125 (12.77)	28.375 (16.84)	52.000 (6.93)	23.750 (19.14)	36.313
0.7 bar	38.625 (15.57)	33.875 (19.58)	29.875 (23.64)	23.125 (32.23)	49.125 (12.08)	18.375 (37.44)	32.167
Mean	42.083	37.917	34.375	28.542	52.333	23.833	36.514

	S.E.±	C.D. at 5 %
Rootstocks (A)	0.190	0.567
Irrigation regimes (B)	0.135	0.400
Interaction (AB)	0.330	0.982

(Figures in parentheses indicate percentage reduction).

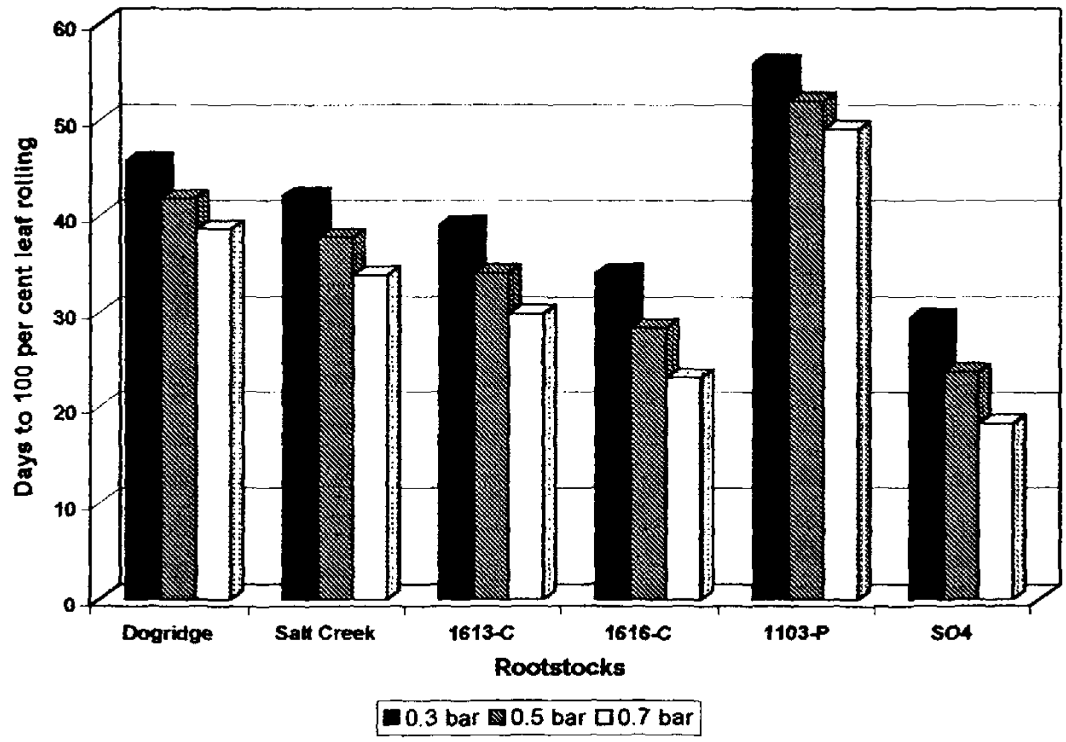


Fig. 12: Effect of water stress on days to 100 per cent leaf rolling of grapevine rootstocks

maximum days to 100 per cent leaf rolling (41.06). The days to 100 per cent leaf rolling were observed with increase in water stress. For 100 per cent rolling required 36.31 days at scheduling of irrigation at 0.5 bar while minimum days required to 100 per cent leaf rolling were recorded during scheduling of irrigation at 0.7 bar (32.17).

Effect of interaction

The interaction effect between irrigation regimes and different grape rootstocks was also significant. Among the different irrigation regimes the maximum days required to 100 per cent leaf rolling were observed by 1103-P (55.88) with scheduling of irrigation at 0.3 bar. Whereas, the scheduling of irrigation at 0.5 and 0.7 bar required 52.00 and 49.13 days, respectively. The minimum days required to 100 per cent leaf rolling were observed by SO4 (18.38). The lowest percentage reduction was recorded by 1103-P with scheduling of irrigation at 0.5 bar (6.93 %) and 0.7 bar (12.08 %) which was followed by Dogridge (8.46 % and 15.57 %, respectively) and Salt Creek (10.38 % and 19.58 %, respectively). On the basis of the reduction percentage in days required to 100 per cent leaf rolling, 1103-P was found to be more drought tolerant followed by Dogridge and Salt Creek.

4.14b Effect of water stress on leaf shrivelling

4.1.4b$_1$ Effect of water stress on days for initiation of leaf shrivelling

The effect of irrigation regimes on days for initiation of leaf shrivelling of different rootstocks are presented in Table 16 and graphically depicted in Fig. 13.

Table 16. Effect of water stress on days for initiation of leaf shrivelling of grapevine rootstocks

Rootstocks / Irrigation regimes (bar)	Days for initiation of leaf shrivelling						Mean
	Dogridge	Salt Creek	1613-C	1616-C	1103-P	SO4	
0.3 bar	30.125	26.375	24.125	20.250	35.000	18.500	25.729
0.5 bar	27.375 (9.12)	23.250 (11.84)	20.750 (13.98)	16.750 (17.28)	32.625 (6.78)	14.875 (19.59)	22.604
0.7 bar	24.875 (17.42)	20.875 (20.85)	18.250 (24.35)	13.750 (32.09)	30.375 (13.21)	11.625 (37.16)	19.958
Mean	27.458	23.500	21.042	16.917	32.667	15.000	22.764

	S.E.±	C.D. at 5 %
Rootstocks (A)	0.133	0.397
Irrigation regimes (B)	0.094	0.281
Interaction (AB)	0.231	0.688

(Figures in parentheses indicate percentage reduction).

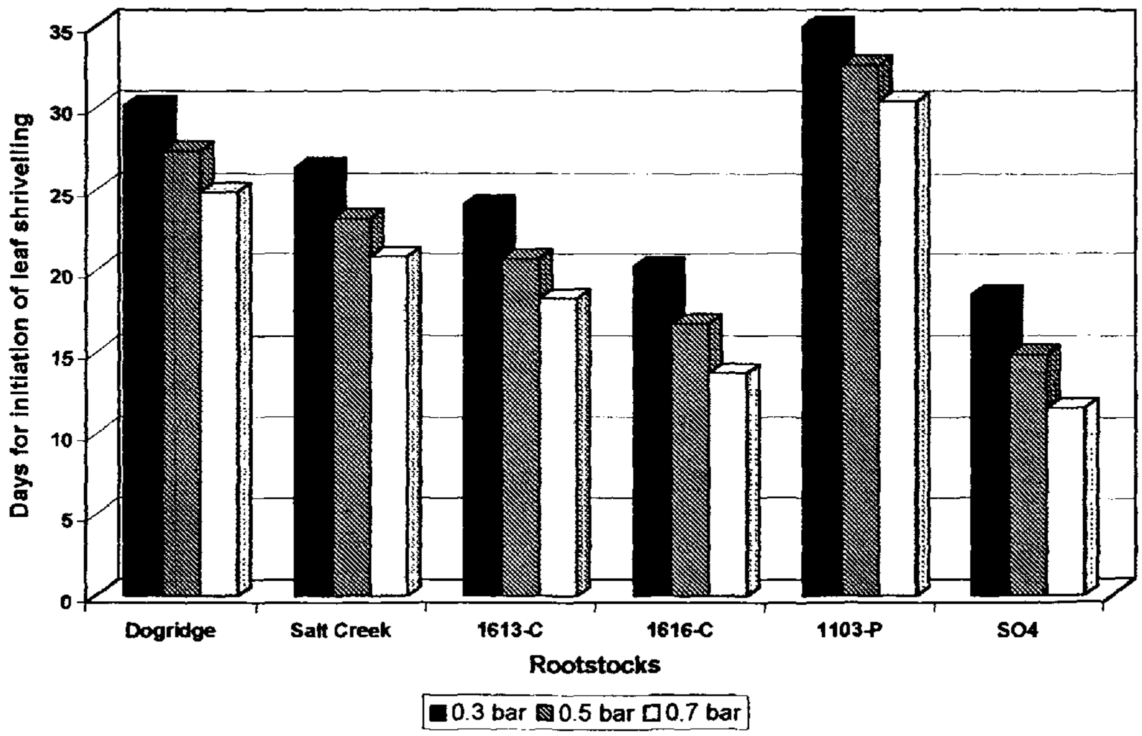


Fig. 13: Effect of water stress on days for initiation of leaf shrivelling of grapevine rootstocks

Effect of rootstocks

The data revealed that there was significant effect of different levels of irrigation regimes and various rootstocks on days for initiation of leaf shrivelling. Among the different rootstocks of grapes the maximum days required for initiation of leaf shrivelling were noticed by 1103-P (32.67) which was followed by Dogridge (27.46), Salt Creek (23.50), 1613-C (21.04) and 1616-C (16.92). The minimum days for initiation of leaf shrivelling were noticed by SO4 (15.00).

Effect of irrigation regimes

The days for initiation of leaf shrivelling was also significantly influenced by various levels of irrigations. Significantly maximum days for initiation of leaf shrivelling were recorded with scheduling of irrigation at 0.3 bar (25.73) i.e. at field capacity which was followed by 0.5 bar (22.60), whereas minimum days for initiation of leaf shrivelling were recorded with scheduling of irrigation at 0.7 bar (19.96).

Effect of interaction

The interaction effect between irrigation regimes and different grape rootstocks was also significant. Among the different levels of irrigations the maximum days for initiation of leaf shrivelling were observed 1103-P (35.00) with scheduling of irrigation at 0.3 bar whereas in the scheduling of irrigation at 0.5 bar and 0.7 bar 1103-P was also recorded the maximum days. i.e. 32.63 and 30.38 days for initiation of leaf shrivelling. The minimum days for initiation of leaf shrivelling were observed by SO4 (11.63). The minimum reduction i.e. 6.78 per cent and

13.21 per cent in days for initiation of leaf shrivelling were recorded by 1103-P when scheduling of irrigation was done at 0.5 bar and 0.7 bar, respectively; it was followed by Dogridge (9.12 % and 17.42 %, respectively) and Salt Creek (11.84 % and 20.85%, respectively). Based on reduction percentage in days for initiation of leaf shrivelling it was indicated that 1103-P rootstock was found to be more tolerant to water stress followed by Dogridge and Salt Creek.

4.1.4b_2 Effect of water stress on days to greater than 50 per cent leaf shrivelling

The data in respect of days to greater than 50 per cent leaf shrivelling as influenced by various irrigation regimes are presented in Table 17 and graphically depicted in Fig. 14.

Effect of rootstocks

The results showed that there was significant effect of different irrigation regimes of irrigation scheduling and various rootstocks on days to greater than 50 per cent leaf shrivelling. In all the rootstocks of grapes, the maximum days required to greater than 50 per cent leaf shrivelling were noticed by 1103-P (45.96) which was followed by Dogridge (37.42), Salt Creek (33.54), 1613-C (30.71) and 1616-C (25.08). The minimum days to greater than 50 per cent leaf shrivelling were observed by SO4 (22.29).

Table 17. Effect of water stress on days for initiation > 50 per cent leaf shrivelling of grapevine rootstocks

Rootstocks / Irrigation regimes (bar)	Days for initiation of > 50 per cent leaf shrivelling						Mean
	Dogridge	Salt Creek	1613-C	1616-C	1103-P	SO4	
0.3 bar	41.000	37.500	35.250	30.125	49.250	27.250	36.729
0.5 bar	37.250 (9.14)	33.250 (11.33)	30.375 (13.82)	25.000 (17.01)	45.875 (6.85)	22.125 (18.80)	32.313
0.7 bar	34.000 (17.07)	29.875 (20.33)	26.500 (24.82)	20.125 (33.19)	42.750 (13.19)	17.500 (35.77)	28.458
Mean	37.417	33.542	30.708	25.083	45.958	22.292	32.500

	S.E.±	C.D. at 5 %
Rootstocks (A)	0.125	0.371
Irrigation regimes (B)	0.088	0.262
Interaction (AB)	0.216	0.642

(Figures in parentheses indicate percentage reduction).

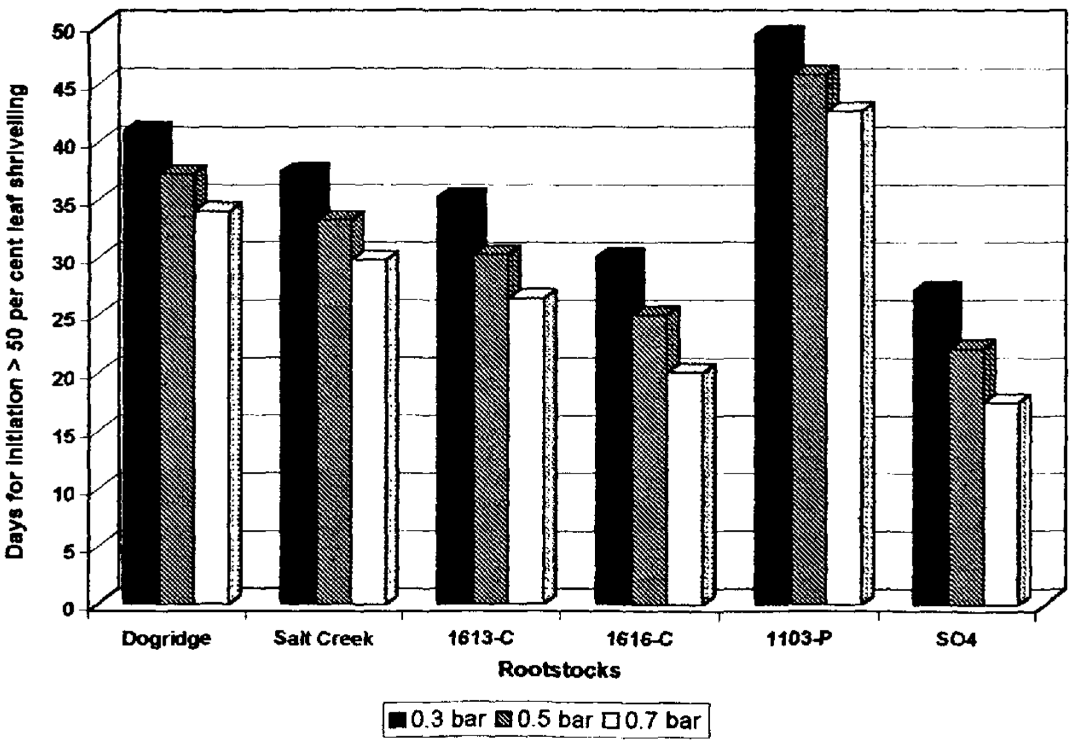


Fig. 14: Effect of water stress on days for initiation > 50 per cent leaf shrivelling of grapevine rootstocks

Effect of irrigation regimes

The days to greater than 50 per cent leaf shrivelling were also significantly influenced by various levels of irrigations. The maximum days to greater than 50 per cent leaf shrivelling were recorded when irrigation was scheduled at 0.3 bar (36.73) which was followed by 0.5 bar (32.31). As there was increase in the water stress the days to greater than 50 per cent leaf shrivelling were decreased. The minimum days to greater than 50 per cent leaf shrivelling were observed with scheduling of irrigation at 0.7 bar (28.46).

Effect of interaction

The interaction effect between different rootstocks and irrigation regimes was significant. Among the different irrigation regimes the maximum days to greater than 50 per cent leaf shrivelling were observed by 1103-P (49.25) with scheduling of irrigation at 0.3 bar. 1103-P had also noted the maximum days to greater than 50 per cent leaf shrivelling i.e. 45.88 and 42.75 days were observed with scheduling of irrigation at 0.5 bar and 0.7 bar, respectively. The minimum days to greater than 50 per cent leaf shrivelling were found by SO4 (17.50). The lowest reduction of 6.85 per cent and 13.19 per cent in days to greater than 50 per cent leaf shrivelling were also recorded by 1103-P with irrigation level at 0.5 and 0.7 bar, respectively which was followed by Dogridge (9.14 % and 17.07 %, respectively) and Salt Creek (11.33 % and 20.33 %, respectively. In view above result reduction percentage in days to greater than 50 per cent leaf shrivelling it was indicated that 1103-P was observed more drought tolerant followed by Dogridge and Salt Creek in comparison with 1616-C and SO4.

4.1.4c Effect of water stress on days to dryness of leaf

The data regarding the days to dryness of leaf as influenced by different irrigation regimes on various rootstocks are presented in Table 18 and graphically shown in Fig. 15.

Effect of rootstocks

The data revealed that there was significant influence of different levels of irrigation regimes and various rootstocks on days to dryness of leaf. Among the different rootstocks of grapes the maximum days to dryness of leaf was noticed in 1103-P (57.54) which was followed by Dogridge (45.42), Salt Creek (39.88), 1613-C (35.29) and 1616-C (29.42). The maximum days to dryness of leaf was recorded in SO4 (25.96).

Effect of irrigation regimes

The days to dryness of leaf was also significantly influenced by various levels of irrigation regimes. Significantly maximum days required to dryness of leaf were recorded with scheduling of irrigation at 0.3 bar (44.13) i.e. at field capacity which was followed by 0.5 bar (38.69) and minimum days to dryness of leaf was recorded with scheduling of irrigation at 0.7 bar (33.94).

Table 18. Effect of water stress on days to dryness of leaf of grapevine rootstocks

Rootstocks / Irrigation regimes (bar)	Days to dryness of leaf						Mean
	Dogridge	Salt Creek	1613-C	1616-C	1103-P	SO4	
0.3 bar	49.875	44.875	40.875	35.250	61.750	32.125	44.125
0.5 bar	45.250 (9.27)	39.625 (11.69)	35.125 (14.06)	29.000 (17.73)	57.375 (7.08)	25.750 (19.84)	38.688
0.7 bar	41.125 (17.54)	35.125 (21.72)	29.875 (26.91)	24.000 (31.91)	53.500 (13.36)	20.000 (37.74)	33.938
Mean	45.417	39.875	35.292	29.417	57.542	25.958	38.917

	S.E.±	C.D. at 5 %
Rootstocks (A)	0.168	0.500
Irrigation regimes (B)	0.119	0.353
Interaction (AB)	0.291	0.866

(Figures in parentheses indicate percentage reduction).

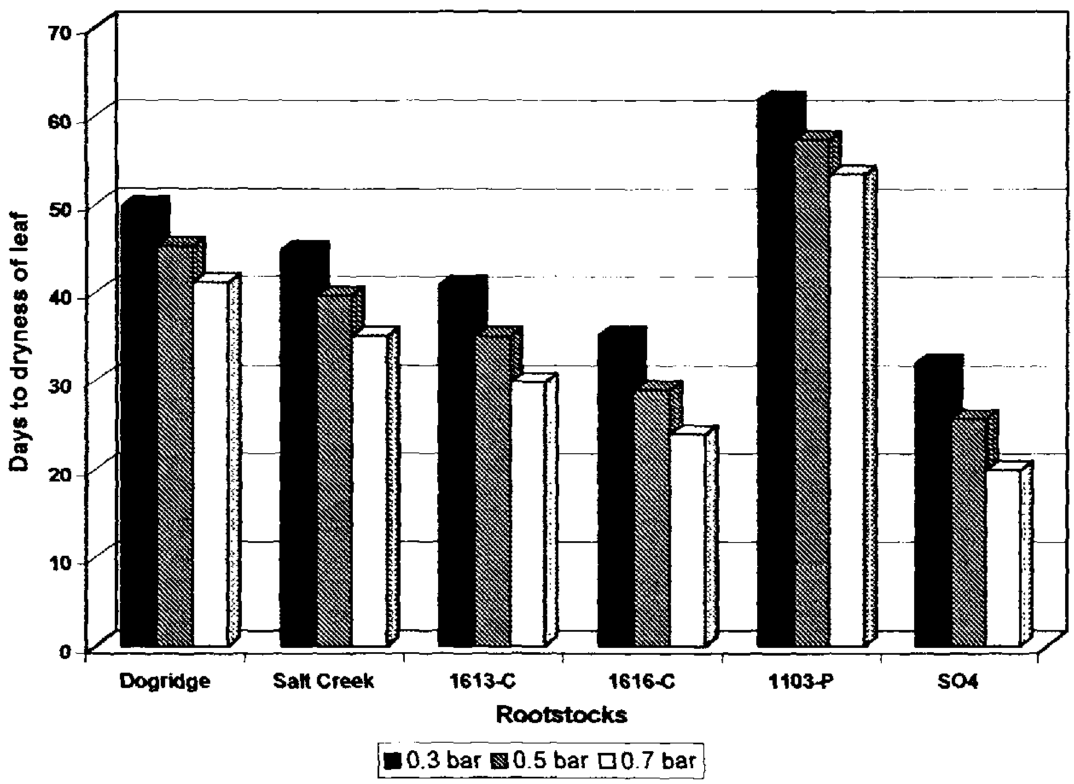


Fig. 15: Effect of water stress on days to dryness of leaf of grapevine rootstocks

Effect of interaction

The interaction effect between irrigation regimes and different grape rootstocks was also significant. Among the different levels of irrigations the maximum days to dryness of leaf was observed in 1103-P (61.75) with scheduling of irrigation at 0.3 bar 1103-P rootstock also attained the maximum days to dryness of leaf with scheduling of irrigation at 0.5 bar (57.38) and also at 0.7 bar (53.50). The minimum days to dryness of leaf was noticed in SO4 (20.00). The minimum reduction in days to dryness of leaf was recorded by 1103-P when scheduling of irrigation was done at 0.5 bar (7.08 %) and 0.7 bar (13.36 %) which was followed by Dogridge (9.27 % and 17.54 %, respectively) and Salt Creek (11.69 % and 21.72 %, respectively). Based on reduction percentage in days to dryness of leaf it was indicated that 1103-P rootstock was found to be more drought tolerant than rest of the rootstocks except Dogridge and Salt Creek.

4.2 Physiological parameters

4.2.1 Effect of water stress on relative leaf water content (%)

The results on relative leaf water content as influenced by different levels of irrigations on various rootstocks are presented in Table 19 and graphically depicted in Fig. 16.

Table 19. Effect of water stress on relative leaf water content of grapevine rootstocks

Rootstocks / Irrigation regimes (bar)	Relative leaf water content (%)						Mean
	Dogridge	Salt Creek	1613-C	1616-C	1103-P	SO4	
0.3 bar	82.333	80.283	73.068	78.300	84.527	74.298	78.801
0.5 bar	76.010 (7.67)	71.803 (10.56)	64.152 (12.20)	67.055 (14.36)	79.155 (6.35)	61.810 (16.80)	69.998
0.7 bar	71.398 (13.28)	66.888 (16.68)	56.910 (22.11)	*	75.343 (10.86)	*	45.090
Mean	76.580	72.991	64.710	48.452	79.675	45.369	64.629

	S.E.±	C.D. at 5 %
Rootstocks (A)	0.133	0.397
Irrigation regimes (B)	0.094	0.281
Interaction (AB)	0.231	0.688

(Figures in parentheses indicate percentage reduction).
* Sample was not available.

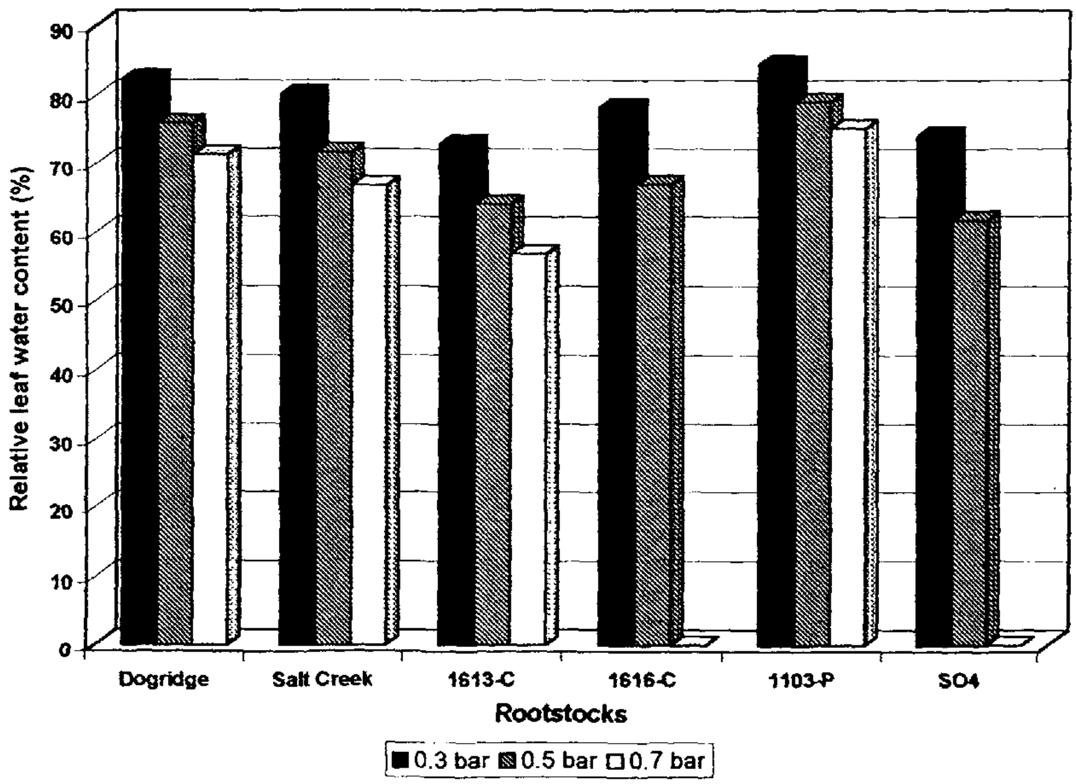


Fig. 16: Effect of water stress on relative leaf water content of grapevine rootstocks

Effect of rootstocks

The data revealed that there was significant effect of different levels of irrigation schedules and various rootstocks on relative leaf water content. Among the different rootstocks of grapes under study the maximum relative leaf water content was recorded by 1103-P (79.68 %) followed by Dogridge (76.58 %), Salt Creek (72.99 %), 1613-C (64.71 %) and 1616-C (48.45 %). The lowest relative leaf water content was observed by SO4 (45.37 %).

Effect of irrigation regimes

The relative leaf water content was also significantly influenced by various irrigation regimes. The vines receiving irrigation level of 0.3 bar i.e. at field capacity recorded significantly maximum relative leaf water content (78.80 %) followed by scheduling of irrigation at 0.5 bar (70.00 %), relative leaf water content was decreased with increase in water stress. The lowest relative leaf water content was recorded with scheduling of irrigation at 0.7 bar (45.09 %).

Effect of interaction

The interaction effect between irrigation regimes and different grape rootstocks was significant. Among the different levels of irrigations, the maximum relative leaf water content was observed by 1103-P (84.53%) with scheduling of irrigation at 0.3 bar. The maximum relative leaf water content i.e. 79.15 per cent and 75.34 per cent was also recorded by 1103-P with the scheduling of irrigation at 0.5 bar and 0.7 bar, respectively. The minimum relative leaf water content was recorded by SO4 (61.81 %) with scheduling of irrigation at 0.5 bar while the 1616-C and SO4 could not stand to the irrigation at 0.7 bar. The minimum reduction in relative leaf water content i.e. 6.35 per cent and 10.86 per cent was noticed by 1103-P when scheduling of irrigation was done at 0.5 bar and 0.7 bar, respectively which was followed by Dogridge (7.67 % and 13.28 %, respectively) and Salt Creek (10.56 % and 16.68 %, respectively). Based on reduction percentage in respect of relative leaf water content it was indicated that 1103-P rootstock was found to be more drought tolerant than 1616-C and SO4 except Dogridge and Salt Creek.

4.2.2 Effect of water stress on fresh weight of shoot (g)

The data pertaining to the fresh weight of shoot as influenced by various levels of irrigations are presented in Table 20 and graphically depicted in Fig. 17.

Effect of rootstocks

The results showed that there was significant effect of different irrigation regimes of irrigation scheduling and various rootstocks on fresh weight of shoot. The rootstocks of grapes under study the maximum fresh weight of shoot was noticed by 1103-P (39.71 g) followed by Dogridge (36.20g), Salt Creek (32.69g), 1613-C (30.61g) and 1616-C (29.09g). The lowest fresh weight of shoot was observed by SO4 (26.45g).

Table 20. Effect of water stress on fresh weight of shoot of grapevine rootstocks

Rootstocks / Irrigation regimes (bar)	Fresh weight of shoot per vine (g)						Mean
	Dogridge	Salt Creek	1613-C	1616-C	1103-P	SO4	
0.3 bar	40.089	37.073	35.448	36.536	42.115	34.115	37.562
0.5 bar	36.098 (9.95)	32.780 (11.57)	30.476 (14.02)	28.888 (20.93)	39.500 (6.20)	25.790 (24.40)	32.255
0.7 bar	32.420 (19.12)	28.224 (23.86)	25.908 (26.91)	21.850 (40.19)	37.516 (10.92)	19.455 (42.97)	27.562
Mean	36.202	32.692	30.610	29.091	39.710	26.453	32.460

	S.E.±	C.D. at 5 %
Rootstocks (A)	0.168	0.501
Irrigation regimes (B)	0.119	0.354
Interaction (AB)	0.292	0.868

(Figures in parentheses indicate percentage reduction).

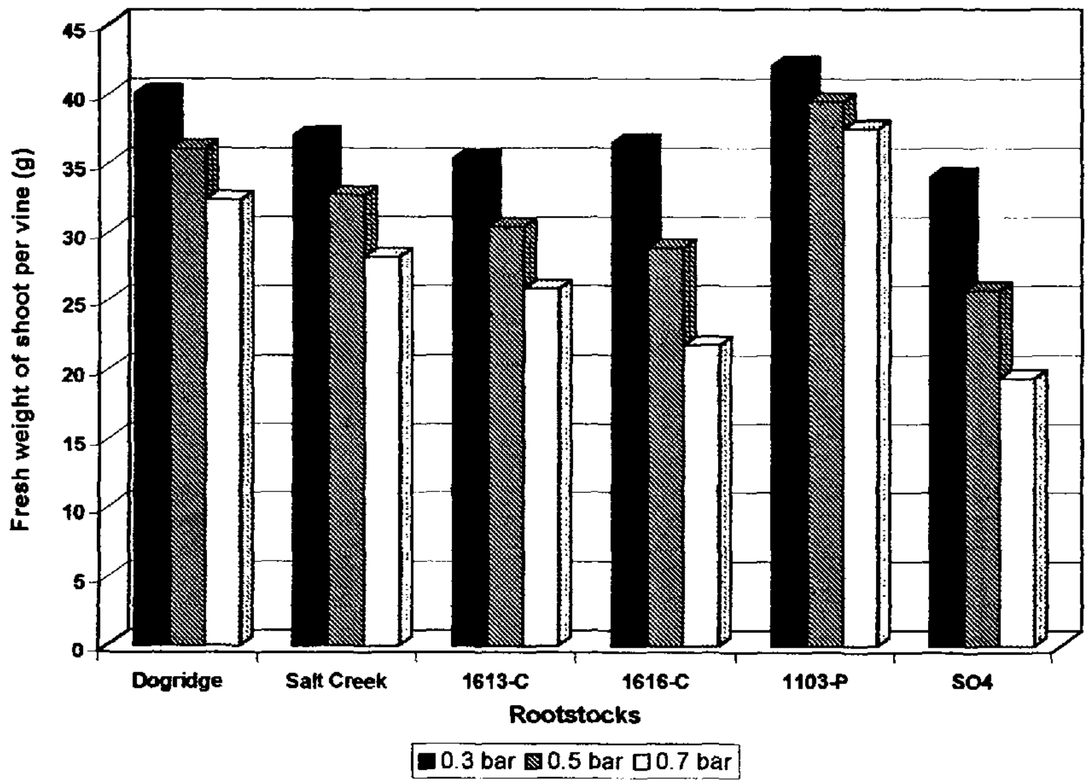


Fig. 17: Effect of water stress on fresh weight of shoot of grapevine rootstocks

Effect of irrigation regimes

The fresh weight of shoot was also significantly influenced by various levels of irrigations. The maximum fresh weight of shoot was recorded when irrigation was scheduled at 0.3 bar (37.56 g) which was followed by 0.5 bar (32.26g). As there was increase in water stress the fresh weight of shoot was decreased. The lowest fresh weight of shoot was observed with scheduling of irrigation at 0.7 bar (27.56 g).

Effect of interaction

The interaction effect between different rootstocks and irrigation regimes was significant. Among the different irrigation regimes the maximum fresh weight of shoot was observed by 1103-P (42.12 g) with scheduling of irrigation at 0.3 bar 1103-P also noted the maximum fresh weight of shoot i.e. 39.50g and 37.52 g scheduling of with irrigation at 0.5 bar and at 0.7 bar, respectively. The lowest fresh weight of shoot was recorded by SO4 (19.46 g). The minimum reduction in fresh weight of shoot was recorded in 1103-P with irrigation level at 0.5 bar (6.20 %) and 0.7 bar (10.92 %) followed by Dogridge (9.95% and 19.12 %, respectively) and Salt Creek (11.57 % and 23.86 %, respectively). In view of reduction percentage in fresh weight of shoot 1103-P was found to be better for water stress condition followed by Dogridge and Salt Creek.

4.2.3 Effect of water stress on fresh weight of root (g)

The relevant data on the weight of fresh root affected by different irrigation regimes are presented in Table 21 and graphically shown in Fig. 18.

Table 21. Effect of water stress on fresh weight of root of grapevine rootstocks

Rootstocks / Irrigation regimes (bar)	Fresh weight of root per vine (g)						Mean
	Dogridge	Salt Creek	1613-C	1616-C	1103-P	SO4	
0.3 bar	51.123	41.495	35.450	32.345	61.815	25.416	41.274
0.5 bar	43.619 (14.67)	34.287 (17.37)	28.120 (20.67)	23.118 (28.52)	55.281 (10.57)	17.627 (30.64)	33.675
0.7 bar	37.378 (26.88)	27.943 (32.65)	23.013 (35.08)	16.380 (49.35)	50.069 (19.00)	11.514 (54.69)	27.716
Mean	44.040	34.575	28.861	23.948	55.722	18.186	34.222

	S.E.±	C.D. at 5 %
Rootstocks (A)	0.120	0.359
Irrigation regimes (B)	0.085	0.253
Interaction (AB)	0.209	0.621

(Figures in parentheses indicate percentage reduction).

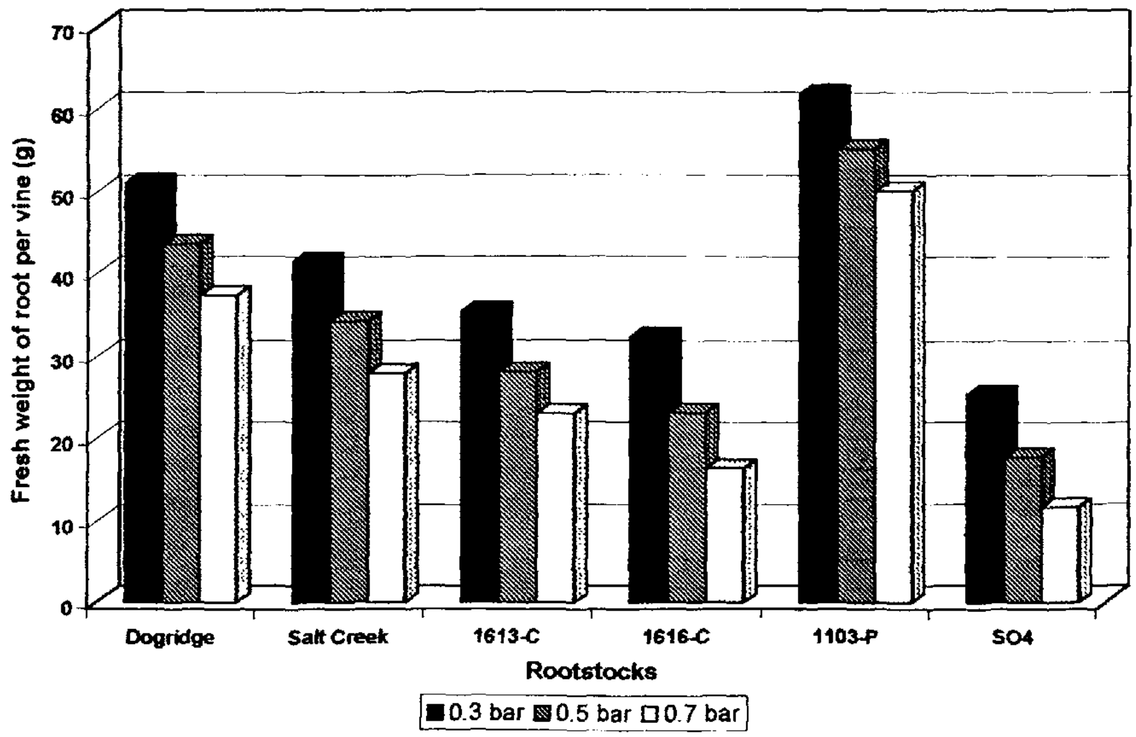


Fig. 18: Effect of water stress on fresh weight of root of grapevine rootstocks

Effect of rootstocks

The data revealed that there was significant effect of different levels of irrigation regimes and various rootstocks on weight of fresh root. The rootstocks under study, the maximum weight of fresh root was observed by 1103-P (55.72g) followed by Dogridge (44.04g), Salt Creek (34.58g), 1613-C (28.86g) and 1616-C (23.95g). The lowest weight of fresh root was recorded by SO4 (18.19g).

Effect of irrigation regimes

The weight of fresh root was also significantly influenced by various irrigation regimes. The rootstocks with scheduling of irrigation at 0.3 bar i.e. at field capacity recorded significantly maximum weight of fresh root (41.27g). The weight of fresh root was decreased with increase in water stress. The highest weight of fresh root was observed while scheduling of irrigation at 0.5 bar (33.68g) while minimum weight of fresh root was recorded during scheduling of irrigation at 0.7 bar (27.72g).

Effect of interaction

Significant interaction effect was observed between irrigation regimes and different grape rootstocks. Among the different irrigation regimes the maximum weight of fresh root was observed by 1103-P (61.82 g) with scheduling of irrigation at 0.3 bar whereas 55.28 g and 50.07 g weight of fresh root was recorded when scheduling of irrigation at 0.5 bar and 0.7 bar, respectively. The lowest weight of fresh root was observed by SO4 (11.51g). The lowest percentage reduction was recorded by 1103-P with scheduling of irrigation at 0.5 bar (10.57 %) and at 0.7 bar (19.00 %)

which was followed by Dogridge (14.67 % and 26.88 %, respectively) and Salt Creek (17.37 % and 32.65 %, respectively). On the basis of the reduction percentage in weight of fresh root, 1103-P can sustain under water stress situation followed by Dogridge and Salt Creek.

4.2.4 Effect of water stress on dry weight of shoot (g)

The effect of irrigation regimes on weight of dry shoot of different rootstocks are displayed in Table 22 and graphically depicted in Fig. 19.

Effect of rootstocks

The data revealed that there was significant effect of different levels of irrigation regimes and various rootstocks on weight of dry shoot. Among the different rootstocks of grapes in the investigation, the maximum weight of dry shoot was noticed by 1103-P (17.76g) which was followed by Dogridge (15.92g) and Salt Creek (14.26g). The rootstock 1613-C possess weight of dry root (13.27g) which was at par with 1616-C (13.08g). The minimum weight of dry shoot was noticed by SO4 (11.90g).

Effect of irrigation regimes

The weight of dry shoot was also significantly influenced by various levels of irrigations. Significantly maximum weight of dry shoot was recorded when irrigation was scheduled at 0.3 bar i.e. field capacity (16.97g) which was followed by 0.5 bar (14.23g), while minimum weight of dry shoot was recorded when irrigation was scheduled at 0.7 bar (11.90g).

Table 22. Effect of water stress on dry weight of shoot of grapevine rootstocks

Rootstocks / Irrigation regimes (bar)	Dry weight of shoot per vine (g)						Mean
	Dogridge	Salt Creek	1613-C	1616-C	1103-P	SO4	
0.3 bar	18.033	16.679	15.949	16.439	19.369	15.349	16.969
0.5 bar	15.880 (11.93)	14.175 (15.01)	13.148 (17.56)	12.991 (20.97)	17.668 (8.78)	11.494 (25.11)	14.226
0.7 bar	13.859 (23.14)	11.926 (28.49)	10.723 (32.76)	9.808 (40.33)	16.234 (16.18)	8.849 (42.34)	11.900
Mean	15.924	14.260	13.273	13.079	17.757	11.897	14.365

	S.E.±	C.D. at 5 %
Rootstocks (A)	0.074	0.220
Irrigation regimes (B)	0.052	0.155
Interaction (AB)	0.128	0.381

(Figures in parentheses indicate percentage reduction).

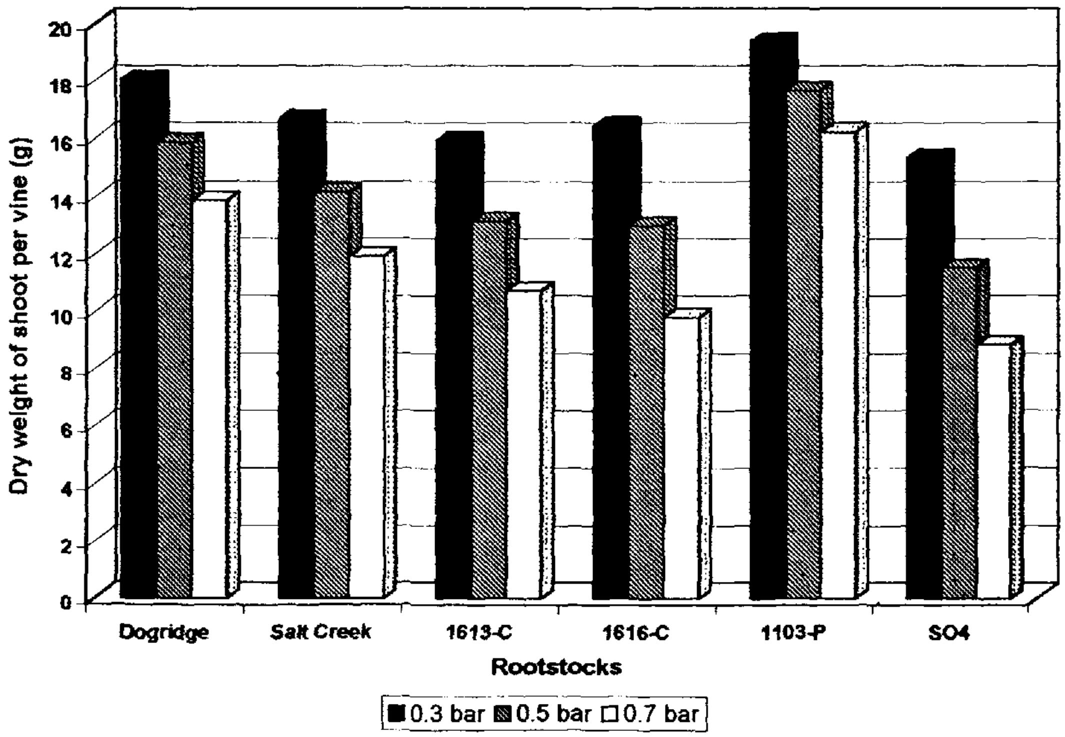


Fig. 19: Effect of water stress on dry weight of shoot of grapevine rootstocks

Effect of interaction

The interaction effect between irrigation regimes and different grape rootstocks was significant. In all the different levels of irrigations, the maximum weight of dry shoot was observed by 1103-P (19.37g) with scheduling of irrigation at 0.3 bar whereas in the scheduling of irrigation at 0.5 bar and 0.7 bar the same rootstock i.e. 1103-P was recorded the maximum weight of dry shoot i.e. 17.67 g and 16.23g, respectively. The lowest weight of dry shoot was observed by SO4 (8.85g). The minimum reduction in weight of dry shoot was recorded by 1103-P when scheduling of irrigation was done at 0.5 bar (8.78 %) and 0.7 bar (16.18 %) which was followed by Dogridge (11.93 % and 23.14 %, respectively) and Salt Creek (15.01 % and 28.49 %, respectively). Based on reduction percentage in weight of dry shoot it was indicated that 1103-P rootstock was found better for water stress condition followed by Dogridge and Salt Creek.

4.2.5 Effect of water stress on dry weight of root (g)

The data in respect of weight of dry root as influenced by various irrigation regimes are presented in Table 23 and graphically depicted in Fig. 20.

Effect of rootstocks

The results showed that there was significant effect of different irrigation regimes of irrigation scheduling and various rootstocks on weight of dry root .The rootstocks under investigation, the maximum weight of dry root was noticed by 1103-P (30.23g) which was followed by

Table 23. Effect of water stress on dry weight of root of grapevine rootstocks

Rootstocks / Irrigation regimes (bar)	Dry weight of root per vine (g)						Mean
	Dogridge	Salt Creek	1613-C	1616-C	1103-P	SO4	
0.3 bar	25.056	18.724	14.170	12.508	35.219	8.122	18.966
0.5 bar	20.574 (17.88)	14.981 (19.99)	11.009 (22.30)	9.080 (27.40)	29.863 (15.20)	5.731 (29.43)	15.206
0.7 bar	16.924 (32.45)	12.203 (34.82)	8.413 (40.62)	6.500 (48.03)	25.611 (27.28)	4.084 (49.71)	12.289
Mean	20.851	15.303	11.197	9.363	30.231	5.979	15.487

	S.E.±	C.D. at 5 %
Rootstocks (A)	0.052	0.155
Irrigation regimes (B)	0.037	0.110
Interaction (AB)	0.090	0.270

(Figures in parentheses indicate percentage reduction).

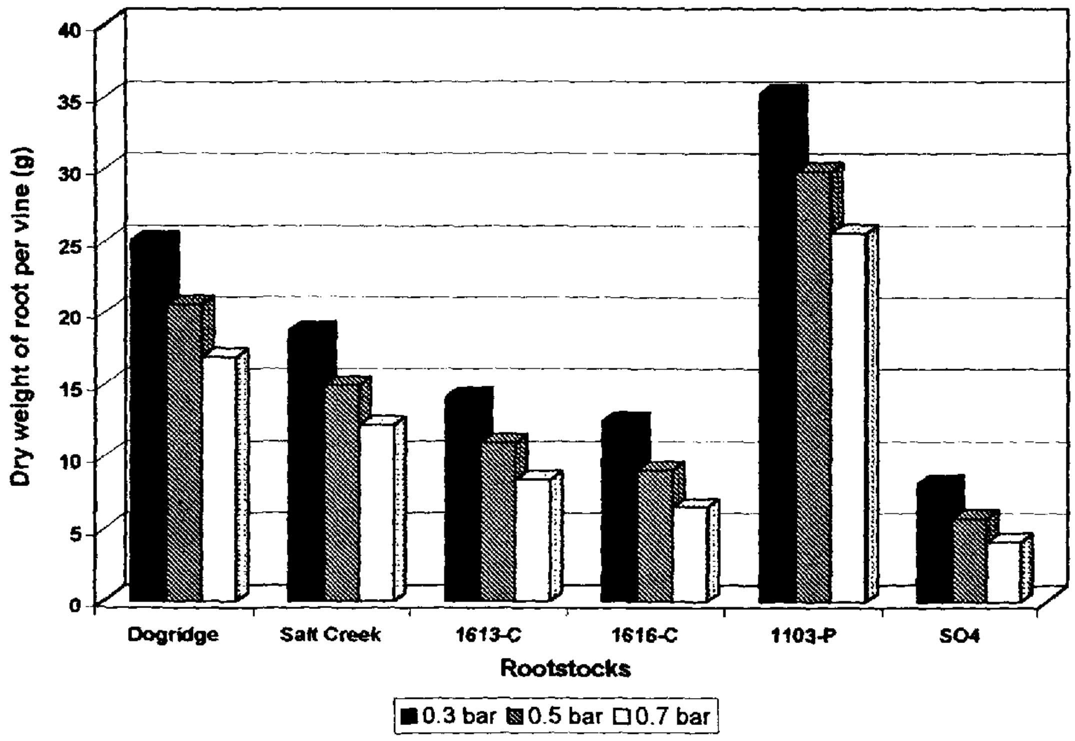


Fig. 20: Effect of water stress on dry weight of root of grapevine rootstocks

Dogridge (20.85g), Salt Creek (15.30g), 1613-C (11.20g) and 1616-C (9.36g). The minimum weight of dry root was observed by SO4 (5.98 g).

Effect of irrigation regimes

The weight of dry root was also significantly influenced by various levels of irrigations. The maximum weight of dry root was recorded when irrigation was scheduled at 0.3 bar (18.97g) which was followed by 0.5 bar (15.21g). It was indicated that there was increase in water stress the weight of dry root was decreased. The minimum weight of dry root (12.29g) was observed with scheduling of irrigation at 0.7 bar.

Effect of interaction

Effect of interaction between different rootstocks and irrigation regimes was also significant. Among the different irrigation regimes the maximum weight of dry root was observed in 1103-P (35.22g) with scheduling of irrigation at 0.3 bar whereas rootstock 1103-P also noted that the maximum weight of dry root i.e. 29.86 g and 25.61g with irrigation scheduling at 0.5 bar and 0.7 bar, respectively. The lowest weight of dry root was noticed by SO4 (4.08g) while considering the lowest reduction percentage in weight of dry root i.e. 15.20 per cent and 27.28 per cent was recorded by 1103-P with irrigation level at 0.5 bar and 0.7 bar, respectively which was followed by Dogridge (17.88% and 32.45 %, respectively) and Salt Creek (19.99 % and 34.82 %, respectively). Based on reduction percentage in dry weight of root 1103-P was found to be better for drought condition followed by Dogridge and Salt Creek.

4.2.6 Effect of water stress on root : *shoot ratio on* fresh weight basis

The data regarding root : shoot ratio on fresh weight basis as influenced by different irrigation regimes on various rootstocks are presented in Table 24 and graphically shown in Fig. 21.

Effect of rootstocks

The data revealed that there was significant effect of different levels of irrigation regimes and various rootstocks on root : shoot ratio based on fresh weight. The different rootstocks under study, the maximum root : shoot ratio on fresh weight basis was noticed in 1103-P (1.40) which was followed by Dogridge (1.21), Salt Creek (1.05), 1613-C (0.94) and 1616-C (0.81). The minimum root : shoot ratio on fresh weight basis was recorded by SO4 (0.67).

Effect of irrigation regimes

The root : shoot ratio on fresh weight basis was also significantly influenced by various levels of irrigations. Significantly maximum ratio on fresh weight basis was recorded with scheduling of irrigation at 0.3 bar (1.08) i.e. field capacity which was followed by 0.5 bar (1.01) whereas lowest ratio on fresh weight basis was recorded with scheduling of irrigation at 0.7 bar (0.95).

Effect of interaction

The interaction effect between irrigation regimes and different grape rootstocks was non significant.

Table 24. Effect of water stress on root : shoot ratio on fresh weight basis of grapevine rootstocks

Rootstocks / Irrigation regimes (bar)	Root : Shoot ratio on fresh weight basis						Mean
	Dogridge	Salt Creek	1613-C	1616-C	1103-P	SO4	
0.3 bar	1.277	1.119	1.000	0.885	1.468	0.745	1.082
0.5 bar	1.209	1.047	0.923	0.800	1.400	0.684	1.010
0.7 bar	1.154	0.990	0.888	0.749	1.335	0.577	0.949
Mean	1.213	1.052	0.937	0.812	1.401	0.669	1.014

	S.E.±	C.D. at 5 %
Rootstocks (A)	0.006	0.020
Irrigation regimes (B)	0.004	0.014
Interaction (AB)	0.011	N.S.

N.S. – Non significant

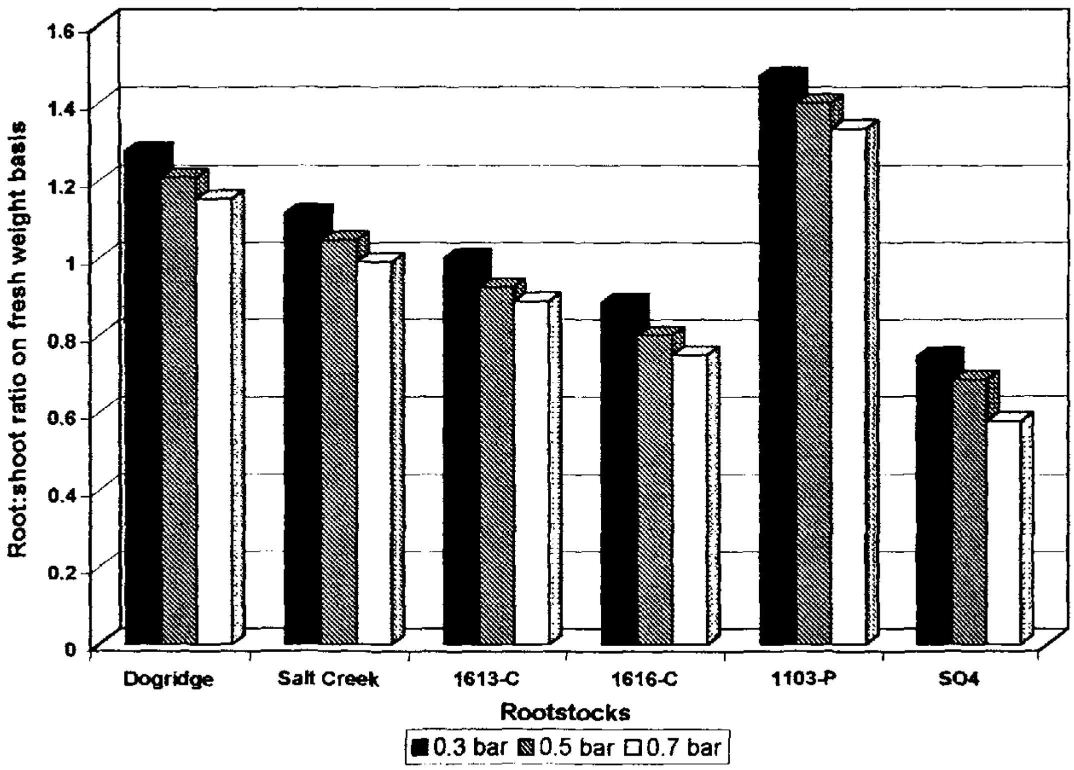


Fig. 21: Effect of water stress on root : shoot ratio on fresh weight basis of grapevine rootstocks

4.2.7 Effect of water stress on root : shoot ratio on dry weight basis

The results on root : shoot ratio on dry weight basis as influenced by different levels of irrigations on various rootstocks are presented in Table 25 and graphically depicted in Fig. 22.

Effect of rootstocks

The data revealed that there was significant effect of different levels of irrigation schedules and various rootstocks on root : shoot ratio based on dry weight. The different rootstocks of grapes under study, the maximum ratio based on dry weight was recorded in 1103-P (1.70) followed by Dogridge (1.30), Salt Creek (1.07), 1613-C (0.84) and 1616-C (0.71). The lowest ratio on dry weight basis was observed in SO4 (0.50).

Effect of irrigation regimes

The root : shoot ratio on dry weight basis also significantly influenced by various irrigation regimes. The vines receiving irrigation level of 0.3 bar i.e. at field capacity recorded significantly maximum ratio based on dry weight (1.09) followed by when scheduling of irrigation at 0.5 bar (1.01). The ratio on dry weight basis was decreased with increase in water stress. The lowest ratio based on dry weight was recorded with scheduling of irrigation at 0.7 bar (0.96).

Effect of interaction

The interaction effect between irrigation regimes and different grape rootstocks was also significant. Among the different levels of irrigations, the maximum root : shoot ratio based on dry weight was observed by 1103-P (1.82) with scheduling of irrigation at 0.3 bar whereas

Table 25. Effect of water stress on root : shoot ratio on dry weight basis of grapevine rootstocks

Rootstocks / Irrigation regimes (bar)	Root : shoot ratio on dry weight basis						Mean
	Dogridge	Salt Creek	1613-C	1616-C	1103-P	SO4	
0.3 bar	1.391	1.123	0.888	0.761	1.818	0.529	1.085
0.5 bar	1.297	1.058	0.840	0.699	1.691	0.499	1.014
0.7 bar	1.222	1.024	0.785	0.662	1.578	0.462	0.955
Mean	1.303	1.068	0.838	0.707	1.696	0.496	1.018

	S.E.±	C.D. at 5 %
Rootstocks (A)	0.007	0.020
Irrigation regimes (B)	0.004	0.014
Interaction (AB)	0.012	0.036

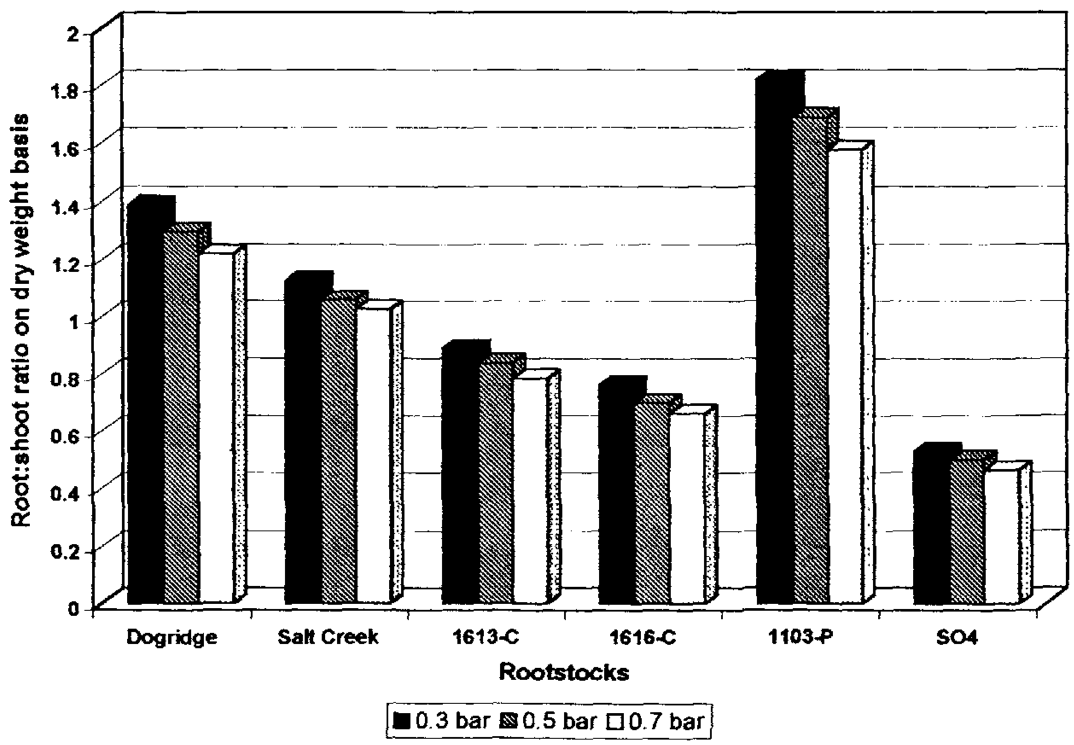


Fig. 22: Effect of water stress on root : shoot ratio on dry weight basis of grapevine rootstocks

in the same rootstock it was observed that the maximum ratio based on dry weight i.e. 1.69 and 1.58 with scheduling of irrigation at 0.5 bar and 0.7 bar, respectively. The minimum root : shoot ratio based on dry weight was recorded by SO4 (0.46) with scheduling of irrigation at 0.7 bar. Considering the above result the highest root : shoot ratio based on dry weight it was indicated that 1103-P rootstock was found more tolerant to water stress condition followed by Dogridge had 1.39, 1.30 and 1.22 ratio while scheduling of irrigation at 0.3 bar, 0.5 bar and 0.7 bar, respectively and Salt Creek had 1.12, 1.06 and 1.02 with scheduling of irrigation at 0.3 bar, 0.5 bar and 0.7 bar, respectively.

4.2.8 Effect of water stress on stomatal frequency per mm^2

The data pertaining to the stomatal frequency as influenced by various levels of irrigation are presented in Table 26 and graphically depicted in Fig. 23.

Effect of rootstocks

The results revealed that there was significant effect of different irrigation regimes of irrigation scheduling and various rootstocks on stomatal frequency. The rootstocks of grapes under investigation, the minimum stomatal frequency was observed in 1103-P (96.69 per mm^2) followed by Dogridge (124.85 per mm^2), Salt Creek (147.33 per mm^2), 1613-C (177.40 per mm^2) and 1616-C (191.34 per mm^2). The maximum stomatal frequency was noticed by SO4 (214.91 per mm^2).

Table 26. Effect of water stress on stomatal frequency of grapevine rootstocks

Rootstocks / Irrigation regimes (bar)	Stomatal frequency per mm^2 of leaf						Mean
	Dogridge	Salt Creek	1613-C	1616-C	1103-P	SO4	
0.3 bar	138.938	160.063	186.875	195.000	108.063	218.563	167.917
0.5 bar	124.313 (10.52)	147.063 (8.12)	177.125 (5.21)	187.688 (3.74)	96.688 (10.52)	211.250 (3.34)	157.354
0.7 bar	111.313 (19.88)	134.875 (15.73)	168.188 (9.99)	*	85.313 (21.05)	*	124.922
Mean	124.854	147.333	177.396	191.344	96.688	214.906	150.064

	S.E.±	C.D. at 5 %
Rootstocks (A)	0.653	1.940
Irrigation regimes (B)	0.462	1.372
Interaction (AB)	1.131	3.361

(Figures in parentheses indicate percentage reduction).
* Sample was not available.

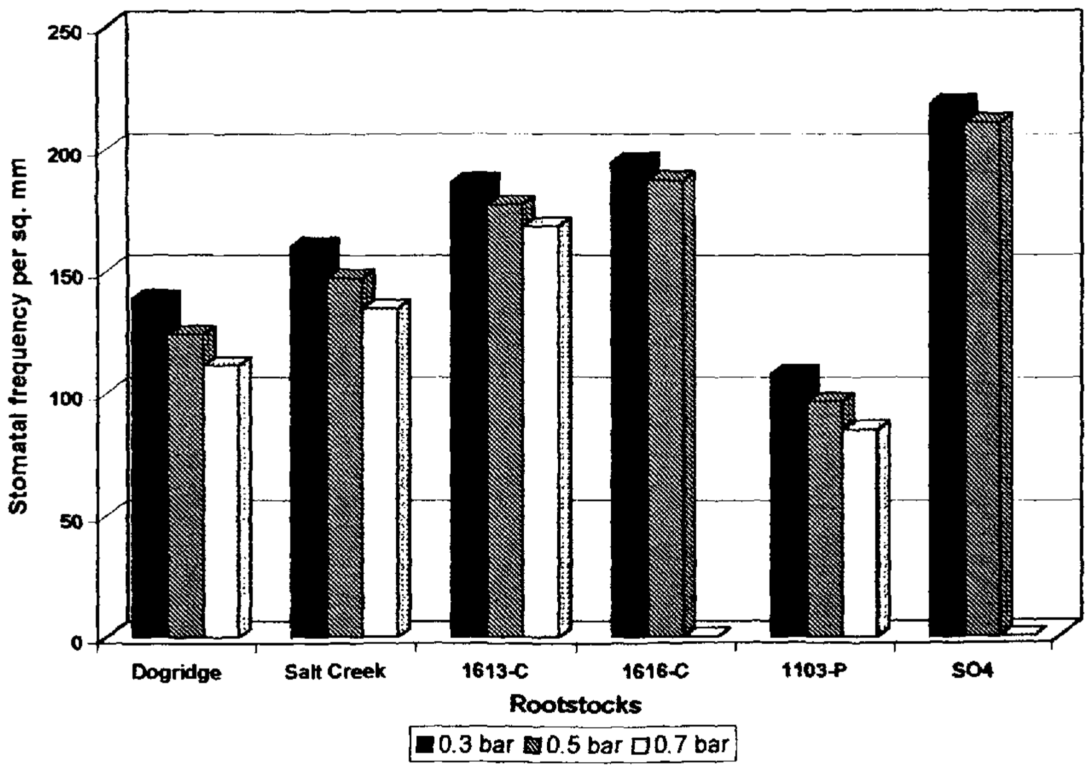


Fig. 23: Effect of water stress on stomatal frequency of grapevine rootstocks

Effect of irrigation regimes

The stomatal frequency was also significantly influenced by various levels of irrigations. As there was increase in water stress in stomatal frequency was decreased. The lowest stomatal frequency was observed with scheduling of irrigation at 0.7 bar (124.93 per mm^2) which was followed by 0.5 bar (157.35 per mm^2). The highest stomatal frequency was recorded when irrigation was scheduled at 0.3 bar (167.92 per mm^2).

Effect of interaction

Significant interaction effect was noticed between different rootstocks and irrigation regimes. Among the different irrigation regimes the minimum stomatal frequency was observed in 1103-P with scheduling of irrigation at 0.3 bar (108.06 per mm^2) and at 0.5 bar (96.69 per mm^2) and at 0.7 bar (85.31 per mm^2). The vines of 1616-C and SO4 were wilted as these rootstocks were susceptible to drought. The maximum stomatal frequency was recorded in SO4 (218.56 per mm^2) with scheduling of irrigation at 0.3 bar and at 0.5 bar (211.25 per mm^2). The maximum decrease in stomatal frequency i.e. 10.52 per cent and 21.05 per cent was observed in 1103-P with scheduling of irrigation at 0.5 bar and 0.7 bar, respectively followed by Dogridge (10.52 % and 19.88 %, respectively) and Salt Creek (8.12 % and 15.73 %, respectively). Based on reduction percentage highest reduction in stomatal frequency was observed in 1103-P which was found to be more tolerant to water stress followed by Dogridge and Salt Creek.

4.3 Biochemical parameters

4.3.1 Effect of water stress on chlorophyll 'a' content (mg g^{-1} FW)

The effect of irrigation regimes on chlorophyll 'a' of different rootstocks are displayed in Table 27 and graphically depicted in Fig. 24.

Effect of rootstocks

The data revealed that there was significant effect of different levels of irrigation regimes and various rootstocks on chlorophyll 'a' content. Among the different rootstocks of grapes, the maximum chlorophyll 'a' content was recorded by 1103-P (1.638 mg g^{-1} FW) which was followed by Dogridge (1.403 mg g^{-1} FW), Salt Creek (1.236mg g^{-1} FW), 1613-C (1.081 mg g^{-1} FW) and 1616-C (0.711 mg g^{-1} FW). The lowest chlorophyll 'a' content was noticed by SO4 (0.610 mg g^{-1} FW).

Effect of irrigation regimes

The chlorophyll 'a' content was also significantly influenced by various levels of irrigations. Significantly maximum chlorophyll 'a' (1.365 mg g^{-1} FW) was recorded with scheduling of irrigation at 0.3 bar i.e. field capacity which was followed by 0.5 bar (1.180 mg g^{-1} FW). The minimum chlorophyll 'a' content was recorded with scheduling of irrigation at 0.7 bar (0.795 mg g^{-1} FW).

Effect of interaction

The interaction effect between irrigation regimes and different grape rootstocks were significant. In all the different levels of irrigations the maximum chlorophyll 'a' content was observed by

Table 27. Effect of water stress on chlorophyll 'a' content in leaf of grapevine rootstocks

Rootstocks / Irrigation regimes (bar)	Chlorophyll 'a' content in leaf (mg g^{-1} FW)						Mean
	Dogridge	Salt Creek	1613-C	1616-C	1103-P	SO4	
0.3 bar	1.528	1.405	1.281	1.189	1.749	1.037	1.365
0.5 bar	1.392 (8.90)	1.238 (11.88)	1.078 (15.84)	0.944 (20.60)	1.633 (6.63)	0.794 (23.43)	1.180
0.7 bar	1.287 (15.77)	1.066 (24.12)	0.884 (30.99)	*	1.531 (12.46)	*	0.795
Mean	1.403	1.236	1.081	0.711	1.638	0.610	1.113

	S.E.±	C.D. at 5 %
Rootstocks (A)	0.002	0.008
Irrigation regimes (B)	0.001	0.005
Interaction (AB)	0.004	0.014

(Figures in parentheses indicate percentage reduction).
* Sample was not available.

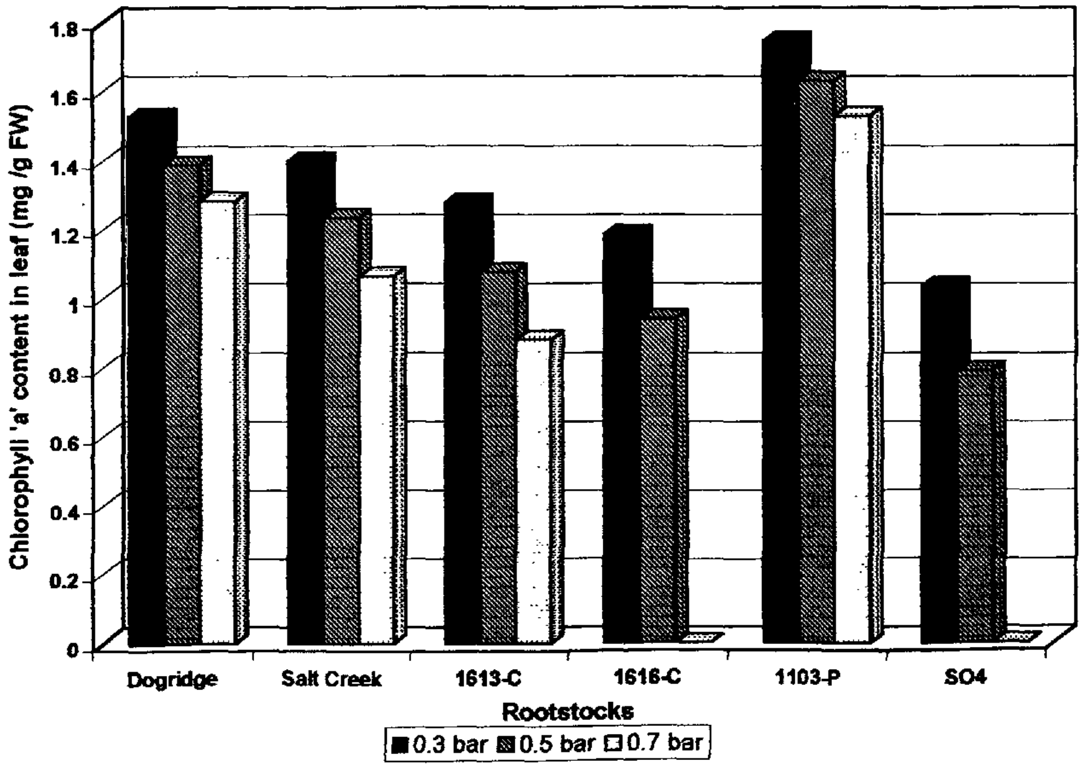


Fig. 24: Effect of water stress on chlorophyll 'a' content in leaf of grapevine rootstocks

1103-P (1.749 mg g^{-1} FW) with scheduling of irrigation at 0.3 bar whereas in the scheduling of irrigation at 0.5 bar and 0.7 bar the 1103-P had also recorded the maximum chlorophyll 'a' content i.e. 1.633 mg g^{-1} FW and 1.531 mg g^{-1} FW, respectively. The leaf sample of rootstocks 1616-C and SO4 was not available because of their low ability to sustain to the drought. The minimum reduction i.e. 6.63 per cent and 12.46 per cent in chlorophyll 'a' content was recorded by 1103-P when scheduling of irrigation at 0.5 bar and 0.7 bar, respectively; it was followed by Dogridge (8.90 % and 15.77 %, respectively) and Salt Creek (11.88 % and 24.12 %, respectively). On the basis of reduction percentage in chlorophyll 'a' content less reduction in 1103-P, it was indicated that 1103-P rootstock was found to be more tolerant to water stress than rest of rootstocks except Dogridge and Salt Creek.

4.3.2 Effect of water stress on chlorophyll 'b' content (mg g^{-1} FW)

The data in respect of chlorophyll 'b' content as influenced by various irrigation regimes are presented in Table 28 and graphically depicted in Fig. 25.

Effect of rootstocks

The results showed that there was significant effect of different irrigation regimes of irrigation scheduling and various rootstocks on chlorophyll 'b' content. The rootstocks under the investigation the maximum chlorophyll 'b' was noticed by 1103-P (0.608 by mg g^{-1} FW) which was followed by Dogridge (0.577 mg g^{-1} FW), Salt Creek

Table 28. Effect of water stress on chlorophyll 'b' content in leaf of grapevine rootstocks

Rootstocks / Irrigation regimes (bar)	Chlorophyll 'b' content in leaf (mg g^{-1} FW)						Mean
	Dogridge	Salt Creek	1613-C	1616-C	1103-P	SO4	
0.3 bar	0.618	0.598	0.574	0.549	0.641	0.502	0.580
0.5 bar	0.571 (7.60)	0.539 (9.86)	0.504 (12.19)	0.467 (14.93)	0.605 (5.61)	0 407 (18.92)	0.515
0.7 bar	0.543 (12.13)	0.480 (19.73)	0.437 (23.86)	*	0.579 (9.67)	*	0.340
Mean	0.577	0.539	0.505	0.339	0.608	0.303	0.478

	S.E.±	C.D. at 5 %
Rootstocks (A)	0.0012	0.0037
Irrigation regimes (B)	0.0009	0.0026
Interaction (AB)	0.0022	0.0065

(Figures in parentheses indicate percentage reduction).
* Sample was not available.

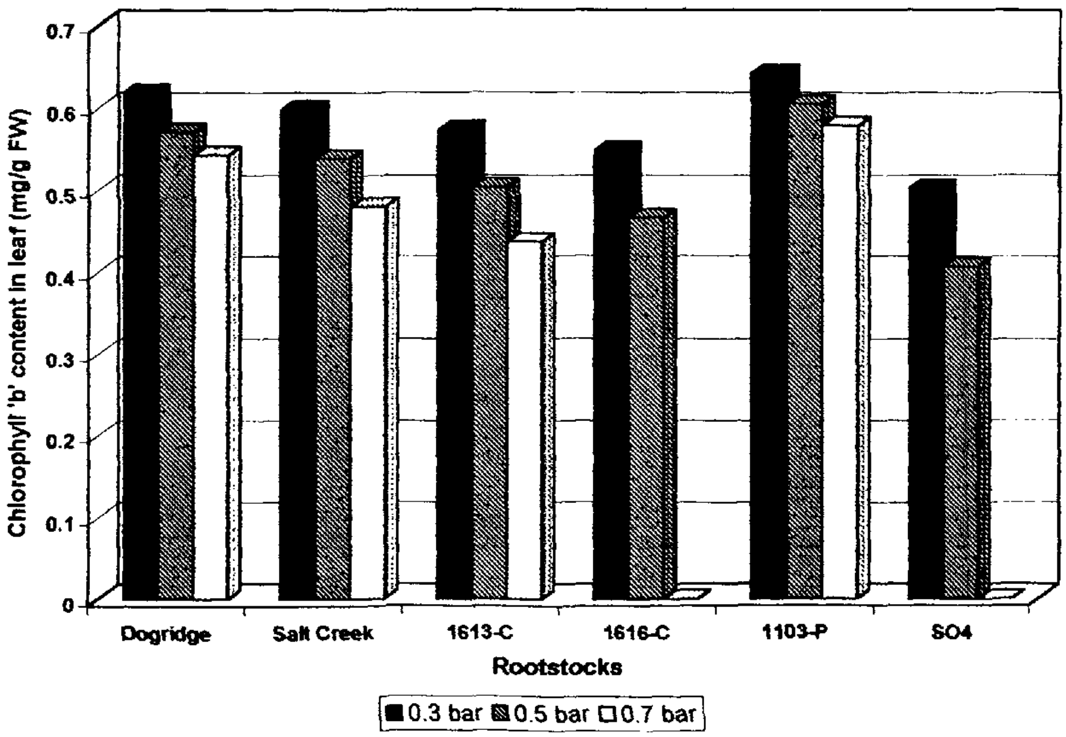


Fig. 25: Effect of water stress on chlorophyll 'b' content in leaf of grapevine rootstocks

(0.539 mg g^{-1} FW), 1613-C (0.505 mg g^{-1} FW) and 1616-C (0.339 mg g^{-1} FW). The lowest chlorophyll 'b' content was observed by SO4 (0.303 mg g^{-1} FW).

Effect of irrigation regimes

The chlorophyll 'b' content was also significantly influenced by various levels of irrigations. The maximum chlorophyll 'b' content (0.580 mg g^{-1} FW) was recorded when irrigation was scheduled at 0.3 bar which was followed by 0.5 bar (0.515 mg g^{-1} FW). The chlorophyll 'b' content was decreased with increase in water stress. The minimum chlorophyll 'b' content was observed with scheduling of irrigation at 0.7 bar (0.340 mg g^{-1} FW).

Effect of interaction

Effect of interaction between different rootstocks and irrigation regimes were significant. Among the different irrigation regimes the maximum chlorophyll 'b' content was observed in 1103-P (0.641 mg g^{-1} FW) with scheduling of irrigation at 0.3 bar whereas this rootstocks also recorded the maximum chlorophyll 'b' content i.e. 0.605 mg g^{-1} FW and 0.579 mg g^{-1} FW was observed with scheduling of irrigation at 0.5 bar and 0.7 bar, respectively. The leaf sample in SO4 and 1616-C was not available as these two rootstocks could not sustain under water stress. The lowest reduction percentage of 5.61 per cent and 9.67 per cent in chlorophyll 'b' content was recorded by 1103-P with irrigation level at 0.5 bar and 0.7 bar, respectively which was followed by Dogridge (7.60 % and 12.13 %, respectively) and Salt Creek (9.86 % and 19.73 %, respectively). Based on reduction percentage in chlorophyll 'b' content 1103-P was observed more tolerant to water stress condition followed by Dogridge and Salt Creek.

4.3.3 Effect of water stress on total chlorophyll content (mg g^{-1} FW)

The data regarding total chlorophyll content as influenced by different irrigation regimes on various rootstocks are presented in Table 29 and graphically shown in Fig. 26.

Effect of rootstocks

The data revealed that there was significant effect of different levels of irrigation regimes and various rootstocks of grapes on total chlorophyll content. The different rootstocks of grapes under investigation, the maximum total chlorophyll content was recorded by 1103-P (2.246 mg g^{-1} FW) which was followed by Dogridge (1.982 mg g^{-1} FW), Salt Creek (1.775 mg g^{-1} FW), 1613-C (1.586 mg g^{-1} FW) and 1616-C (1.050 mg g^{-1} FW). The minimum total chlorophyll content was recorded by SO4 (0.913 mg g^{-1} FW).

Effect of irrigation regimes

The total chlorophyll content was also significantly influenced by various levels of irrigations. Significantly maximum total chlorophyll content (1.945 mg g^{-1} FW) was recorded with scheduling of irrigation at 0.3 bar i.e. field capacity which was followed by 0.5 bar (1.697 mg g^{-1} FW) while lowest total chlorophyll content was recorded with scheduling of irrigation at 0.7 bar (1.134 mg g^{-1} FW).

Table 29. Effect of water stress on total chlorophyll content in leaf of grapevine rootstocks

Rootstocks / Irrigation regimes (bar)	Total chlorophyll content in leaf (mg g^{-1} FW)						Mean
	Dogridge	Salt Creek	1613-C	1616-C	1103-P	SO4	
0.3 bar	2.146	2.002	1.855	1.738	2.390	1.539	1.945
0.5 bar	1.971 (8.15)	1.777 (11.23)	1.582 (14.71)	1.412 (18.75)	2.238 (6.35)	1.201 (21.96)	1.697
0.7 bar	1.830 (14.72)	1.546 (22.77)	1.321 (28.78)	*	2.110 (11.71)	*	1.134
Mean	1.982	1.775	1.586	1.050	2.246	0.913	1.592

	S.E.±	C.D. at 5 %
Rootstocks (A)	0.003	0.009
Irrigation regimes (B)	0.002	0.006
Interaction (AB)	0.005	0.016

(Figures in parentheses indicate percentage reduction).
* Sample was not available.

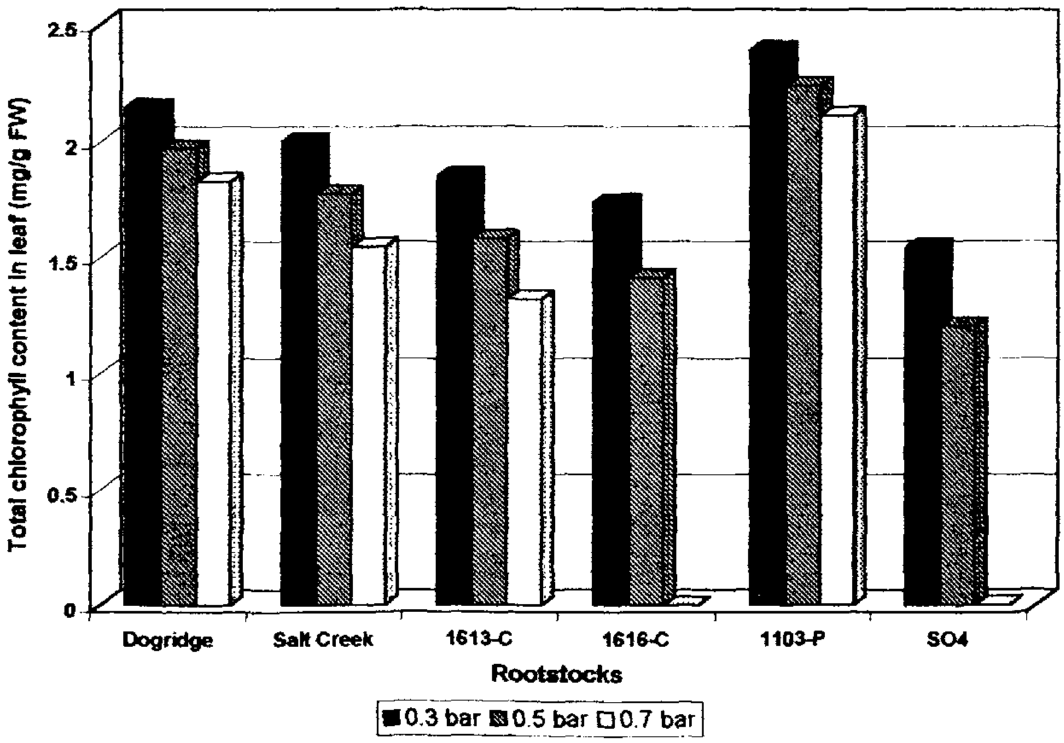


Fig. 26: Effect of water stress on total chlorophyll content in leaf of grapevine rootstocks

Effect of interaction

The interaction effect between irrigation regimes and different grape rootstocks were significant. Among the different levels of irrigations the maximum total chlorophyll content was observed by 1103-P (2.390 mg g^{-1} FW) with scheduling of irrigation at 0.3 bar. Whereas the rootstock showed the maximum total chlorophyll content i.e. 2.238 mg g^{-1} FW and 2.110 mg g^{-1} FW with scheduling of irrigation at 0.5 bar and 0.7 bar also by 1103-P. The leaf samples of 1616-C and SO4 were not available, as they could not survive under water stress at 0.7 bar. The minimum reduction i.e. 6.35 per cent and 11.71 per cent in total chlorophyll was recorded by 1103-P when scheduling of irrigation was done at 0.5 bar and 0.7 bar, respectively which was followed by Dogridge (8.15 % and 14.72 %, respectively) and Salt Creek (11.23 % and 22.77 %, respectively). Based on reduction percentage in total chlorophyll content it was indicated that 1103-P was found to be better for drought condition than rest of rootstocks except Dogridge and Salt Creek.

4.3.4 Effect of water stress on chlorophyll stability index (CSI)

The relevant data on the chlorophyll stability index affected by different irrigation regimes are presented in Table 30 and graphically shown in Fig. 27.

Table 30. Effect of water stress on chlorophyll stability index of grapevine rootstocks

Rootstocks / Irrigation regimes (bar)	Chlorophyll Stability Index						Mean
	Dogridge	Salt Creek	1613-C	1616-C	1103-P	SO4	
0.3 bar	0.556	0.737	0.615	0.686	0.381	0.700	0.612
0.5 bar	0.499 (10.25)	0.676 (8.27)	0.584 (5.04)	0.627 (8.60)	0.326 (14.43)	0.679 (3.00)	0.565
0.7 bar	0.456 (17.98)	0.652 (11.53)	0.563 (8.45)	*	0.279 (26.77)	*	0.488
Mean	0.504	0.688	0.588	0.657	0.328	0.689	0.555

	S.E.±	C.D. at 5 %
Rootstocks (A)	0.004	0.014
Irrigation regimes (B)	0.003	0.010
Interaction (AB)	0.008	0.024

(Figures in parentheses indicate percentage reduction).
* Sample was not available.

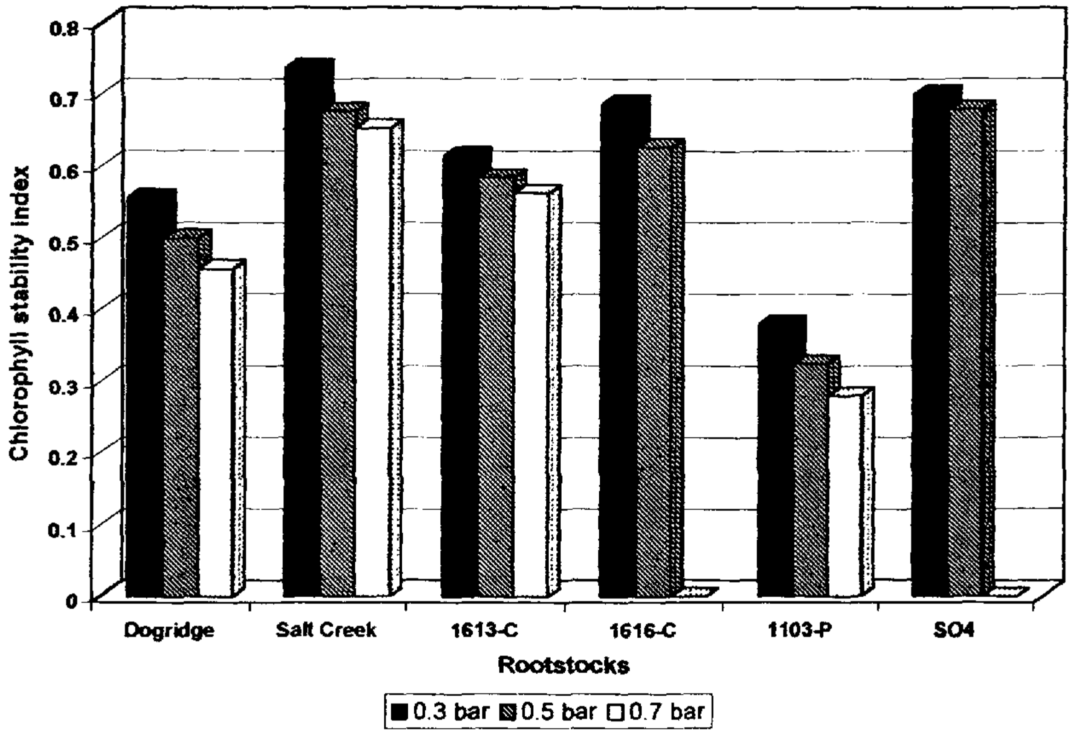


Fig. 27: Effect of water stress on chlorophyll stability index of grapevine rootstocks

Effect of rootstocks

The data revealed that there was significant effect of different levels of irrigation regimes and various rootstocks on chlorophyll stability index. The rootstocks used under investigation, the highest C.S.I. was observed by SO4 (0.689) which was at par with Salt Creek (0.688) while the minimum C.S.I was observed by 1103-P (0.328) followed by Dogridge (0.504), 1613-C (0.588) and 1616-C (0.657).

Effect of irrigation regimes

The C.S.I. was also significantly influenced by various irrigation regimes. The rootstocks with scheduling of irrigation at 0.3 bar i.e. at field capacity recorded significantly maximum C.S.I (0.612) followed by scheduling of irrigation at 0.5 bar (0.565). The C.S.I. was decreased with increase in water stress. The minimum C.S.I. was recorded during scheduling of irrigation at 0.7 bar (0.488).

Effect of interaction

Significant interaction effect was observed between irrigation regimes and different grape rootstocks. Among the different irrigation regimes, the minimum C.S.I. was observed by 1103-P (0.381) when scheduling of irrigation at 0.3 bar whereas C.S.I. i.e. 0.326 and 0.279 was recorded when scheduling of irrigation at 0.5 bar and 0.7 bar, respectively. The maximum C.S.I. was observed by Salt Creek (0.652) with scheduling of irrigation at 0.7 bar. The leaf sample of SO4 and 1616-C was not available because of their low sustainability under water stress condition. The highest percentage reduction in C.S.I. was recorded by 1103-P with scheduling of irrigation at 0.5 bar (14.43 %) and at 0.7 bar (26.77 %) which was followed by Dogridge (10.25 % and 17.98 %, respectively) and Salt Creek (8.27 % and 11.53 %, respectively). In view of above investigation the reduction percentage was highest in 1103-P indicated that it was more tolerant to water stress condition followed by Dogridge and Salt Creek.

DISCUSSION

5. DISCUSSION

Maharashtra is the leading grape growing state and the area under grape is increasing constantly. However, the irrigation becomes the limiting factor for increasing area which was adversely affected yield and quality of grapes. Hence, an attempt was made to conduct the experiment on "Screening of grape rootstock for drought tolerance". Based on the response of various rootstocks of grapes to different scheduling of irrigation regime the investigation was done under pot culture. The interpretation and illustration of results was done in previous chapter and discussed below.

5.1 Morphological characters

The morphological characters such as height of shoot, diameter of shoot, number of shoots per vine, length of internode, total number of leaves per vine, leaf area, number and length of root per vine, leaf rolling etc. are the better attributes to discriminate grape rootstocks under water stress condition.

5.1.1 Effect of water stress on growth attributes

5.1.1a Effect of water stress on height of shoot (cm)

The data on the effects due to water stress on the rootstocks height of shoot have been presented in Table 5 and graphically depicted in Fig.2.

The shoot height of 1103-P recorded the lowest decrease in height of shoot indicating there by it was least affected rootstock followed by Dogridge, Salt Creek, 1613-C and 1616-C. The maximum reduction in height of shoot was observed in the SO4 indicating that it could not sustain under water stress.

The height of shoot of susceptible rootstocks was decreased due to reduction in the size of the meristematic cells of vine. In the studies 1103-P, Dogridge and Salt Creek rootstocks were found to be relatively drought tolerant. Of these rootstocks comparatively the reduction in the size of meristematic cell was lower. Under water stress condition, the expansion of meristematic cells are reduces as it was observed that the reduction percentage in height of shoot was lower as compared to the rest of rootstocks in 1103-P.

These findings are in confirmity with those reported earlier by El-Barkouki *et al.* (1979), they reported that reduction of the available water was resulted in a reduction in height of shoot of grapevine. Fanizza and Riccardi (1990) in comparison with genotypes of grapevines under stress and non stress condition, the weekly elongation rate of shoot increases in the first period of stress and then it decreases while under non stress condition it increase continuously. These results was also obtained by Fanizza and Castrignano (1993), Shikhamany and Prakash (1995), During *et al.*(1995), Patil *et al.*(1995) and Ramteke *et al.* (1999).

5.1.1b Effect of water stress on diameter of shoot (mm)

The results on diameter of shoot as influenced by different levels of irrigations on various rootstocks are presented in Table 6 and graphically depicted in Fig. 3.

The maximum diameter of shoot was noticed by Dogridge, followed by 1613-C, 1103-P, 1616-C and Salt Creek. The minimum diameter of shoot was noticed by SO4. As there was increase in the water stress the diameter of shoot was decreased. The lowest reduction in diameter of shoot was recorded by 1103-P followed by Dogridge, Salt Creek, 1613-C and 1616-C. The lowest reduction in diameter of shoot was observed in SO4 indicated that it was susceptible to water stress while 1103-P was tolerant to the drought.

The diameter of the shoot is mainly determined by the mass of growth tissue i.e. the cambium layer where the bark and wood meet. The cell divisions in this layer and turgidity of the cells cause increase in diameter of shoot of vine. The rootstock SO4 registered the maximum decrease in shoot diameter by losing the turgidity of cells indicating thereby that the diameter was significantly reduced due to water stress. In 1103-P had the lowest reduction in the shoot diameter, this might be because of minimum reduction in turgidity of cells.

These findings are in confirmity with those reported by Hsiao (1973). According to him, the cell growth depends on cell turgor pressure as its driving force. The degree of cell turgidity of a plant is based on the relative rates of absorption. Similarly May and Mitthorpe (1962) reported that water deficit caused a loss of turgor. The expansion of cells and cell division are reduced resulting into decrease in diameter of stem. These results were agreement with the results showed by Chandel and Chauhan (1992).

Based on the above comment it is indicated that 1103-P, Dogridge and Salt Creek could relatively maintained the turgidity while rootstock SO4 lost its turgidity due to the effect of water stress.

5.1.1c Effect of water stress on number of shoots per vine

The data pertaining to the number of shoots per vine as influenced by various levels of irrigation are presented in Table 7 and graphically shown in Fig 4.

The maximum number of shoots per vine was recorded by 1103-P followed by 1613-C, Dogridge, 1616-C and Salt Creek. The minimum number of shoots per vine was recorded by SO4. The number of shoots per vine was decreased with increase in water stress. The lowest reduction in percentage in respect of number of shoots per vine was recorded by 1103-P while the maximum reduction was recorded by SO4. The reduction percentage of Dogridge, Salt Creek, 1613-C and 1616-C was in between 1103-P and SO4. From the least reduction in number of shoots per vine was observed by 1103-P which was drought tolerant while SO4 can not tolerate under water stress condition.

The shoot arises from the each node of the vine. As due to the water stress the length of the vine decreases this might be results into the decrease in the number of nodes and ultimately the number of shoots.

There was minimum reduction in height was recorded by 1103-P and on the contrary maximum reduction in height was recorded by SO4 i.e. the maximum number of shoots were observed by 1103-P followed by that of Dogridge and Salt Creek as compared to SO4 in which very less number of shoots per vine were observed.

These findings are in confirmity with Patil *et al.* (1995). They recorded that the number of internodes were decreased with the increase in water stress which was resulted into decrease in number of nodes and ultimately it was resulted into reduction in number of shoots per vine due to decrease in number of nodes.

From this, it is clear that the relatively drought tolerant rootstock 1103-P, Dogridge and Salt Creek were recorded comparatively maximum number of shoots per vine while SO4 noticed the minimum number of shoots per vine which could not stand under water stress.

5.1.1d Effect of water stress on length of internode (cm)

The relevant data on length of internode affected by different irrigation regimes are presented in Table 8 and graphically depicted in Fig. 5.

The maximum length of internode was noticed by 1103-P which was followed by Dogridge, Salt Creek, 1613-C and 1616-C. The lowest length of internode was recorded by SO4. As there was increase in the water stress the length of the internode was decreased. The maximum length of internode was recorded during the irrigation at field capacity while it was reduced with increase in water stress. The lowest reduction in length of internode was recorded by 1103-P followed by Dogridge, Salt Creek, 1613-C and 1616-C. The maximum reduction in length of internode was recorded by SO4.

As water stress was increased the length of the vine was decreased which causes decrease in number and length of internodes per shoot. This was due to the reduction in the meristematic cells which were present in between the internode of the vine. The reduction in meristematic cells was more in SO4 which was resulted in reduction in internodal length, while in 1103-P these cells had less reduction.

These findings are supported by Patil *et al.* (1995). They showed that the number of internodes and length of internode was decreased with increase in water stress. These results were also obtained by Miah *et al.* (1988) and Ramteke *et al.* (1999). Mhetre (1999) reported that grapevines experiencing moisture stress may exhibit stunted growth due to shorter internodes near the tip and loss of turgidity.

In view of above findings, it is clear that the maximum length of internode was observed by 1103-P followed by Dogridge and Salt Creek while minimum length of internode was recorded by SO4. Hence 1103-P and then after Dogridge and Salt Creek were the drought tolerant rootstocks, whereas SO4 could sustain under water stress.

5.1.2 Effect of water stress on leaf attributes

5.1.2a Effect of water stress on total number of leaves per vine

The effect of irrigation regimes on total number of leaves per vine of different rootstocks are displayed in Table 9 and graphically shown in Fig. 6.

As there was increase in the water stress the total number of leaves per vine were decreased. Among the rootstocks of grapes under study, the maximum total number of leaves were noticed by 1103-P which was followed by Dogridge, Salt Creek, 1613-C and 1616-C. The lowest total number of leaves per vine were observed by SO4. The maximum total number of leaves per vine were recorded when irrigation at field capacity while it was decreased with increase in water stress. The lowest reduction in total number of leaves per vine were recorded by 1103-P (10.40%) followed by Dogridge (16.76 %), Salt Creek (29.58 %), 1613-C (38.65 %) and 1616-C (47.87 %). The maximum reduction in total number of leaves per vine as increase in water stress was noticed by SO4.

Due to the scheduling of irrigation at field capacity the leaves appeared long, soft and yellowish green to shorter, with increase in water stress the leaves becomes harder, darker to greyish green and finally the leaves drops down. The abscisic acid content in leaves was increased while auxin content was decreased which ultimately affects the total number of leaves contents in plants (Livne and Vaadia, 1972).

The similar results are reported by the El-Borkouki *et al.* (1979). They recorded that total number of leaves per plant had significantly decreased after reduction in available water upto 25 per cent and 12.5 per cent compared with that of plants grown under 50 per cent and 100 per cent of available water. During *et al.* (1995) reported that leaf number in water stressed plants were significantly reduced.

Among all the rootstocks 1103-P had the lowest reduction in number of leaves indicating that based on this attributes the relative drought tolerance could be ranked as 1103-P, Dogridge and Salt Creek.

5.1.2b Effect of water stress on leaf area (cm^2)

The data in respect of leaf area as influenced by various irrigation regimes are presented in Table 10 and graphically depicted in Fig.7.

In all the rootstocks the maximum leaf area was observed by Salt Creek followed by 1613-C, Dogridge, 1616-C and SO4. The minimum leaf area was observed by 1103-P. The maximum leaf area was observed with irrigation at field capacity while it was decreased with increase in water stress because of its genetical character; however, the maximum reduction in leaf area 54.77 per cent, 48.74 per cent and 35.42 per cent were recorded by 1103-P, Dogridge and Salt Creek, respectively.

The increase in the water stress reduces the leaf area by reducing the cell division. Reduction in the turgor pressure results into reduction in the leaf area. Leaf area is mainly concerned with the photosynthetic area as the leaf area decreased, the photosynthetic area is also reduced which ultimately affect photosynthesis and leaf area. The leaf area was also reduced due to the drying and rolling of the leaf margins.

These results are in confirmity with those reported by Nevryanskaya (1989). According to him, under soil moisture regimes of 70 per cent and 35 per cent of field capacity, moisture stress reduced the leaf area. These results were also obtained by Kozlowski (1976), and Winkel and Rambal (1993). Patil *et al.* (1999) reported the rootstocks which having drought resistance showed less leaf area, as they reported in *V. berlandiri*, *V. champini* cv. Digraset and Dogridge, *V. tiliefolia* and *Berlandiri* x *Riparia*. In the drought tolerant rootstocks the leaf area was reduced. The similar results were obtained by Carbonneau (1985) and During *et al.* (1995).

From this it is clear that the minimum reduction in leaf area was observed by 1103-P, Dogridge and Salt Creek indicating that, the relative drought tolerant could be ranked as 1103-P, Dogridge and Salt Creek.

5.1.3 Effect of water stress on root attributes

5.1.3a Effect of water stress on length of main root (cm)

The data pertaining to the length of main root as influenced by various levels of irrigation are presented in Table 11 and graphically shown in Fig. 8.

Among the different rootstocks of grapes, the maximum length of main root was noticed by 1103-P which was followed by Dogridge, 1613-C, Salt Creek and 1616-C. The lowest length of main root was recorded by SO4. The length of main root was decreased with increase in water stress. Significantly maximum length of root was recorded with scheduling of irrigation at field capacity while length of root was decreased with increase in water stress. The minimum reduction in length of main root was recorded by 1103-P which was followed by Dogridge, Salt Creek, 1613-C and 1616-C. Maximum reduction in length of main root was noticed by SO4.

As there was increase in the water stress the length of main root was decreased. The decrease in length was because of the reduction the size of the meristematic cells from the roots. The relative reduction in meristematic cells might be noted by 1103-P, Dogridge and Salt Creek while SO4 recorded the minimum length of main root might be due to maximum reduction in the size of meristematic cells. Comparatively the 1103-P, Dogridge and Salt Creek the diameter of the roots will be more however, it was not in case of susceptible ones.

The similar results are reported by the Stocker and Schmidt (1943) commented that drought resistant variety owed its resistance to a larger root system. They further reported that a deep and extensive root system may be an useful criteria for drought resistance, it was also supported by Yadav (1999) showed that the drought tolerant rootstocks are capable of exploring large volumes of soil horizon by producing both active feeder root in top 15-20 cm layer of soil. Poni *et al.* (1992) reported that the root growth of the stressed plants generally less than in controls which is about 25 per cent on average. Similar results are reported by Chandel and Chauhan (1992) while working on delicious apple.

Based on the less reduction in length of main root it was indicated that the 1103-P, Dogridge and Salt Creek are the relative tolerant to water stress.

5.1.3b Effect of water stress on number of primary roots per vine

The results irrespective of number of primary roots per vine are presented in Table 12 and graphically depicted in Fig. 9.

In all the rootstocks of grapes the maximum number of primary roots per vine were noticed by 1103-P which was followed by Dogridge, 1613-C which was at par with Salt Creek and 1616-C. The lowest number of primary roots per vine were observed by SO4. As the water stress increased the number of primary roots per vine were decreased. The maximum number of primary roots per vine were observed with scheduling of irrigation at field capacity while with increase in water stress the number of primary roots per vine were decreased. The minimum reduction in number of primary roots per vine were recorded by 1103-P followed by Dogridge, Salt Creek, 1613-C and 1616-C while maximum reduction in number of primary roots were recorded in SO4.

With the increase in water stress the height of shoot and ultimate number of leaves were reduced. This was resulted into reduction in the production of the food material and due to limited translocation of food material the length of the root as well as the number of the primary roots were decreased. This might be happens due to the rootstocks which not sustain under water stress condition which resulted into minimum number of the primary roots per vine. In the drought tolerant rootstock the diameter of primary root was more than the drought susceptible ones.

These findings are in confirmity with the Ivanow (1922). According to him, the ability of a plant to resist the adverse effect of drought was directly proportional to the density and extent of root development. Similar results are reported by Newman (1974) and Miller (1986). They recorded that, next to root depth, extensive root branching is often the most important characteristic of root system which favours the uptake of water. Further, if there is an ample supply of water throughout the active root zone, the size of root system may be more than ample to supply the needs of the plants and the removal of an appreciable part of the root system can have little effect on the total water uptake (Andrews and Newman, 1968). Perry *et al.* (1983) reported that the highest number of roots by Dogridge under thicker category than under feeder and finer category.

From this, it is clear that the drought tolerant rootstock 1103-P has the maximum number of primary roots per vine followed by Dogridge and Salt Creek as compared to the drought susceptible rootstock SO4.

5.1.3c Effect of water stress on number of secondary roots per vine

The data pertaining to the number of secondary roots per vine as influenced by various levels of irrigation are presented in Table 13 and graphically shown in Fig.10.

Among the different rootstocks of grapes the maximum number of secondary roots were recorded by 1103-P followed by

Dogridge, Salt Creek which was at par with 1613-C and 1616-C. The lowest value of this attribute was recorded by SO4. The maximum number of secondary roots per vine were observed by the vines receiving irrigation at field capacity while with increase in the water stress the number of secondary roots per vine were decreased. The minimum reduction in number of secondary roots per vine were recorded by 1103-P followed by Dogridge, Salt Creek, 1613-C and 1616-C where as the maximum reduction in number of secondary roots per vine roots were recorded by SO4.

As in the drought tolerant rootstocks maximum number of primary roots per vine were observed, the rootstock develops more extensive system for the absorption of the water and hence due to which the number of secondary roots per vine were observed maximum by drought tolerant rootstock as compared with the drought susceptible rootstock. In which secondary roots might be dried due to water stress.

The similar results are reported by Yadav (1999). According to him, the rootstocks growing under drought is capable of exploring large volume of soil horizon by producing both active feeder root in the top 15-20 cm layer of soil. These findings are also more or less in confirmity with Ivanow (1922) and Stocker and Schmidt (1943), who concluded that longer and extensive root system may be criteria for drought resistance in plant species. More or less similar results were also reported by Fregoni (1977) who claimed that drought tolerant rootstock varieties of grapevine usually had extensive and deep root system.

5.1.4 Effect of water stress on days to appearance of stress

5.1.4a Effect of water stress on leaf rolling

5.1.4a$_1$ Effect of water stress on days to 50 per cent leaf rolling

The relevant data on the days required to 50 per cent leaf rolling affected by different irrigation regimes are presented in Table 14 and graphically depicted in Fig.11.

In all the rootstocks of grapes the maximum days required to 50 per cent leaf rolling were noticed by 1103-P, followed by Dogridge, Salt Creek, 1613-C and 1616-C. The minimum days required for 50 per cent leaf rolling were observed by SO4. As the water stress increased the days required for 50 per cent leaf rolling were decreased. The maximum days were required for 50 per cent leaf rolling when scheduling of irrigation at field capacity while minimum days required for 50 per cent leaf rolling with increase in water stress. The minimum reduction in days required for 50 per cent leaf rolling was recorded in 1103-P which was followed by Dogridge, Salt Creek, 1613-C and 1616-C. The maximum reduction in days required for 50 per cent leaf rolling was recorded by SO4.

With the increase in water stress the turgor pressure of the cells of leaf was decreased which results into decrease in leaf area. During the leaf rolling leaf margins turned inward or outward according to the different species of rootstocks and then becomes curved due to stress. The cells of the leaves maintain the turgidity. When there was water stress the cells of the leaves loose turgidity and rolling of the leaves takes place. The rootstocks like 1103-P, Dogridge and Salt Creek the days required for leaf rolling of leaves were greater this might be because of the cells maintains turgor pressure while drought susceptible rootstock loose turgor pressure and early wilting takes place.

These findings are in confirmity with the O' Toole and Chang (1979). According to them, the leaf rolling is perhaps the most universally obvious symptom of drought. Rolling of leaves indicates a decrease in turgor pressure potential of a leaf tissue giving the leaf lamina its lateral extensibility. During (1985) suggested that the leaf wilting test based on water holding capacity of leaves is a very good test for selection of drought tolerant types. These results are more or less on similar line of work done by Matthews *et al.* (1990) and Mhetre (1999).

From the comments as narrated above, it is indicated that 1103-P, Dogridge and Salt Creek needs relatively higher days for 50 per cent leaf rolling as compared to SO4.

5.1.4a$_2$ Effect of water stress on days to 100 per cent leaf rolling

The effect of irrigation regimes on days to 100 per cent leaf rolling of different rootstocks are displayed in Table 15 and graphically depicted in Fig. 12.

Among all the rootstocks the maximum days required for 100 per cent leaf rolling were observed by 1103-P followed by Dogridge, Salt Creek, 1613-C and 1616-C. The maximum days required to 100 per cent leaf rolling were recorded by SO4. The days required for 100 per cent leaf rolling with scheduling of irrigation at field capacity will be more with increase in water stress days required for leaf rolling were minimum. The lowest percentage reduction in days to 100 per cent leaf rolling were recorded by 1103-P followed by Dogridge, Salt Creek, 1613-C and 1616-C. The maximum reduction percentage was recorded by SO4.

The leaf size was determined by the turgor pressure of the cells of the leaves. As there was increase in the water stress the leaves loose their turgidity and commanded the leaf rolling. The inward leaf rolling was observed by Salt Creek, 1616-C and SO4 while outward leaf rolling was observed by Dogridge, 1613-C and 1103-P. In drought tolerant rootstocks the days required to 100 per cent leaf rolling were maximum this might be due to the maintains of the turgidity of cell in drought tolerant rootstock while the drought susceptible rootstock loose their turgidity immediately after water stress.

The supporting reference given are contradictory, Begg and Turner (1976) reported that leaf rolling reduces the interception of radiation, which increases the temperature of leaves due to closing of stomata. Similar findings were obtained by Matthews *et al.* (1990). According to them, the resistant lines showed more leaf rolling than the susceptible ones. Further, they reported that leaf rolling in resistant lines after the micro-climate so that stomata may remain open and the growth may continue without associated high rates of water loss. These findings are in confirmity with those of O' Toole and Chang (1979).

From this, it is clear that the relatively drought tolerant rootstock like 1103-P, Dogridge and Salt Creek requires more days to 100 per cent leaf rolling as compared to the susceptible rootstocks like SO4.

5.1.4b Effect of water stress on leaf shrivelling

5.1.4b$_1$ Effect of waters stress on days for initiation of leaf shrivelling

The data in respect of days for initiation of leaf shrivelling as influenced by various irrigation regimes are presented in Table 16 and graphically shown in Fig. 13.

In all the rootstocks of the grapes, the maximum days required for leaf shrivelling were noticed by 1103-P which was followed by Dogridge Salt Creek, 1613-C and 1616-C. The minimum days for initiation of leaf shrivelling were noticed by SO4. Significantly maximum days for initiation of leaf shrivelling were recorded with scheduling of irrigation at field capacity which was decreased with increase in water stress. The minimum reduction in days for initiation of shrivelling were recorded by 1103-P which was followed by Dogridge, Salt Creek, 1613-C and 1616-C. The maximum reduction in days for initiation of leaf shrivelling were noticed by SO4.

As increase in the water stress the plant cells losses their turgor pressure. Due to decrease in the turgidity of cells of the vine the leaf shrivelling was started. The leaf shrivelling helps the plant to decrease the moisture loss from the leaf surface. In the drought tolerant rootstock significantly more days were required for initiation of leaf shrivelling.

These results are in confirmity with Mhetre (1999). According to him grapevines experiencing moisture stress may exhibit one or more symptoms depending upon the degree and duration of water stress. Succulent young shoots experiencing sudden water reduction may wilt and drop their basal leaves.

From the above discussion it is clear that the 1103-P was the drought tolerant rootstock which requires maximum days for initiation of leaf shrivelling while drought susceptible rootstock SO4 requires minimum days for initiation of leaf shrivelling.

5.1.4b$_2$ Effect of water stress on days to greater than 50 per cent leaf shrivelling

The data regarding the days to greater than 50 per cent leaf shrivelling as influenced by different irrigation regimes on various rootstocks are presented in Table 17 and graphically depicted in Fig. 14.

Among the different rootstocks of the grape, the maximum days required to greater than 50 per cent leaf shrivelling were noticed by 1103-P which was followed by Dogridge, Salt Creek, 1613-C and 1616-C. The minimum days to greater than 50 per cent leaf shrivelling were observed by SO4. The maximum days were required for greater than 50 per cent leaf shrivelling when scheduling of irrigation at field capacity while days required to greater than 50 per cent leaf shrivelling were decreased with increase in water stress. The lowest reduction in days to greater than 50 per cent leaf shrivelling were recorded by 1103-P which was followed by Dogridge, Salt Creek, 1613-C and 1616-C. The maximum reduction in days to greater than 50 per cent leaf shrivelling were recorded by SO4.

As the water stress condition was advanced after the initiation of shrivelling vine attains the greater than 50 per cent leaf shrivelling. This was also due to the more loss of water from the leaf which results into loss in the turgidity of cells.

These results are also in confirmity with Mhetre (1999). He reported that grapevines experiencing moisture stress may exhibit one or more symptoms depending upon the degree and duration of water stress. Succulent young shoots experiencing sudden water reduction may wilt and drop their basal leaves. If stress prolonged shoot tips die back and flagging of leaves observed.

From this, it is clear that 1103-P, Dogridge and Salt Creek requires relatively more days to greater than 50 per cent leaf shrivelling while in drought susceptible rootstock SO4 requires minimum days to greater than 50 per cent leaf shrivelling.

5.1.4c Effect of water stress on days to dryness of leaf

The results on days to dryness of leaf as influenced by different levels of irrigations on various rootstocks are presented in Table 18 and graphically shown in Fig. 15.

The rootstocks of grapes under study the maximum days to dryness of leaf was noticed by 1103-P which was followed by Dogridge, Salt Creek, 1613-C and 1616-C whereas the minimum days to dryness of leaf recorded by SO4. Significantly maximum days were required to dryness of leaf when scheduling of irrigation at field capacity and with increase in water stress days required for drying were decreased. The minimum reduction in days to dryness were recorded by 1103-P which was followed by Dogridge, Salt Creek, 1613-C and 1616-C while the maximum reduction in days to dryness of leaf was recorded by SO4.

As the water stress advanced after the days to greater than 50 per cent leaf shrivelling. Finally, the drying of the leaves takes place. With the increase in water stress photosynthetic area of the leaf was decreased due to loss of the turgor pressure. As more transpiration from the leaf surface the shrivelling and rolling of leaves takes place it was resulted in dryness.

These results are confirmity with the Mhetre (1999). According to him, in case of the prolonged stress, shoot tip die back and leaves and shoots dry up, stunted growth of shoots and a shorter internodes near the tip, a change from normal green appearance, loss of turgidity and flagging of leaves were observed.

From this, we can conclude that the maximum days were required for drought tolerant rootstock line 1103-P followed by Dogridge and Salt Creek whereas, SO4 had the lowest value of this parameter.

5.2 Physiological parameters

5.2.1 Effect of water stress on relative leaf water content (%)

The data pertaining to the relative leaf water content as influenced by various levels of irrigation are presented in Table 19 and graphically depicted in Fig. 16.

The different rootstocks of grapes under investigation, 1103-P recorded the maximum relative leaf water content followed by Dogridge, Salt Creek, 1613-C and 1616-C. The lowest relative leaf water content was observed by SO4. The vines receiving irrigation at field capacity recorded significantly maximum relative leaf water content which was decreased with increase in water stress. The minimum reduction in relative leaf water content was noticed by 1103-P followed by Dogridge, Salt Creek, 1613-C and 1616-C. While the vines of the rootstocks 1616-C and SO4 could not stand at higher water stress (i.e. at 0.7 bar).

The drought tolerant rootstock showed the highest relative leaf water content while in drought susceptible genotypes the relative leaf water content was significantly lowered. The cells of the vine maintains the turgor pressure in the leaves of the vine. In drought tolerant rootstock the maximum RLWC may be due to be maintains of the cell turgidity while in drought susceptible rootstocks cell turgidity was lost readily.

These results are found similar with the El-Barkouki *et al.* (1979). According to them, the relative leaf water content of leaves increased as available water increased. The maximum values of relative water content was obtained from control treatment (100 % available water) in contrast to lowest values obtained at 12.5 per cent available water. These results were also obtained by Slatyer (1960) and Barrs (1968). Prakash and Bhatt (1999) showed that imposition of water stress strongly decreased the relative leaf water content of leaves in all rootstocks by the end of stress cycle. The reduction was as steep as 27 per cent in Salt Creek to 6 per cent R x R, next only Dogridge where it was 12 per cent suggesting that the rootstocks able to maintain the water levels in leaves under water stress. The similar results were also obtained by Allweldt *et al.* (1982), Rodrigues *et al.* (1993), Patil *et al.* (1994) and Ramteke *et al.* (1999).

From this, it is clear that rootstock 1103-P has the maximum RLWC indicated that this rootstock is more tolerable under water stress situation followed by Dogridge and Salt Creek.

5.2.2 Effect of water stress on fresh weight of shoot (g)

The relevant data on the fresh weight of shoot affected by different irrigation regimes are presented in Table 20 and graphically shown in Fig. 17.

In all the rootstocks of grapes, the maximum fresh weight of shoot was noticed by 1103-P followed by Dogridge, Salt Creek, 1613-C and 1616-C. The lowest fresh weight of shoot was observed by SO4. The maximum fresh weight of shoot was recorded when irrigation was scheduled at field capacity which was decreased with increase in water stress. The minimum reduction in fresh weight of shoot was recorded by 1103-P followed by Dogridge, Salt Creek, 1613-C and 1616-C. The maximum values in respect of reduction in fresh weight of shoot was observed by SO4.

As the stress was advanced shoot height was decreased, the total number of leaves as well as total number of shoots per vine also decreased. The leaf area was also decreased due to loss of turgor pressure of the cell because of which the fresh weight of the shoot was decreased.

These findings are in confirmity with those reported earlier by Prakash and Bhatt (1999) studied six rootstocks of grapevine and showed that the total length of shoot recorded at the time of uprooting the plants from the pots showed highest growth in Dogridge with highest shoot weight followed by Salt Creek. The similar findings are obtained by Perry *et al.* (1983) and During (1979). Miah *et al.* (1988) reported that the differences between the fresh weights of stressed and unstressed plants was gradually decreased.

From this, it is clear that the relative drought tolerant rootstock *viz.*, 1103-P, Dogridge and Salt Creek recorded the relatively highest shoot weight indicating that these rootstocks were found to be tolerable under drought condition.

5.2.3 Effect of water stress on fresh weight of root (g)

The effect of irrigation regimes on fresh weight of root of different rootstocks are displayed in Table 21 and graphically depicted in Fig. 18.

The different rootstocks under study, 1103-P was observed the maximum weight of fresh root followed by Dogridge, Salt Creek, 1613-C and 1616-C. The lowest weight of fresh root was recorded by SO4. The rootstocks with scheduling of irrigation of field capacity recorded significantly maximum fresh weight at root which was decreased with increase in water stress. The lowest reduction percentage in fresh weight of root was observed in 1103-P which was followed by Dogridge, Salt Creek, 1613-C and 1616-C. The maximum reduction percentage in fresh weight of root was observed by SO4.

Due to increase in the water stress the length of the main root was decreased with decrease in size of the meristematic cells and turgidity of cells. Similarly, the number of primary roots per vine as well as number of secondary roots per vine were also decreased which affect fresh weight of root.

These findings are similar with those reported by Prakash and Bhatt (1999) According to him, the root weights of grapevine in different categories showed that, in all the categories the Dogridge had maximum root weight while lowest in Arka Neelamani. Hanson *et al.* (1979) prolonged PEG stress and observed that in the first four days fruits weight steadily fell to less than half of a initial value. Ashraf and Mehmood (1990) studied four species of *Brassica* and reported that during drought stress, the drought tolerant species *B. napus* produced relatively greater fresh weight while drought susceptible species *B. carinata* produced significantly lower fresh weight. The similar results are obtained by Perry *et al.* (1983), During (1979) and Miah *et al.* (1980).

From this, it is clear that rootstock 1103-P has the high fresh weight of root indicated that 1103-P was found to be more tolerant under water stress condition.

5.2.4 Effect of water stress on dry weight of shoot (g)

The data in respect of dry weight of shoot as influenced by various irrigation regimes are presented in Table 22 and graphically shown in Fig. 19.

In all the rootstocks of grapes, the maximum dry weight of shoot was noticed by 1103-P which was followed by Dogridge, Salt Creek, 1613-C which was at par with 1616-C. The minimum dry weight of shoot was noticed by SO4. Significantly maximum dry weight of shoot was recorded with scheduling of irrigation at field capacity which was decreased with increase in water stress. The minimum reduction in dry weight of shoot was recorded by 1103-P which was followed by Dogridge, Salt Creek, 1613-C and 1616-C. The maximum reduction percentage in respect of dry weight of shoot was recorded by SO4.

The fresh weight of the shoot was decreased significantly with increase in water stress ultimately the dry weight of shoot was also declined.

These results are in confirmity with those reported by During (1979) in his opinion the soil moisture stress led to a reduction of shoot growth and dry weight of the shoot. Rosaria and Fajardo (1988) reported significant interaction between peanut cultivars and water stress on root dry weight basis. Similar findings were also reported by the Hanson *et al.* (1977), Singh and Singh (1986) and Astraf and Mehmood (1990).

From this, it is clear that the 1103-P was found to be more tolerant to water stress followed by Dogridge and Salt Creek as these rootstocks having highest weight of dry shoot.

5.2.5 Effect of water stress on dry weight of root (g)

The data regarding dry weight of root as influenced by different irrigation regimes on various rootstocks are presented in Table 23 and graphically depicted in Fig. 20.

Among the different rootstock the maximum dry weight of root was noticed by 1103-P which was followed by Dogridge, Salt Creek, 1613-C and 1616-C. The minimum dry weight of root was recorded by SO4. The maximum dry weight of root was recorded when scheduling of irrigation at field capacity which was decreased with increase in water stress. The lowest reduction percentage in dry weight of root was recorded by 1103-P which was followed by Dogridge, Salt Creek, 1613-C and 1616-C. The maximum reduction percentage in dry weight of root was recorded by SO4.

As the fresh weight of the root was decreased significantly with increase in water stress ultimately the dry weight of the root was also decreased.

These findings are in confirmity with those reported earlier by Prakash and Bhatt (1999). According to them, the root weight on dry weight basis in different category of roots showed that, in all the categories Dogridge had maximum root weight while lowest in Arka Neelamani. These results suggested the vigour as observed by shoot growth also manifested itself by producing maximum number of roots. These results was also supported by Miah *et al.* (1988). Rosario and Fajardo (1988) and Ashraf and Mehmood (1990).

5.2.6 Effect of water stress on Root : Shoot ratio on fresh weight basis

The results on root:shoot ratio on fresh weight basis as influenced by different levels of irrigations on various rootstocks are presented in Table 24 and graphically shown in Fig. 21.

In all the rootstocks of grapes, the maximum root:shoot ratio on fresh weight basis was, noticed by 1103-P which was followed by Dogridge, Salt Creek, 1613-C and 1616-C however, the minimum root:shoot ratio on fresh weight basis was recorded by SO4. Significantly maximum ratio on fresh weight basis was recorded with scheduling of irrigation at field capacity which was decreased with increase in water stress. The interaction effect between irrigation regimes and different rootstocks were non significant.

The fresh weight of the shoot was observed with increase in water stress as there was decrease in height of shoot, total number of leaves and shoots. As decrease in fresh weight of the shoot fresh weight of the root was also decreased with decrease in length of main root, number of primary and secondary roots and ultimately the root : shoot ratio on fresh weight basis was decreased.

These results are found similar with those reported by During (1979). According to him, the grapevine cultivar Muller-Thurgau, Riesling was more drought tolerant had a higher root : shoot ratio. These results are also reported by Sandhu and Laude (1958), Begg and Turner (1976) and Kummerow (1980). These results are more or less confirmity with Eibach and Alleweldt (1985) showed that different effect of drought on shoot and root growth cause a pronounced alteration of the shoot to root ratio. This ratio being low at a low water supply.

From this, we can conclude that the drought tolerant rootstock 1103-P has the highest root : shoot ratio on fresh weight basis while drought susceptible rootstock SO4 has the lowest root : shoot ratio on fresh weight basis.

5.2.7 Effect of water stress on root:shoot ratio on dry weight basis

The data pertaining to the root:shoot ratio on dry weight basis as influenced by various levels of irrigation are presented in Table 25 and graphically depicted in Fig. 22.

Among the different rootstocks of grapes, the maximum ratio on dry weight basis was recorded by 1103-P followed by Dogridge, Salt Creek, 1613-C and 1616-C. The lowest ratio on dry weight basis was observed by SO4. The vines receiving irrigation level at field capacity recorded significantly maximum ratio on dry weight basis which was decreased with increase in water stress. The 1103-P which was tolerant to water stress has the maximum root : shoot ratio (1.70) on dry weight basis.

As the dry weight of the shoot and root was decreased due to decrease in the fresh weight of root and shoot. Similarly, the ratio of root : shoot on dry weight basis was decreased with increase in water stress.

These findings are in confirmity with those reported by Begg and Turner (1976). According to them, the root to shoot ratio of plants increased with the increase in the water stress. During (1979) reported that the grapevine cultivar Muller-Thurgau, Riesling was more drought tolerant had a higher root : shoot ratio. These results are also obtained by Sandhu and Laude (1958), Kummerow (1980) and Matthews *et al.* (1990). These results are also more or less confirmity with Eibach and Alleweldt (1985) showed that different effect of drought on shoot and root growth cause a pronounced alteration of shoot to root ratio. This ratio being low at a low water supply.

From this, it is clear that as the highest root : shoot ratio on dry weight basis observed by 1103-P and subsequently by Dogridge and Salt Creek indicated that these rootstocks tolerant to water stress while drought susceptible rootstocks SO4 has the lowest root : shoot ratio on dry weight basis.

5.2.8 Effect of water stress on stomatal frequency per mm^2

The relevant data on the stomatal frequency affected by different irrigation regimes are presented in Table 26 and graphically shown in Fig. 23.

The rootstocks of grapes under investigation, the maximum stomatal frequency were noticed by SO4 followed by 1616-C, 1613-C, Salt Creek and Dogridge. The minimum stomatal frequency was observed by SO4. The highest stomatal frequency was recorded when irrigation was scheduled at field capacity which was decreased with increase in water stress. The maximum decrease in stomatal frequency was observed by 1103-P followed by Dogridge, Salt Creek, 1613-C and 1616-C. The lowest decrease in stomatal frequency was observed by SO4. The vines of rootstocks 1616-C and SO4 could not stand with scheduling of irrigation at 0.7 bar.

The number of stomata per unit leaf area per mm^2 has been shown to vary among genotypes and within a species. Stomata plays an important role in photosynthesis and respiration process as the exchange of gases take place through their pores. Similarly, they are responsible for the evaporation of water from the mesophyll tissue of leaves. Stomatal frequency has great significance in the physiological process of plants. The stomata also act as plant protective mechanisms by decreasing water loss through their closure during periods of plant water deficits and light intensity.

These results are in confirmity with those reported by During (1980). According to him, the variation in stomatal frequency in five *Vitis* species to the range of 177 to 376/mm^2. In *Vitis rupestris* he observed lowest stomatal frequency among the *Vitis* species in his study Dernoeden and Butler (1979) also supported that stomatal density of leaves was much greater on the adaxial surface as compared to the abaxial surface Patil and Patil (1994) observed the highest stomatal frequency in *V. assamica* and lowest in *V. mollis*. Patil *et al.* (1999) showed that stomatal frequency was very less in *V. champini* Cv. Digraset, *V. tiliefolia* and *Berlandiri* x *Riparia*. However, all these characters exhibit their tolerance to drought. Stomatal frequency was maximum in *Vitis paniflora*, while minimum in *Berlandiri* x *Riparia*.

From this, it is clear that the drought tolerant rootstock posses minimum frequency while drought susceptible rootstock has maximum frequency.

5.3 Biochemical parameters

5.3.1 Effect of water stress on chlorophyll 'a' content (mg g^{-1} FW)

The data in respect of chlorophyll 'a' content as influenced by various regimes are presented in Table 27 and graphically shown in Fig. 24.

In all the rootstocks of grapes the maximum chlorophyll 'a' content was noticed by 1103-P followed by Dogridge, Salt Creek, 1613-C and 1616-C. The lowest chlorophyll 'a' content was noticed by SO4.

Significantly, maximum chlorophyll 'a' content was recorded with scheduling of irrigation at field capacity which was decreased with increase in water stress. The minimum reduction in chlorophyll 'a' content was recorded by 1103-P followed by Dogridge, Salt Creek, 1613-C and 1616-C. The maximum reduction in chlorophyll 'a' content was recorded by SO4. The rootstocks 1616-C and SO4 were could not stand under high water stress (i.e. scheduling of irrigation at 0.7 bar).

From these results, it is indicated that rootstocks 1103-P, Dogridge and Salt Creek were significantly less affected in respect of decline in the contents of chlorophyll 'a' than those of SO4, 1616-C and 1613-C, indicating there by that former three rootstocks were more tolerant to drought than later. However, no reports are available to support these specific findings. Under these circumstances, these findings need further confirmation.

5.3.2 Effect of water stress on chlorophyll 'b' content (mg g^{-1} FW)

The data regarding chlorophyll 'b' content as influenced by different irrigation regimes on various rootstocks are presented in Table 28 and graphically depicted in Fig. 25.

Among the different rootstocks of grapes, the maximum chlorophyll 'b' content was noticed by 1103-P which was followed by Dogridge, Salt Creek, 1613-C and 1616-C. The lowest chlorophyll 'b' content was observed by SO4. The maximum chlorophyll 'b' content was recorded when irrigation was scheduled at field capacity which was decreased with increase in water stress. The lowest reduction percentage in chlorophyll 'b' content was recorded in 1103-P which was followed by Dogridge, Salt Creek, 1613-C and 1616-C. The highest reduction percentage in chlorophyll 'b' content was recorded by SO4.

From the results, it is clear that the decrease in the contents of chlorophyll 'a' registered under the rootstocks 1103-P followed by Dogridge and Salt Creek were significantly less affected that those registered under the rootstocks of SO4, 1616-C and 1613-C indicating thereby superiority of the former group over the later in regard to their ability to tolerant drought conditions. However, no specific reports in respect of decline in the contents of chlorophyll 'a' due to water stress are available to support these findings.

5.3.3 Effect of water stress on total chlorophyll content (mg g^{-1} FW)

The results on total chlorophyll content as influenced by different levels of irrigations on various rootstocks are presented in Table 29 and graphically shown in Fig. 26.

In all the different rootstocks of grapes, the maximum total chlorophyll was observed by 1103-P followed by Dogridge, Salt Creek, 1613-C and 1616-C. The minimum total chlorophyll content was recorded by SO4. Significantly maximum total chlorophyll content was recorded with scheduling of irrigation at field capacity which was decreased with increase in water stress. The minimum reduction in total chlorophyll content was recorded by 1103-P which was followed by Dogridge, Salt

Creek, 1613-C and 1616-C. The maximum reduction was noticed by SO4. The rootstocks of 1616-C and SO4 were susceptible to drought hence the leaf sample was not available at high water stress (i.e. scheduling of irrigation at 0.7 bar).

The chloroplasts-green plastids in which chlorophyll was present which was the site of photosynthesis, by which CO_2 from the air and water from the soil are combined by light energy to form sugar. Moderate water stress slows chlorophyll formation (Bourque and Naylor 1971),(Alberte *et al.* 1975) and severe dehydration of plant tissue not only interferes with chlorophyll formation but also caused destruction of that already present. As a result, leaves of plants subjected to drought tend to turn yellow. The light harvesting chlorophyll 'a' and chlorophyll 'b' protein is most severely affected by water stress (Alberte *et al.* 1977).

These findings are in confirmity with those obtained by Doroftei *et al.* (1993). According to them, the photosynthetic pigments in the leaves of grape under different soil moisture condition reduces the production of green pigment. Ramteke *et al.* (1999) showed that Tas-A-Ganesh vines on Dogridge rootstock to imposed water stress reduces the chlorophyll content significantly by 15.1 per cent under the soil moisture stress than irrigated ones. The more or less similar results are obtained by Dwivedi *et al.* (1979) and Sharma *et al.* (1990).

From this, it is clear that the drought tolerant rootstocks 1103-P followed by Dogridge registered minimum decrease in total chlorophyll content while drought susceptible rootstocks showed maximum decrease in total chlorophyll content.

5.3.4 Effect of water stress on Chlorophyll stability index (CSI)

The effect of irrigation regimes on chlorophyll stability index of different rootstocks are displayed in Table 30 and graphically depicted in Fig. 27.

Among the different rootstocks the minimum C.S.I. was observed by 1103-P followed by Dogridge, 1613-C and 1616-C. The highest C.S.I. was observed by SO4 however it was at par with Salt Creek. The rootstocks with scheduling of irrigation at field capacity recorded significantly maximum C.S.I. which was decreased with increase in water stress. The highest percentage of reduction in C.S.I. was observed by 1103-P which was followed by Dogridge, 1616-C, Salt Creek and 1613-C while minimum percentage of reduction in C.S.I was observed by SO4. The vines of rootstock 1616-C and SO4 not stand with scheduling of irrigation at 0.7 bar.

These findings are in confirmity with those reported by Koleyoseas (1958). According to him the C.S.I. is very less in *Vitis berlandiri*, *V. champini* cv. Digraset, *V. longi*, *V. tiliefolia* and *Berlandiri* x *Riparia*. Hence, these types are significantly superior for drought resistance than other types studied. The lower the chlorophyll stability index the higher was the drought resistance (Anonymous, 1962), Patil *et al.* (1999) had opinioned that the wide variations in C.S.I. of grape cultivars *Vitis* species and rootstocks. In grape cultivars of *Vitis vinifera* cv. Gulabi, *V. labrusca* cv. Concord and *V. rotundifolia* cv. James have better drought resistance. Likewise, *V. arizonica, V. berlandiri, V. candicans* and *V. tiliefolia* and rootstocks *Berlandiri* x *Riparia* and Digraset confirms their drought resistance. The similar results are obtained by Murthy and Mujumdar (1962), Matthews and Ramadasan (1973), Chhabra *et al.* (1981) and Sharma and Gill (1981).

From this, it is clear that the rootstock 1103-P registered lower C.S.I. value indicating, perhaps, their superiority to drought condition over the rest of rootstock species except Dogridge.

Based on the values of percent reduction in respect of morphological, physiological and biochemical attributes irrigation regimes are presented in Table 31.

Among the various rootstocks under investigation, the minimum reduction in morphological characters were observed with scheduling of irrigation at 0.5 bar and 0.7 bar, in 1103-P (7.72 % and 13.72 %) followed by Dogridge (10.68 % and 19.13 %), Salt Creek (15.86 % and 28.80 %), 1613-C (20.07 % and 35.64 %) and 1616-C (24.90 % and 44.45 %), respectively. While maximum reduction (29.01 % and 53.49 %) was observed in SO4 with scheduling of irrigation at 0.5 bar and 0.7 bar, respectively.

The minimum reduction in physiological characters were observed with scheduling of irrigation at 0.5 bar and 0.7 bar in 1103-P (9.42 % and 16.85 %) followed by Dogridge (12.42 and 22.97 %), Salt

Creek (14.90 % and 27.30 %), 1613-C (17.35 % and 31.50 %) and 1616-C (22.44 % and 44.48 %), respectively. The maximum reduction (25.28 % and 47.43 %) was observed in SO4 with scheduling of irrigation at 0.5 bar and 0.7 bar, respectively.

The rootstocks of 1616-C and SO4 can not withstand to high water stress i.e. scheduling of irrigation at 0.7 bar. The minimum reduction in biochemical characters were observed with scheduling of irrigation at 0.5 bar and 0.7 bar by 1103-P (6.20 % and 11.28 %) followed by Dogridge (8.22 % and 14.21 %), Salt Creek (10.99% and 22.21 %), 1613-C (14.25 % and 27.88 %) and 1616-C (18.09 %), respectively. The maximum reduction (21.44 %) was observed in SO4 with scheduling of irrigation at 0.5 bar.

From this, it is clear that the minimum reduction in morphological, physiological and biochemical characters were observed by 1103-P followed by Dogridge, Salt Creek, 1613-C and 1616-C while maximum reduction was observed by SO4.

Table 31. Percentage reduction values in respect of morphological, physiological and biochemical attributes of different grape rootstocks based on irrigation regimes

Sr. No.	Character	Per cent reduction																	
		Dogridge			Salt Creek			1613-C			1616-C			1103-P			SO4		
		0.3 bar	0.5 bar	0.7 bar	0.3 bar	0.5 bar	0.7 bar	0.3 bar	0.5 bar	0.7 bar	0.3 bar	0.5 bar	0.7 bar	0.3 bar	0.5 bar	0.7 bar	0.3 bar	0.5 bar	0.7 bar
A.	**Morphological character**																		
1.	**Growth attributes**																		
i.	Height of shoot (cm)	0.00	10.56	19.13	0.00	18.48	35.74	0.00	24.73	43.24	0.00	27.06	49.25	0.00	7.41	12.71	0.00	36.04	64.09
ii.	Diameter of shoot (mm)	0.00	9.77	16.83	0.00	17.22	33.34	0.00	24.40	44.64	0.00	30.47	50.48	0.00	7.72	13.12	0.00	36.48	65.55
iii.	No. of shoots per vine	0.00	17.64	31.93	0.00	21.35	37.86	0.00	27.45	47.71	0.00	31.40	57.85	0.00	10.07	17.05	0.00	34.90	65.09
iv.	Length of internode (cm)	0.00	8.26	15.04	0.00	16.89	31.11	0.00	21.11	38.46	0.00	25.47	47.65	0.00	6.35	11.34	0.00	31.05	57.91
2.	**Leaf attributes**																		
i.	Total number of leaves per vine	0.00	10.34	16.76	0.00	16.78	29.58	0.00	22.82	38.65	0.00	27.03	47.87	0.00	5.86	10.40	0.00	40.99	71.80
3.	**Root attributes**																		
i.	Length of main root (cm)	0.00	13.76	21.74	0.00	20.34	34.35	0.00	24.66	41.86	0.00	29.27	52.29	0.00	9.43	16.46	0.00	34.21	63.55
ii.	No. of primary roots per vine	0.00	10.79	19.88	0.00	19.20	34.43	0.00	24.09	42.77	0.00	30.64	54.03	0.00	9.23	15.76	0.00	33.94	63.30
iii.	No. of secondary roots per vine	0.00	12.83	22.29	0.00	19.84	35.49	0.00	24.63	43.01	0.00	36.90	57.53	0.00	9.03	15.57	0.00	34.10	61.84
4.	**Days to appearance of stress**																		
i.	Leaf rolling																		
a.	Days to 50 % rolling	0.00	8.89	17.43	0.00	10.81	20.07	0.00	12.44	23.23	0.00	16.66	31.42	0.00	7.66	14.11	0.00	18.08	35.10
b.	Days to 100 per cent rolling	0.00	8.46	15.57	0.00	10.38	19.58	0.00	12.77	23.64	0.00	16.84	32.23	0.00	6.93	12.08	0.00	19.14	37.44
ii.	Leaf shrivelling																		

Table 31 contd.....

a.	Day to initiation for shrivelling	0.00	9.12	17.42	0.00	11.84	20.85	0.00	13.98	24.35	0.00	17.28	32.09	0.00	6.78	13.21	0.00	19.59	37.16
b.	Days to >50 % shrivelling	0.00	9.14	17.07	0.00	11.33	20.33	0.00	13.82	24.82	0.00	17.01	33.19	0.00	6.85	13.19	0.00	18.80	35.77
iii.	*Days to dryness of leaf*	0.00	9.27	17.54	0.00	11.69	21.72	0.00	14.06	26.91	0.00	17.73	31.91	0.00	7.08	13.36	0.00	19.84	37 74
	Sub mean	**0.00**	**10.68**	**19.13**	**0.00**	**15.86**	**28.80**	**0.00**	**20.07**	**35.64**	**0.00**	**24.90**	**44.45**	**0.00**	**7.72**	**13.72**	**0.00**	**29.01**	**53.49**
B.	**Physiological parameters**																		
1.	Relative water content (%)	0.00	7.67	13.28	0.00	10.56	16.68	0.00	12.20	22.11	0.00	14.36	*	0.00	6.35	10.86	0.00	16.80	*
2.	Fresh weight of shoot per vine (g)	0.00	9.95	19.12	0.00	11.57	23.86	0.00	14.02	26.91	0.00	20.93	40.19	0.00	6.20	10.92	0.00	24.40	42.97
3.	Fresh weight of root per vine (g)	0.00	14.67	26.88	0.00	17.37	32.65	0.00	20.67	35.08	0.00	28.52	49.35	0.00	10.57	19.00	0.00	30.64	54.69
4.	Dry weight of shoot per vine (g)	0.00	11.93	23.14	0.00	15.01	28.49	0.00	17.56	32.76	0.00	20.97	40.33	0.00	8.78	16.18	0.00	25.11	42.34
5.	Dry weight of root per vine (g)	0.00	17.88	32.45	0.00	19.99	34.82	0.00	22.30	40.62	0.00	27.40	48.03	0.00	15.20	27.28	0.00	29.43	49.71
	Sub mean	**0.00**	**12.42**	**22.97**	**0.00**	**14.90**	**27.30**	**0.00**	**17.35**	**31.50**	**0.00**	**22.44**	**44.48**	**0.00**	**9.42**	**16.85**	**0.00**	**25.28**	**47.43**
C.	**Biochemical parameters**																		
1.	Chlorophyll 'a' content	0.00	8.90	15.77	0.00	11.88	24.12	0.00	15.84	30.99	0.00	20.60	*	0.00	6.63	12.46	0.00	23.43	*
2.	Chlorophyll 'b' content	0.00	7.60	12.13	0.00	9.86	19.73	0.00	12.19	23.86	0.00	14.93	*	0.00	5.61	5.67	0.00	18.92	*
3.	Total chlorophyll content	0.00	8.15	14.72	0.00	11.23	22.77	0.00	14.71	28.78	0.00	18.75	*	0.00	6.35	11.71	0.00	21.96	*
	Sub mean	**0.00**	**8.22**	**14.21**	**0.00**	**10.99**	**22.21**	**0.00**	**14.25**	**27.88**	**0.00**	**18.09**	*	**0.00**	**6.20**	**11.28**	**0.00**	**21.44**	*
	Mean	**0.00**	**10.74**	**19.34**	**0.00**	**14.93**	**27.50**	**0.00**	**18.59**	**33.54**	**0.00**	**23.34**	**44.45**	**0.00**	**7.91**	**14.12**	**0.00**	**27.04**	**52.06**

* Sample was not available.

SUMMARY AND CONCLUSION

6. SUMMARY AND CONCLUSION

The investigation on "Screening of grape rootstocks for drought tolerance" was conducted in pot culture under glass house conditions in the Department of Horticulture, Mahatma Phule Krishi Vidyapeeth, Rahuri during the year 2000-2001 with a view to study morphological, physiological and biochemical characters of the different rootstocks to evaluate rootstocks for drought tolerance from those under study. For this purpose, six grape rootstock species *viz.* Dogridge, Salt Creek, 1613-C, 1616-C, 1103-P and SO4 were replicated two times in factorial completely randomised design (FCRD). Six months old rooted cuttings of these rootstocks were transplanted in pot and recut was taken after six months for uniform growth of rooted cuttings. They were subjected to moisture stress according to the moisture tension 0.3 bar, 0.5 bar and 0.7 bar. Based on the morphological, physiological and biochemical parameters and the results under investigation are briefly summarised.

6.1 Morphological parameters

6.1.1 Growth attributes

6.1.1a. Height of shoot (cm)

All the rootstocks had significantly higher shoot height, 1103-P recorded maximum height (61.79 cm). The vines which were receiving of irrigation at 0.7 bar had significantly lower height (40.77 cm) as compared to vines which received irrigation at 0.3 bar (64.73 cm). The minimum height of shoot was recorded by SO4 (22.49 cm) with scheduling of irrigation at 0.7 bar.

6.1.1b. Diameter of shoot (mm)

All the rootstocks were significantly superior to the rootstock SO4 and among the rootstock under study Dogridge was the most significant (3.38 mm). The water stress with scheduling of irrigation at 0.7 bar caused the lowest diameter of shoot (2.28 mm) compare to irrigation scheduling at 0.3 bar (3.67 mm).

6.1.1c. Number of shoots per vine

The rootstocks *viz.* 1103-P, 1613-C and Dogridge were significantly superior to remaining rootstocks *viz.* Salt Creek, 1616-C and SO4 in respect of number of shoots per vine. The vines with scheduling of irrigation at 0.7 bar recorded significantly less number of shoots per vine (8.75) compared to scheduling of irrigation at 0.3 bar (15.23).

6.1.1d. Length of internode (cm)

The significantly maximum length of internode was recorded by 1103-P (6.85 cm) followed by Dogridge (6.28 cm) and Salt Creek (5.53 cm). The length of internode was significantly reduced in vines receiving irrigation at 0.7 bar (4.43 cm) as compared to 0.3 bar (6.58 cm) and 0.5 bar (5.41 cm).

6.1.2 Leaf attributes

6.1.2a. Total number of leaves per vine

All the rootstocks had significantly higher total number of leaves per vine. 1103-P recorded the maximum total number of leaves per vine (98.83) followed by Dogridge (78.00) and 1613-C (75.33). The minimum total number of leaves per vine were recorded by SO4 (35.96). The vines receiving irrigation at 0.7 bar had significantly lower total number of leaves per vine (54.52) as compared to vines receiving irrigation at 0.3 bar (80.94) and 0.5 bar (65.69).

6.1.2b. Leaf area (cm^2)

Salt Creek and 1613-C had significantly greater leaf area while the minimum leaf area was noticed by 1103-P (51.35 cm^2). The vines with scheduling of irrigation at 0.7 bar had significantly lower leaf area (54.06 cm^2) as compared to scheduling of irrigation at 0.3 bar (78.19 cm^2) and at 0.5 bar (65.02 cm^2).

6.1.3 Root attributes

6.1.3a. Length of main root (cm)

The rootstock 1103-P recorded significantly maximum root length (56.03 cm) followed by Dogridge (50.67 cm) and 1613-C (43.78 cm). The root length was significantly reduced by vines which receiving irrigation at 0.7 bar (34.03 cm) as compared to vines receiving irrigation at 0.3 bar (54.00 cm) and at 0.5 bar (42.49 cm).

6.1.3 b. Number of primary roots per vine

1103-P and Dogridge were significantly superior to rest of rootstocks under investigation. Significantly lower number of primary roots per vine were recorded by vines with scheduling of irrigation at 0.7 bar (12.23) than scheduling of irrigation at 0.3 bar (18.96) and at 0.5 bar (15.21).

6.1.3c. Number of secondary roots per vine

1103-P and Dogridge were significantly superior to other rootstocks. Significantly lower number of secondary roots per vine were recorded by vines with scheduling of irrigation at 0.7 bar (20.79) than scheduling of irrigation at 0.3 bar (32.83) and at 0.5 bar (25.79).

6.1.4 Days to appearance of stress

6.1.4a. Leaf rolling

6.1.4.a_1. Days to 50 per cent leaf rolling

The rootstock 1103-P recorded the maximum days to 50 per cent leaf rolling (37.79) followed by Dogridge (32.04) and Salt Creek (29.04). The days to 50 per cent leaf rolling was significantly lower under scheduling of irrigation at 0.7 bar (24.38) as compared to scheduling of irrigation at 0.3 bar (31.35) and at 0.5 bar (27.68).

6.1.4 a_2. Days to 100 per cent leaf rolling

The rootstock 1103-P recorded the maximum days to 100 per cent leaf rolling (52.33) followed by Dogridge (42.08) and Salt Creek (37.92). The days to 100 per cent leaf rolling was significantly lower under scheduling of irrigation at 0.7 bar (32.17) as compared to scheduling of irrigation at 0.3 bar (41.06) and at 0.5 bar (36.31).

6.1.4b. Leaf shrivelling

6.1.4b$_1$. Days to initiation of leaf shrivelling

In all the rootstocks 1103-P recorded the maximum days to initiation of leaf shrivelling (32.67) followed by Dogridge (27.46) and Salt Creek (23.50). The days to initiation of leaf shrivelling was significantly lower under scheduling of irrigation at 0.7 bar (19.96) as compared to scheduling of irrigation at 0.3 bar (25.73) and at 0.5 bar (22.60).

6.1.4b$_2$. Days to greater than 50 per cent leaf shrivelling

Among the different rootstocks 1103-P recorded the maximum days to greater than 50 per cent leaf shrivelling (45.96) followed by Dogridge (37.42) and Salt Creek (33.54). The days to greater than 50 per cent leaf shrivelling was significantly lower under scheduling of irrigation at 0.7 bar (28.46) as compared to scheduling of irrigation at 0.3 bar (36.73) and at 0.5 bar (32.31).

6.1.4c. Days to dryness of leaf

The rootstock 1103-P recorded the maximum days to dryness of leaf (57.54) followed by Dogridge (45.42) and Salt Creek (39.88). The days to dryness of leaf was significantly lower with scheduling of irrigation at 0.7 bar (33.94) as compared to scheduling of irrigation at 0.3 bar (44.13) and at 0.5 bar (38.69).

6.2 Physiological parameters

6.2.1 Relative leaf water content (%)

The rootstocks *viz.* 1103-P, Dogridge and Salt Creek were significantly superior to rootstocks *viz.* 1613-C, 1616-C and SO4 in respect of relative leaf water content. The vines with scheduling of irrigation at 0.7 bar recorded significantly less relative leaf water content (45.09%) compared to scheduling of irrigation at 0.3 bar (78.80%) and at 0.5 bar (70.00%).

6.2.2 Fresh weight of shoot (g)

1103-P and Dogridge had significantly greater fresh weight of shoot while the lowest fresh weight of shoot was noticed by SO4 (26.45g). The vines with scheduling of irrigation at 0.7 bar had significantly lower fresh weight of shoot (27.56 g) as compared to scheduling of irrigation at 0.3 bar (37.56 g) and at 0.5 bar (32.26 g).

6.2.3 Fresh weight of root (g)

In all the rootstocks 1103-P recorded the maximum fresh weight of root (55.72 g) followed by Dogridge (44.04 g) and Salt Creek (34.58 g). The fresh weight of root was significantly lower under scheduling of irrigation at 0.7 bar (27.72 g) as compared to scheduling of irrigation at 0.3 bar (41.27 g) and at 0.5 bar (33.68 g).

6.2.4 Dry weight of shoot (g)

1103-P and Dogridge had significantly greater dry weight of shoot while minimum dry weight of shoot was noticed by SO4 (11.90 g). The vines with scheduling of irrigation at 0.7 bar had significantly lower dry weight of shoot (11.90 g) as compared to scheduling of irrigation at 0.3 bar (16.97 g) and at 0.5 bar (14.23 g).

6.2.5 Dry weight of root (g)

Among the different rootstocks 1103-P recorded the maximum dry weight of root (30.23 g) followed by Dogridge (20.85 g) and Salt Creek (15.30 g). The dry weight of root was significantly lower under scheduling of irrigation at 0.7 bar (12.29 g) as compared to scheduling of irrigation at 0.3 bar (18.97 g) and at 0.5 bar (15.21 g).

6.2.6 Root : shoot ratio on fresh weight basis

The rootstock 1103-P recorded the highest fresh root : shoot ratio (1.40) followed by Dogridge (1.21) and Salt Creek (1.05). The vines receiving irrigation at 0.7 bar were observed lower root : shoot ratio on fresh weight basis (0.95) as compared with scheduling of irrigation at 0.3 bar (1.08) and at 0.5 bar (1.01).

6.2.7 Root : shoot ratio on dry weight basis

The rootstock 1103-P recorded the highest dry root : shoot ratio (1.70) followed by Dogridge (1.30) and Salt Creek (1.07). The vines receiving irrigation at 0.7 bar were observed lower root : shoot ratio on dry weight basis (0.96) as compared with scheduling of irrigation at 0.3 bar (1.08) and at 0.5 bar (1.01).

6.2.8 Stomatal frequency per mm^2

In all the rootstocks 1103-P recorded the lowest stomatal frequency (96.69 per mm^2) while highest stomatal frequency was observed in SO4 (214.91 per mm^2). The rootstocks with scheduling of irrigation at 0.7bar had significantly lower stomatal frequency (124.92 per mm^2) as compared to scheduling of irrigation at 0.3 bar (167.92 per mm^2) and at 0.5 bar (157.35 per mm^2).

6.3 Biochemical parameters

6.3.1 Chlorophyll 'a' content (mg g^{-1} FW)

The rootstocks *viz.* 1103-P, Dogridge and Salt Creek were significantly superior to rootstocks *viz.* 1613-C, 1616-C and SO4 in respect of chlorophyll 'a' content on fresh weight basis. The vines with scheduling of irrigation at 0.7 bar recorded significantly less chlorophyll 'a' content (0.795 mg g^{-1} FW) compared to scheduling of irrigation at 0.3 bar (1.365 mg g^{-1} FW) and at 0.5 bar (1.180 mg g^{-1} FW).

6.3.2 Chlorophyll 'b' content (mg g^{-1} FW)

1103-P and Dogridge recorded the highest chlorophyll 'b' content indicating their tolerance to drought. The rootstock SO4 recorded the lowest chlorophyll 'b' content (0.303 mg g^{-1} FW) indicating susceptible to drought. The vines receiving irrigation at 0.7bar had lower chlorophyll 'b' content (0.340 mg g^{-1} FW) as compared to scheduling of irrigation at 0.3 bar (0.580 mg g^{-1} FW) and at 0.5 bar (0.515 mg g^{-1} FW).

6.3.3 Total chlorophyll content (mg g^{-1} FW)

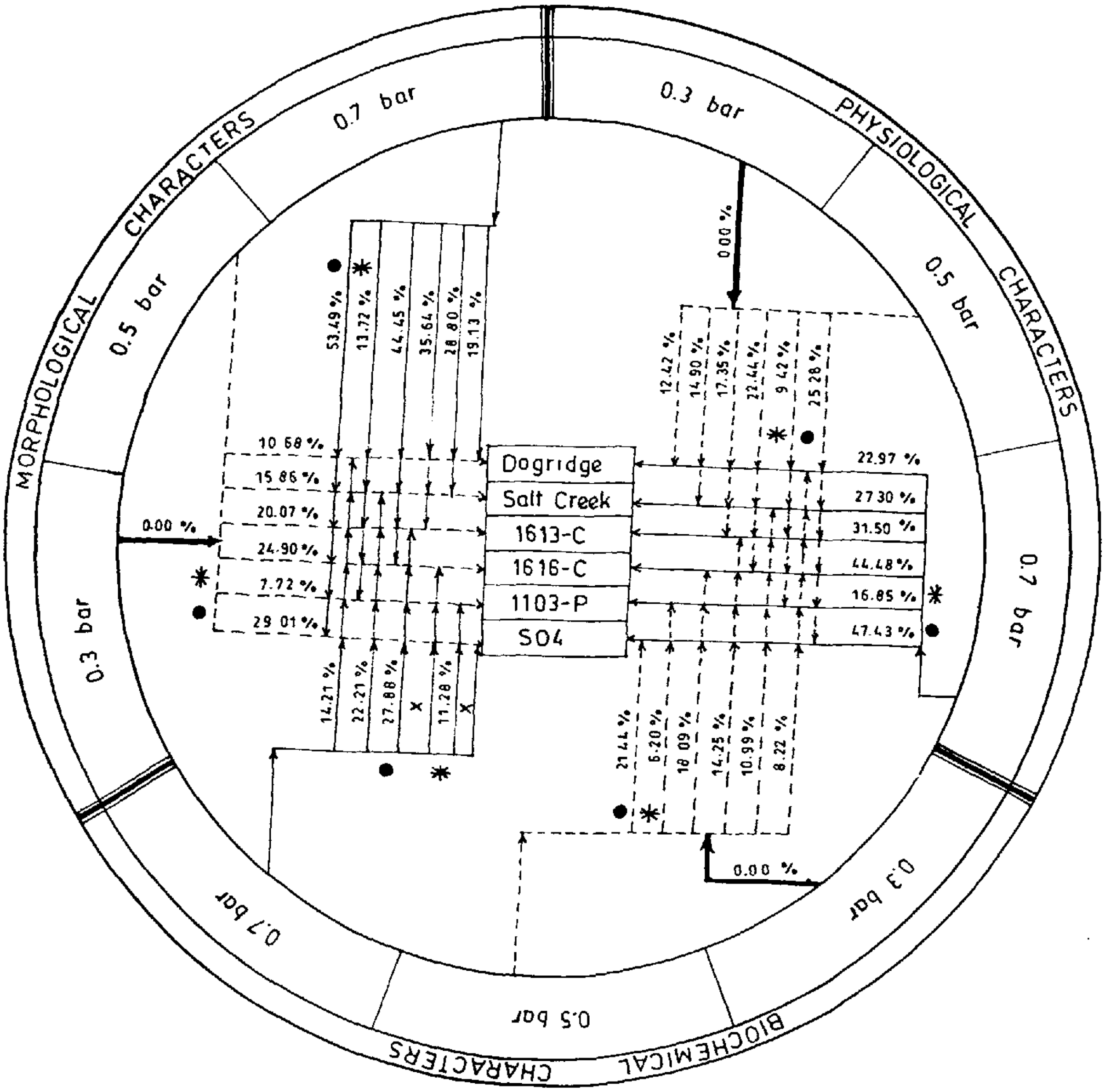
In all the rootstocks 1103-P recorded the highest total chlorophyll content (2.246 mg g^{-1} FW) while lowest total chlorophyll content was observed by SO4 (0.913 mg g^{-1} FW). The rootstocks with scheduling of irrigation at 0.7 bar had significantly lower total chlorophyll content (1.134 mg g^{-1} FW) as compared to scheduling of irrigation at 0.3 bar (1.945 mg g^{-1} FW) and at 0.5 bar (1.697 mg g^{-1} FW).

6.3.4 Chlorophyll stability index (CSI)

Salt Creek and SO4 recorded the highest CSI indicating there susceptibility to water stress. The rootstock 1103-P recorded the lowest CSI (0.328) indicating tolerant to drought. The vines receiving irrigation at 0.7 bar had lower CSI (0.488) as compared to scheduling of irrigation at 0.3 bar (0.612) and at 0.5 bar (0.565).

Based on these results, the morphological parameters *viz.* minimum decrease in height of shoot, diameter of shoot, number of shoots per vine, length of internode, total number of leaves, length of main root, number of primary and secondary roots and days to leaf rolling, shrivelling and drying while maximum reduction in leaf area. Physiological parameters *viz.* less reduction in relative leaf water content, fresh and dry weight of root and shoot, highest root : shoot ratio on fresh and dry weight basis and maximum reduction in stomatal frequency, biochemical parameters *viz.* lowest chlorophyll stability index and highest chlorophyll 'a', 'b' and total chlorophyll content were found to be criteria for screening grape rootstocks for their drought tolerance. Considering these criteria, the rootstock species *viz.* 1103-P and Dogridge were most drought tolerant followed by Salt Creek, 1613-C, 1616-C and SO4.

Based on the investigation undertaken, it is suggested that 1103-P and Dogridge rootstocks can sustain under water stress condition and these rootstocks can be used for commercial grape garden in the arid as well as region having scarcity of water.



x Sample was not available

— 0.3 bar
---- 0.5 bar
— 0.7 bar
✳ Lowest reduction values
● Highest reduction values

Fig 28 Relative drought tolerance of grapevines based on irrigation regimes.

LITERATURE CITED

7. LITERATURE CITED

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*** Original not seen**

APPENDIX

8. APPENDIX - I

Observations on temperature and humidity under glasshouse conditions

Meteorological week	Temperature °C				Humidity %	
	Morning 07.30 Hrs.		Evening 14.30 Hrs.		Morning 07.30 hrs.	Evening 14.30 hrs.
	Maximum	Minimum	Maximum	Minimum		
The experiment was started on 6th February, 2001						
6	15.70	12.98	39.40	28.48	72.70	43.50
7	17.01	1436	41.21	26.56	74.46	31.07
8	18.77	14.54	43.19	27.21	62.21	27.79
9	19.94	15.69	40.86	25.74	63.64	28.43
10	20.60	16.17	41.06	25.56	62.60	27.50
11	21.93	18.50	41.76	25.94	71.07	27.11
12	23.16	19.13	42.91	25.44	67.93	22.68
13	22.91	18.17	43.37	25.36	62.12	21.64
14	22.81	18.68	43.10	24.31	66.82	18.79
15	22.71	18.50	42.43	24.86	65.89	22.46
16	20.91	16.11	40.68	25.33	60.04	27.43
17	23.63	18.57	42.74	26.46	60.68	26.32
18	24.33	20.33	43.23	26.93	68.88	26.69

APPENDIX - II

Characteristics of initial soil

A)	**Physical properties**	
1.	Field capacity	28.13 %
2.	Permanent wilting point	14.07 %
3.	Bulk Density	1.28 gm/cm^3
4.	Available water holding capacity	3.60 %
B)	***Chemical properties***	
1.	Available N (kg ha^{-1})	198.47
2.	Available P (kg ha^{-1})	16.80
3.	Available K (kg ha^{-1})	252.64
4.	Iron	4.64 ppm
5.	Manganese	6.84 ppm
6.	Zinc	1.50 ppm
7.	Copper	2.38 ppm

VITA

9. VITA

KADAM JITENDRAKUMAR HANAMANT

A candidate for the degree
of
MASTER OF SCIENCE (AGRICULTURE)
in
HORTICULTURE

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