

**EFFECT OF WATER STRESS AND MULCHING ON
MORPHOLOGICAL AND BIOCHEMICAL
CHARACTERISTICS OF *Matricaria chamomilla* L.**

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**EFFECT OF WATER STRESS AND MULCHING ON
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CHARACTERISTICS OF *Matricaria chamomilla* L.**

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In partial fulfillment of the requirements

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in

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Affectionately dedicated

To

my beloved parents

HORMOZ HONARY

MARYAM TAHMASEBI

my lovely family

KHATY SADR NABAVI

HASTI HONARY

&

My Adorable Chairperson

Dr. M. VASUNDHARA

**DIVISION OF HORTICULTURE
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BANGALORE**

CERTIFICATE

This is to certify that the thesis entitled “**EFFECT OF WATER STRESS AND MULCHING ON MORPHOLOGICAL AND BIOCHEMICAL CHARACTERISTICS OF *Matricaria chamomilla* L.**” submitted by **Mr. HOUMAN HONARY, ID No. PAK 7048** in partial fulfillment of the requirements for the Degree of **DOCTOR OF PHILOSOPHY in HORTICULTURE** to the University of Agricultural Sciences, Bangalore, is a record of research work carried out by him during the period of his study in this University under my guidance and supervision, and that no part of the thesis has been submitted for the award of any other degree, diploma, associateship, fellowship or other similar titles.

**BANGALORE
JULY, 2010**

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ABSTRACT

In this study *Matricaria chamomilla* L. belonging to the family Asteraceae was planted for 2 seasons (the pot and field investigations) under 3 different moisture conditions ($W_{100}=100\%$, $W_{80}=80\%$ and $W_{60}=60\%$ of field capacity) and 3 different mulch treatments (M_0 = No mulch or control M_1 = Dry lemon grass mulch M_2 = Plastic mulch) at UAS, GKVK, Bangalore.

In the pot experiment, the effect of water stress showed that highest dry flower yield, essential oil percentage and yield was obtained with W_{80} (irrigation at 80% FC). Further, the results of the interaction between water stress levels and mulching types showed that $W_{80}M_1$ (irrigation at 80% FC with lemon grass mulch) gave significantly high dry flower yield and essential oil yield when compared to the control. With regard to the proline production due to effect of water stress, highest proline production was obtained with W_{60} .

Under field experiment, the effect of water stress, recorded highest dry flower yield & essential oil yield in W_{80} and essential oil percentage in W_{60} treatments. Also, in the effect of mulching types, highest dry flower yield and essential oil yield was obtained with M_1 . Further, the results of the interaction between water stress levels and mulching types showed that $W_{80}M_1$ gave significantly high dry flower yield and essential oil yield compared to the control. Highest proline production was obtained with W_{60} . Main components of oil such as α -Bisabolol oxide B, α -Bisabolone oxide A, α -Bisabolol, Chamazulene, α -Bisabolol oxide A and (Z)-En-yn-dicycloether were obtained from $W_{60}M_0$, $W_{80}M_2$, $W_{100}M_0$, $W_{80}M_2$, $W_{80}M_1$ and $W_{60}M_1$, respectively.

The research underlines the fact that *Matricaria chamomilla* L. var. Vallary can be commercially viable under low irrigation regimes. Excessive watering decreased plant productivity, similarly water stress. Chamomile can be grown in a controlled environmental system for improved phytochemical production, as well as specific metabolite to target.

Signature of Student
(Houman Honary)

Signature of Major Advisor
(Dr. M. Vasundhara)

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Introduction

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I. INTRODUCTION

As many as 35,000-70,000 species of plants have been used at one time or another for medicinal purposes (Farnsworth & Soejarto, 1991). Medicinal and aromatic plants are offered in a wide variety of products in the market. These plants have been used in treating human diseases for thousands of years. Traditional medicine is still the primary source of treating disease for the majority of people in developing countries. Even among those to whom Western medicine is available, the number of people using complementary or alternative medicine is rapidly increasing worldwide (Lambert *et al.*, 1997).

The international trade is dominated by only few countries. About 80 % of the world-wide imports and exports are allotted to only 12 countries with the dominance of temperate Asian and European countries. While Japan and the Republic of Korea are the main consumers of pharmaceutical plants, China and India are the world's leading producing nations and Hong Kong, the USA and Germany stand out as important trade centers (Lange, 2004).

The human population is expected to increase to over 8 billion by the year 2020 (Ashraf and Harris, 2006). There seems to be an increasing interest by natural product chemists and the pharmaceutical industry in exploring the plant world for possible new medical products. To meet the increased demand for quality medicinal and aromatic plant products during the next 25 years, growers and processors will need to focus on various aspects of production, plant protection/conservation, crop domestication, genetic transformation, and product standardization (Craker, 2003).

The well known old-time drug, chamomile, is ascribed to *Matricaria chamomilla* Linn. ($2n = 18$) belonging to the family Asteraceae; Compositae. The German or Hungarian or small chamomile, having a variety of uses also yields an

essential oil, commonly known as 'Blue oil', on account of its deep blue colour; is of medicinal and aromatic importance and is in great demand throughout the world. Vernacular names of chamomile are **Bangla** - Babuna; **Gujarati**- Babuna, Sonamoti; **Hindi**- Babura, Bebunga, Sonamati; **Marati** - Babuna, Sonamoti; **Punjabi**- Sutelgul; **Tamil** - Seemasevanthi Poo; **English**- Bitter chamomile, Chamomile, German Chamomile (Deshpande, 2008).

The German chamomile is indigenous to Europe; its cultivation is fairly widespread in many European countries, viz., Germany, France, Yugoslavia, Hungary and Russian republics and India (Deshpande, 2008, Baby *et al.*, 2007).

Chamomile was introduced to India during Mughal period. It has been cultivated in Lucknow for about two hundred years and the crop was introduced in Punjab about three hundred years ago. It was introduced into Jammu in 1957. It is now grown on a commercial scale in Lucknow (UP), New Delhi, Bombay, Jammu, Punjab, Himachal Pradesh, Uttaranchal and Uttar Pradesh (Deshpande, 2008, Karia *et al.*, 2007).

Chamomile is an annual, herbaceous, much-branched, spreading or erect aromatic crop, reaching a height of 60-90 cm. The leaves are doubly pinnate, with narrow linear segments. The flower-heads are terminal and solitary with 1.3-2.5 cm diameter. The fruit is a small achene with 3-5 ridges and a single head has 40-50 seeds. The seeds are less than 1.0 mm and yellow or light-brownish in colour (Farooqi and Sreeramu, 2001).

The leaves are used as depurating, antihelmintic and antispasmodic. The flowers are used as expectorant, diuretic, in constitutional debility and dyspepsia. The oil is used in Homoeopathic, Ayurvedic and Unani medicines as tonic, gastric stimulant, dyspepsia, antirheumatic, in flatulence, colic, indigestion, apoplexies of the breast, diarrhoea, fever, benign neurosis, gastric ulcer, antiallergic, sedative, in

skin diseases, ophthalmic, jaundice, obesity and eye problem. As an essential aromatic oil it is used in cosmetics, beverages, confectionery, aromatherapy, lotion manufacturing, in hair oils, shampoo, soaps, creams, hair dye and talcum powder. In traces, it is similar to the aroma of Lavender and hence preferred in high- grade perfumes (Deshpande, 2008).

In the widest biological sense, stress can be any factor that may produce an adverse effect in individual organisms, populations, or communities. It has become traditional for ecologists, physiologists, and agronomists to divide stress experienced by plants into two major categories: biotic and abiotic. Abiotic stress management is one of the most important challenges facing agriculture.

Among these abiotic stresses, drought is highly unpredictable in terms of occurrence, severity, duration and its timing in relation to crop phenology. 84 per cent of the world's cultivated lands are rainfed and this has major implications for the global economy and trade. Northwest India includes 3.2 million hectare of land that experiences inherent drought with highly erratic distribution of annual rainfall of 150 to 350 mm (Ashraf and Harris, 2006).

In simple terms, water deficit develops during periods when water loss due to transpiration exceeds absorption. Management of drought is the key issue for sustained agricultural production in areas depending on rains for their cultivation. During the cropping period in drought affected areas, there seems to be no reliable way to increase precipitation. Besides, it is common in arid areas, that irrigation facilities are not available, the only water management options are to employ cultural practices to increase the availability of stored soil moisture, to improve water use efficiency or to exploit other methods by which plants can yield reasonably well under water deficit conditions (Boyer, 1982). Alternatively irrigation can bring cultivation to many drought lands. The assured production through steady and timely irrigation can bring stable and reliable crop yields.

However, continued and unplanned irrigation, with excessive use and without provision for drainage, may prove uneconomic because of a slow buildup of salinity in the effective root zone. The biological approach includes domestication and cultivation of drought tolerant crop species and the incorporation of the drought resistance traits into plants.

Another approach is to use crop management practices that result in maximum storage of water in the soil and optimum use by crop (Bolton, 1981). These depend on local conditions but often involve fallowing, rapid coverage of the soil by mulch to reduce water loss by evaporation and weed control. The general objectives are to store as much water in soil as possible and to use cultural methods that result in the minimum loss by evaporation and the maximum utilization by crop plants.

Hence, the present investigation is an integrated approach to study water stress tolerance in “*Matricaria chamomilla* L.” var Vallary and mulch effects with the following objectives.

To study the growth and yield parameters of “*Matricaria chamomilla* L.” under water stress and mulching,

to study the effect of water stress and mulching on essential oil quantity and quality,

to study the effect of water stress and mulching on proline production in the leaves of “*Matricaria chamomilla* L.”,

to study the correlation among the various physiological and agronomical traits vis-à-vis their influence on growth and yield of “*Matricaria chamomilla* L.”.

II. REVIEW OF LITERATURE

Many attempts to define drought objectively have been made, with the result that different definitions exist depending on the perspectives of the user. The impact of drought on agriculture is due to deficit of moisture in the soil, when the moisture in the soil is no longer sufficient to meet the needs of growing crops. Drought can also be due to lack of input of moisture from rainfall or irrigation for an extended period. Drought may be defined as a period during which soil or plant water deficiencies affect growth and yield (Ashraf and Harris, 2006).

Water is essential for plant growth and makes up 75 to 95 per cent of plant tissue. A vast amount of water moves throughout the plant daily. Plants use water and carbon dioxide to form sugars and more complex carbohydrates, and water also acts as a carrier of nutrients and as a cooling agent, and provides an element of support through turgor pressure and as an intercellular reaction medium (Ashraf and Harris, 2006).

Water supply probably limits the growth more frequently than any other physical input, and yet irrigation scheduling and general management of soil / water resources is still beset with difficulty. Both dry land and irrigated field crops encounter moisture stress of varying frequency, intensity, and duration. The ability of a plant in either situation to maintain positive carbon balance with minimum disruption, despite drought will be advantageous (David Raper and Kramer, 1983).

Where it is not possible to provide irrigation, the choice of drought resistant species, the breeding of drought resistant genotypes and the use of the most efficient management practices help to maximize the efficiency of the use of available water (Simpson, 1981).

With the above background, review of literature in the present study is classified as follows:

2.1 Morphological traits and water stress tolerance

2.2 Effect of mulch on growth yield and quality

2.3 Biomass yield traits and water stress tolerance

2.4 Essential oil traits and water stress tolerance

2.5 Mechanism of plant resistance to water stress and biochemical traits

2.1 Morphological Traits and Water Stress Tolerance

2.1.1 Growth

A great deal of research on plant water stress has been aimed at documenting the effects of water stress on the growth of plants. Information is available on the effects of drought on processes taking place at the cellular level, on cell division and growth, on the whole plant and its components, and on plant communities or crops (Simpson, 1981). Cell division, a process necessary for tissue and plant growth is considered to be less sensitive to water stress than cell enlargement (Vaadia *et al.*, 1961; Hsiao, 1973).

Water stress, induced directly or indirectly, produces both adverse and stimulatory effects on plants. The rate of growth of plants is generally in direct proportion to the available water, although too much water may also be harmful (Ashraf and Harris, 2006).

One of the first signs of water shortage is the decrease of turgor and it will result in decrease of growth and development of cell especially in stem and leaves. The decrease in plant height because of water stress is reported on *Origanum*

majorana L. (Rhizopoulou and Diamantoglou, 1991) and *Cymbopogon martini* (Fatima *et al.*, 1999).

Changes in plant growth and development were studied in Japanese mint (*Mentha arvensis* L. cv. MS 77) growing under selected water stress from deficiency to sufficiency by Misra and Srivastava (2000). As per the results, water stress resulted in significant reductions in total assimilatory area and fresh matter.

Singh-Sangwan *et al.* (1994) investigated on role of drought stress on lemongrass. Two lemongrass varieties *Cymbopogon nardus* (L.) Rendle var. confertiflorus (Steud.) Bor. and *Cymbopogon pendulus* (Steud.) Wats, were grown under mild and moderate water stress for 45 and 90 days. The results revealed that they exhibited differential responses under mild and moderate stress treatments. In general, plant growth was reduced. The responses varied depending upon the level and duration of moisture stress. The observations have been analyzed in terms of possible relevance of some of these responses to their drought stress adaptability tolerance.

Saravanan *et al.* (2009) reported that in *Andrographis paniculata*, plant spacing of 15 x 15 cm produced higher herbage yields of 707.8, 742.3 and 690.6 g/m² in well-watered control, mild and severe water stress treatments, respectively. Dry matter yield was lower under mild and severe water stress conditions.

In *Cymbopogon martinii* and *C. winterianus* and their cultivars, relative water content (RWC) and herbage yield decreased under drought stress (Farooqi *et al.*, 2005).

2.1.2 Recovery on Growth

One remaining aspect that merits discussion with regard to water stress during vegetative growth is the repair of damage accompanying the relief from stress. Alleviation of stress is followed by a rapid rise in leaf water potential and recovery of turgor. In some species there may be a lag in the full reopening of stomata, varying with leaf age and species (Glover, 1959). When plants are recovering from stress there may be a brief period during which growth exceeds that of non-stressed plants (Simpson, 1981).

Reduction in growth rate caused by water deficits was made up by rapid “Compensatory” growth when leaves regained turgor. In some experiments when water becomes available after a short period of stress, growth is very rapid for a short time, so that no net reduction is caused by the stress. This has been observed in *Nitella* cells (Green *et al.*, 1971) and alfalfa, barley, and corn (Kemper *et al.*, 1961). It is sometimes termed stored or compensatory growth, because it is suggested that metabolites accumulated during the period when cell enlargement is inhibited by lack of turgor are available for cell wall synthesis and other processes associated with growth after turgor is restored (Kramer, 1983).

Guenauoui *et al.* (2010) conducted a research on physiological behavior of *Artemisia herba-alba* (Asso.) under drought stressed conditions. The results showed that the highest growth potentialities were recorded for control plants (100%). The stem elongation rate (SER) and leaf elongation rate (LER) decreased as water stress was intensified. Rewatering stressed plants restored these parameters at values close to those of plants permanently irrigated with 100% FC.

2.1.3 Shoot Growth

Stem growth, both length and diameter, can also be inhibited by drought stress. One of the classic manifestations of drought in many plant species is a

marked reduction in total plant height. In crops, this may or may not be significant depending upon whether the economic part of crop is the vegetative or the reproductive portion. The stem has an important role in translocation of mineral nutrients, water and assimilates within the plant. Reduction in stem height reduces the distances water moves from soil to leaf to the atmosphere without reducing the resistance to water flow (Simpson, 1981).

The most obvious general effects of water stress are reduction in plant size and leaf area (Kramer, 1983). Ahmed and El Hassen (2001) showed that *Catharanthus roseus* plant height was significantly reduced as irrigation interval was increased in two seasons. Prolonging irrigation interval from 7-28 days reduced the plant height by 27% in the first season and by 13.7% in the second season.

Moeini Alishah *et al.* (2006) reported that water stress has significant effect on growth parameters of *Ocimum basilicum*. When the stress level increases, the height of plant decreases so that the maximum height (56/46 cm) was in control treatment (non-stress) and the minimum height (14/42 cm) in treatment of 50% field capacity is observed. Results showed that with becoming the decrease of water the fresh and dry herb yield in the vase of *Ocimum basilicum* become less and the differences between different treatments was significant (in level 5%). The fresh herb yield in stresses of 90, 80, 70, 60 and 50% field capacity were decreased to 20.03, 36.15, 51.43, 77.86 and 94.02%, respectively, in comparison to non-stress treatment. The dry herb yield in 90, 80, 70, 60 and 50% field capacity decreased to 18.15, 29.58, 48.32, 75.22 and 91.13%, respectively in comparison to non-stress treatment.

Belitz and Sams (2007) studied on the effect of water stress on the growth and yield of *Silybum marianum*. They reported that the lowest watering rate significantly reduced stem height. Stems were shortest at 40.8 cm, in the 200

ml/day treatment. The 650 and 2000 ml/day were statistically the same with an average stem height of 71.5 cm. The 1100 and 1550 ml/day treatments were also statistically the same with an average height of 123.3 cm.

Ardekani *et al.* (2007) conducted a survey on the effect of water deficit on quantitative and qualitative characters of Balm (*Melissa officinalis* L.). As per the results when the stress level increases, the height of plant decreases so that the maximum height (65.32 cm) was in control (non-stress) and the minimum height (46.92 cm) in treatment of 20% field capacity was observed. The 40 and 60% F.C. were statistically the same with an average stem height of 56.465 cm. The 60 and 80% F.C. treatments were also statistically the same with an average height of 59.9 cm. The lowest watering rate significantly reduced shoot weight. Lowest and highest shoot weight were in the 20% and 100% F.C. treatments with 2319 and 6469 kg/ha, respectively.

Studies were carried out by Dasha Ram *et al.* (2006) to optimize the use of water by *Mentha arvensis* L. with three moisture regimes [0.9, 1.2 and 1.5 irrigation water:cumulative pan evaporation (IW:CPE) ratios]. Soil moisture regimes maintained at 1.2 IW:CPE ratio significantly increased the crop growth and herb as compared with that of 0.9 IW:CPE ratio. The increase in herb yield due to 1.5 and 1.2 IW:CPE ratios was recorded to be 28.5% and 19% respectively, over the irrigation given at 0.9 IW:CPE ratio.

El-Sayed *et al.* (2008) studied the effect of water stress on yield and bioactive chemical constituents of Tribulus species (*Tribulus terrestris* and *T. pentandrus*). They reported from field experiment that aerial parts (fresh weight g/plant & ton/fedd) increased considerably and gradually by increasing levels of water regimes. Plants irrigated every 7 days and 15 days had a high significant increase of aerial parts (fresh weight with mean values 657.3 & 515 g/plant and 4.53 & 4.12 ton/fedd.) as compared with plants which were irrigated every 21 days

produced 433 g/plant and 3.46 ton/fedd. in the first season. Similar trend was observed in the second year also. The aerial part dry weight/plant and ton/fedd increased considerably and gradually by increasing levels of water regimes. Plants irrigated every 7 days (control) and 15 days (moderate water stress), a significant increase of aerial parts (dry weight with mean values 144.3 and 144.6 g/plant and 1.15 and 1.15 ton/fedd.) was observed as compared with plants irrigated every 21 days that produced 127.0 g/plant and 1.01 ton/fedd. in the first season. On the other hand, increasing irrigation level significantly increased leaves, stems and fruits dry weight in both seasons compared with stressed plants and similar trend was observed with aerial parts dry weight.

El-Sayed *et al.* (2008) reported from pot experiment that water stress conditions had a high significant effect on the average of plant height of *Tribulus terrestris* and *T. pentandrus* plants. Control (100% F.C.) and mild water stress (80% F.C.) showed the highest mean values of plant height. Aerial parts of fresh weight had significant response to water stress application, the maximum values were found to be in plants which received 100, 80, 60% of field capacity comparing with the plants growing at 40 and 20% of field capacity which gave the minimum values in two seasons and similar trend was observed in the second season. There was no significant effect between control and mild water stress (80% F.C.) on aerial parts dry weight/plant in pot experiment, while there was a significant effect between the control and moderate water stress (irrigated every 15 days) in field experiment, but there was significant effect between the control and very severe water stress (irrigated every 21 days). Leaves, stems and fruits dry weight of plant have similar trend as with the data recorded on aerial parts dry weight of *Tribulus* plants in both the seasons.

The effect of water deficit on vegetative growth of *Salvia officinalis* aerial parts were investigated by Bettaieb *et al.* (2009). As per the results, plants

subjected to severe water deficit presented thinner stems with fewer, dry and smaller leaves than the control ones. On the other hand, their results showed that water treatments reduced significantly plant height and this effect was more pronounced with the severity of drought. Thus, under severe water deficit (SWD) and moderate water deficit (MWD), the aerial plant height was significantly reduced respectively by 46.2 and 23%, compared with the control. This constraint induced by MWD and SWD led to a substantial decline of water potential (-1.2 to -4.8 MPa). Furthermore, fresh and dry matter weights were significantly affected by drought and were reduced respectively by 35.33% and 17.85% under MWD and 74.60% and 26.33% under SWD. This decrease could be the result of a preferential allocation of biomass production to the roots (Albouchi *et al.*, 2003) or a reduction in chlorophyll content and, consequently, photosynthesis efficiency, as reported by Viera *et al.* (1991).

In *Artemisia herba-alba*, the highest dead leaf number (DLN) was noticed in stressed plants revealing the lowest dry matter production and stem water potentials [(Ψ_w) (Guenauoui *et al.*, 2010)].

Delfine *et al.* (2005) reported from their studies on isoprenoids content and photosynthetic limitations in rosemary and spearmint plants under water stress that at the balsamic period, whole plant and leaf dry mass increment was significantly reduced by both moderate and severe water-stress treatments in both species. In spearmint, however, stem biomass was only reduced by the severe water stress; on the contrary, in rosemary stem biomass was already reduced by the moderate water stress and the severe treatment did not reduce it further. The reduction of total dry mass water-stressed plants was generally larger in spearmint than in rosemary.

2.1.4 Root Growth

The size of plant root systems is dependent upon the both genetic and environmental factors (Simpson, 1981). The depth of penetration, however, tends to depend upon the depth of moisture in the soil, as well as upon genetic factors (Mayaki *et al.*, 1976). The extent of root development within species is governed by environmental factors such as moisture, soil structure, and light.

In general, root growth is decreased or stopped by soil water stress and roots tend to become suberized to their tips (Kramer, 1983). Tolerant plants under water stress appear to shift carbohydrate utilization from shoot growth in to the production of additional root biomass in the early stages of adaptation. However at later stages, carbohydrate concentration may shift toward the shoots (Mathur and Wattal, 1996) accompanied by growth retardation (Ashraf and Harris, 2006).

Singh *et al.* (2002) studied the influence of irrigation, organic mulch and nitrogen application on growth, herbage, oil yield and quality of patchouli [*Pogostemon cablin* (Blanco) Benth.]. As per results, root fresh weight, root dry weight and root volume had significantly increased with an increase in irrigation levels from 0.8 IW:CPE ratio to 1.0 IW:CPE ratio in the first harvest. Similar pattern was noticed with the application of organic mulch. The pronounced effect on crop growth of irrigation at the highest rate may be attributed to the availability of sufficient moisture for the shallow root system of the crop (25 cm effective root system).

In another study, maximum yield of root biomass in *Atropa belladonna* were observed in plants grown under the highest water supply (35% of water depletion) as compared to 55, 65 and 95% of water depletion (Baricevic *et al.*, 1999).

2.1.5 Root:Shoot Ratio

In morphological terms, tolerance can be achieved by substantial and proportional growth reduction and by diversion of carbohydrates to economic parts (Sinks). In plants tolerant to drought, roots have been observed to play an important role, with greater increase in the root growth and biomass than in the shoot (Ashraf and Harris, 2006). In wilting conditions of the Indian arid zone, much longer roots of chickpea (root: shoot ratio >2) were associated with drought situations (Gupta *et al.*, 1995).

The interaction between the root and shoot are of considerable importance: roots require assimilates from the shoot, while the shoot requires water and nutrients from the root.

The ratio of root to above ground dry matter, however, is generally higher for plants growing in dry habitats than for plants growing in moist habitats. The suggestion has often been made that root development is enhanced relative to shoot development during periods of water stress. There is some evidence to suggest that shoot : root ratios are lower in dry than in wet habitats, but the ratio is also affected by other factors such as soil structure and the stage of plant development (Simpson, 1981).

In general, shoot growth is reduced more than root growth because more severe water deficits develop in the transpiring shoots. Thus, root : shoot ratios are generally increased by water stress (Kramer, 1983).

Occasionally, there is an absolute increase in the amount of roots formed on mildly stressed plants, possibly because there is more effective osmotic adjustment in roots than in shoots (Sharp and Davies, 1979). It seems likely that it occurs when mild water stress inhibits shoot growth more than it inhibits photosynthesis, making a surplus of carbohydrate available for root growth (Kramer, 1983).

In order to investigate the effect of water stress and defoliation on *Zataria multiflora*, *Ziziphora clinopodioides*, *Thymus vulgaris* and *Teucrium polium*, an experiment was conducted under greenhouse conditions (Kouchaki *et al.*, 2004). As per the results, all of the plant species under experiment, showed increase in root/shoot ratio with increases of water stress rate. Also different levels of water stress showed significant correlation with root/shoot ratio. Correlation coefficient in *Zataria multiflora*, *Ziziphora clinopodioides*, *Thymus vulgaris* and *Teucrium polium* were 0.98, 0.85, 0.67 and 0.68 respectively. Different species showed different shoot/root ratio in levels of water stress, with highest and lowest ratio obtained from *Zataria multiflora* and *Ziziphora clinopodioides*, respectively.

The shoot and root length in *Plantago ovata* Forsk. were significantly different ($p < 0.01$) with different levels of water stress, but the shoot/root ratio did not show any significant difference (Dori and Nourinia, 2004). Highest shoot and root length was seen respectively in the -3, -6, 0, -9, -12 and -15 bar drought stress levels (26.6, 24.93, 24.8, 21.46, 19.93, 13.7 mm shoot length; 36, 34.67, 34.67, 34.13, 30.87, 30.6 mm root length respectively).

2.1.6 Number of Flowers

Little is known about the effect of water stress on floral initiation. Stress did not affect development of flower primordial in sunflowers, but it increased the time from seed germination to flowering (Yegappan *et al.*, 1980). It has been reported that flower bud differentiation and flowering are sometimes accompanied by perturbations in stomatal conductance, transpiration, and plant water stress. The literature on this topic was reviewed by Longstreth and Kramer (1980). They could find no evidence from their experiments of any change in stomatal conductance, leaf water potential, or plant water stress at flower induction or flowering of either cocklebur or soybean growing in a controlled environment (Kramer, 1983).

In contrast to the increased flower abscission apparently related to water stress in oranges and cotton, Dubetz and Mahalle (1969) found no change in flower abscission of bush beans when soil water stress reached 8 bars before, during or after flowering (Kozlowski, 1972).

Yaniv *et al.* (1983) compared the response of the two solanum species to drought conditions. In *S. khasianum*, none of the tested parameters (Number and weight of fruits, number of buds and inflorescence per plant) was affected by the limited water supply. However, *S. laciniatum* plants showed great sensitivity to water stress. Vegetative growth and number of flowers as well as weight and number of fruits were greatly reduced by water stress.

Shalaby *et al.* (1983) studied the effect of irrigation on growth and fruit production of *Ammi visnaga*. They reported that the number of umbels and fruit weight per plant were responded significantly to the various irrigation interval treatments. The highest number of umbels and dry weight of fruits per plant were obtained at the 30 days irrigation interval. The same treatment gave the highest fruit yield per feddan compared with shorter or longer irrigation intervals. Both seasons showed the same trend.

2.1.7 Flower Weight

Reproductive tissues increase in size during their development because of cell division and expansion. Superimposed on such growth changes are reversible changes in size because of hydration changes. High transpirational losses from leaves during the day lead to extraction of water from reproductive tissues while absorption from the soil is inadequate to supply the leaves (Kozlowski, 1972).

Reducing sink size concurrently with reductions in photosynthesis would minimize change in source-sink ratios which could influence the response to the stress treatments (Brevedan and Egli, 2003).

In *Silybum marianum* bloom diameter was smallest at an average of 2.3 cm in the 200 ml/day treatment and greatest in the 1100 ml/day treatment with an average of 2.9 cm. The other treatments did not change bloom diameter significantly from the 1100 ml/day treatment (Belitz and Sams, 2007).

2.2 Effect of Mulch on Growth, Yield and Quality

Aromatic plants have been cultivated and commercialized for centuries; nevertheless, little is known about cultural techniques and production and little technical information is available for growers (Simon, 1986). Weed control is very important because none of the aromatic plants can successfully compete with weeds (Weller, 1986). Besides, weeds could pollute essential oils mixing themselves with flowered stems at harvesting. Because of the particular use of MAP's, new agronomical techniques alternative to the use of chemical products for fertilization and weed control are required. The use of black plastic mulches could provide weed control while possibly improving crop growth (Hoeberechts *et al.*, 2004).

Water retention can be improved by mulching the soil with crop residues, manure, hay, straw, or artificial plastic mulches (Ashraf and Harris, 2006). Benefits derived from the use of black plastic mulch are well-documented. In addition to controlling weeds, mulches can reduce leaching loss of nutrients and conserve moisture (Ashworth and Harrison, 1983). Soil compaction is decreased, and the CO₂ level around the plant is increased when plastic mulch is used (Bonanno and Lamont, 1987). Another benefit of polyethylene mulch is an increase in soil temperature under the plastic, which can lead to earlier production than would occur with bare soil (Clarkson and Frazier, 1960). The environmental changes associated with plastic mulch can lead to increased crop yields (Bonanno and Lamont, 1987). Therefore, the use of black plastic mulch could effectively and nonchemcially provide weed control while possibly improving crop growth.

Organic mulches such as grass straw, wood chips and shredded paper were excellent alternatives to synthetic (plastic) mulch. Additionally, organic mulch suppressed weeds, increased irrigation water use efficiency, reduced soil surface erosion, and improved economic returns (Palada *et al.*, 2004). Organic mulching has been observed to reduce the water requirement of rose-scented geranium (Singh, 2000) and mint (Saxena and Singh, 1995).

Hoeberechts *et al.* (2004) investigated growth of Lavender (*Lavandula officinalis*) and Rosemary (*Rosmarinus officinalis*) in response to different mulches. It was reported that plant height and canopy diameter of lavender were significantly affected by the treatments over time. Lavender was shortest in the control plot than in the other treatments (201 mm). The best results were obtained with polyethylene and transpiring mulches both in terms of height (218 and 212 mm respectively) and diameter (206 and 198 mm respectively). At the end of the growing season, lavender plants in the control plots produced a number of flowered stems significantly lower (11 flowers) than plants in mulched plots (ca. 61 flowers).

Hoeberechts *et al.* (2004) also reported rosemary canopy diameter was significantly affected by the treatments over time while rosemary plant height was not, but height was statistically influenced by the treatments themselves ($P = 0.001$). In fact, rosemary differed more than lavender due to treatment effects; height increased statistically more with polyethylene mulch than with the others while the worst results were given by the draining mulch. Maximum height and width were registered respectively in plants grown with transpiring (491 mm) and draining mulches (267 mm).

Ricotta and Masiunas (1991) investigated the effect of black polyethylene mulch on weed control and yield of basil, parsley and rosemary. They reported that in general, plastic mulch provided the best weed control within the rows,

although some weeds did emerge through the holes in the plastic. Yield of the herbs in the bare ground-glyphosate plots was reduced compared to the plastic mulched-hoed plots. Rosemary produced significantly greater yields on plastic covered than on bare soil.

Joy *et al.* (2005) studied effect of mulch and sources of nutrients on growth, yield and quality of black musli (*Curculigo orchoides*). They reported that mulching increased plant height and canopy spread significantly and the other growth parameters marginally. The cumulative effect of mulching on growth parameters resulted in marginally higher dry matter production compared to no mulching. Beneficial effects of mulching on growth and dry matter production have also been reported by Das (1999) in ginger, Gill *et al.* (1999) in turmeric and Joy *et al.* (1999) in *Alpinia calcarata*, *Curcuma zedoaria* and *Kaempferia rotunda*. Weed biomass was significantly influenced by mulching.

Onder *et al.* (2006) showed that the mulch treatments (gray and black plastic mulch) had higher yields compared to M₀ (without mulch) under the water stress condition, excepting I₁₀₀ treatment, mulch applications decreased the yield when irrigation amount increased. Excessive moisture reduced the effectiveness of mulches as reported by Mozumder *et al.* (2005). Although the mulch type has no significant effect on the yield, gray mulch type (Mg) has the highest yield.

Dasha Ram *et al.* (2006) recommended that menthol mint crop could be grown profitably by providing 16 irrigations, that is 80 cm water (based on 1.2 IW:CPE ratio) in the sugarcane trash mulched plots compared to the control (without mulch), which could give a highest benefit:cost ratio from menthol mint cropping.

Muni Ram *et al.* (2003) reported that application of paddy straw mulch increased the herb and essential oil yields in geranium by 23% and 27%,

respectively, over the unmulched control at planted crop harvest. Corresponding values at regenerated crop harvest were 18.7% and 19.2%. A significant response to N was observed with 160 kg N/ha in mulched plot over the same level of N in the unmulched plot. Using paddy straw mulch, nitrogen uptake by plants of planted and regenerated crops was increased by 33% and 28.4%, respectively, over the unmulched control. Apparent N recoveries by planted and regenerated crops were estimated to be 33.7% and 22.7% for the unmulched control, as against 40% and 29.2% with paddy straw mulch at 160 kg N/ha. The quality of essential oil of geranium in terms of its major constituents, citronellol and geraniol, was not affected by the use of organic mulching and nitrogen fertilization and these constituents were found to be of a standard acceptable in international trade.

Singh *et al.* (2002) studied the influence of irrigation, organic mulch and nitrogen application on growth, herbage, oil yield and quality of patchouli [*Pogostemon cablin* (Blanco) Benth.]. As per results, application of 5 t ha⁻¹ organic mulch (distilled waste material of palmarosa) increased herbage and oil yield compared to non-mulch. Herbage and oil yields increased by 92.8 and 70.5%, respectively. Interaction effects of organic mulch and N rates were significant for the production of oil yield. Response of patchouli to increasing N rates was greater at the application of 5 t ha⁻¹ organic mulch than non-mulch. Oil content had significantly reduced at 1.0 IW:CPE ratio and by organic mulch which may be due to dilution effect. Patchouli alcohol and α -patchoulene are important constituents of patchouli oil, which regulate the aroma of oil. The quality of the essential oil with 50.7–54.3% patchouli alcohol, 4.3% α -patchoulene and 9.9–10.3% α -bulnesene was found to be good and readily accepted in the market. Mean weed biomass was not influenced by irrigation but organic mulch significantly reduced the weed biomass.

Fontana *et al.* (2006) reported that mulching technique favoured plant growth. Thyme and lavender diameter was positively influenced by mulching. The strong weed presence limited lateral plant development of thyme and rosemary, enhancing their growth height. For all the species considered in both sites no differences were found between the two types of polypropylene mulch tested.

De Falco *et al.* (2006) reported that the first results showed a reduced ability of the mulching against the weed except for the black polyethylene mulch and pressed cellulose in *Rosmarinus officinalis* L. cultivation. Moreover the mulching influenced the trial in a different way: the soil parameters, the plant growth and the essential oil content and composition.

The results indicated that mulching had significant influence on growth and yield of turmeric. However, the highest yield and curcumin content were noted with a combination of mulching + application of nitrogen and potassium at 120 and 160 kg/ha (Sanyal and Dhar, 2008).

2.3 Biomass Yield Traits and Water Stress Tolerance

Particular attention has been paid to differences among genotypes within species as part of the effort to increase yields under dry conditions. Periods of water stress at certain stages of crop development can be of benefit to the economic quality of the crop. In sugarcane, for example, allowing the crop to dry out near maturity produces higher stem sugar content at harvest (Hartt 1967). Droughts of brief duration may have relatively little long term significance, except in the case of plant species with very low drought resistance (Simpson, 1981).

Pirzad *et al.* (2006) showed that different irrigation regimes have significant effect on the yield of dry flower of *Matricaria chamomilla* L. Maximum yield of dry flower (5.226 g/pot) was obtained from irrigation at 85% field capacity, but this value was not significantly different from 70% of field

capacity. Lowest yield of dry flower (3.814 g/pot) was observed in irrigation at 55% field capacity.

Limited water supply inhibited vegetative development in *S. khasianum*, fruit production and yield was not reduced, and fruit maturity was enhanced considerably (Yaniv *et al.*, 1983).

Afzali *et al.* (2007) showed that different irrigation regimes have significant effect on the dry flower yield and flavonol-O-glycosides concentration of *Matricaria chamomilla* L. Maximum yield of dry flower and flavonoids concentration obtained from irrigation at F.C. soil moisture content (control), but these values were not significantly different from 75 depletion percent of soil AWC in dry flower yield. Lowest yield of dry flower and flavonoids concentration were observed in irrigation at 95 depletion percent of soil AWC. Flower dry weight significantly increased with increasing NaCl concentration up to 40 mM while decreased at higher salinity levels. There were no significant differences between salinity treatments up to 80 mM NaCl for flavonol-O-glycosides concentration.

Belitz and Sams (2007) reported that milk thistle can be grown with minimal input of water without decreasing yield.

Mahmoud (2002) had studies on effect of water stress on growth and resin content of *Grindelia camporum* Greene. According to the results the limitation of the water supply-watering in 6 or 8 day intervals only, dramatically decreased the plant growth, the flower yield and the resin content of the plants.

2.4 Essential Oil Traits and Water Stress Tolerance

The phytochemical composition of herbal products is highly variable (Bauer and Tittel, 1996). Reduced variability in herbal quality might be obtained

through breeding techniques but reports on the development of medicinal plant cultivars with enhanced bioactivity are lacking (Canter *et al.*, 2005). With some expectations, such as *Cannabis* sp. (Gilmore and Peakall, 2003) and *Mentha* sp. (Veronese *et al.*, 2001), medicinal plants have not been addressed in molecular marker or bioengineering studies. One obstacle to both conventional and molecular approaches in developing a new variety is the high cost. The lack of reliable bioassays also play an important role in developing new varieties. In addition, environmental factors influence accumulation of key compounds (Fonseca *et al.*, 2006). When clones are cultivated the interaction between the environmental and the clones has been significant (Oksanen, 2003; Wamatu *et al.*, 2003). Given this scenario it is imperative to study how and to what magnitude environmental factors affect phytochemicals with medicinal activity (Fonseca *et al.*, 2006).

A number of factors can affect the quantity and quality of medicinal products including the seed source, temperature, light exposure, water availability, fertility, period, time and method of collection, drying, packing, storage and transportation of raw material, age and part of the plant collected, the method of extraction and contamination with microorganisms (Calixto, 2000). There are no specific reports on production and postharvest handling practices to maximize quality of individual medicinal plants and herbs. Water stress is one of important factors that can potentially alter concentration of key compounds in medicinal plants (Fonseca *et al.*, 2006).

Water stress is not always injurious. Although it reduces vegetative growth, it sometimes improves the quality of plant products. Water stress increases the desirable aromatic properties of Turkish tobacco (Wolf, 1962).

The overall effects of drought stress during development of reproductive structures and growth of seeds varies with species and duration of the stress

period. Compensation for the reduction in one component of yield by the increase in another is a common phenomenon (Simpson, 1981).

Subjecting plants to regulated stress in particular can result in changes in levels of secondary metabolites, some of which may be of medicinal and aromatic interest. The accumulation of these metabolites is driven by the availability of excess carbon. When growth is reduced due to stress, more carbon becomes available for secondary metabolism thus, inducing the production of some phytochemicals (Tuomi *et al.*, 1984). It is known that in various plants environmental stress increases the accumulation of phenolics (Keinanen, 1999).

Furthermore, the degree of water stress has not always been monitored quantitatively, although this is improving. Evenari (1960) also stated that water stress increases the oil content of mint and olive (Kramer, 1983). Manipulating water availability in the production system can result in diverse phytochemical profiles (Fonseca *et al.*, 2006).

Moreover, plant secondary metabolites can be altered by environmental factors and water deficit is considered to be a major one affecting many aspects of plant physiology and biochemistry (Charles *et al.*, 1994). In the case of aromatic crops, drought may cause significant changes in some metabolites yield and compositions (Petropoulos *et al.*, 2008).

Omidbaigi *et al.* (2003) measured essential oil content in *Ocimum basilicum* under different irrigation regimes. Percentage of essential oil were 1.12, 1.04, 1.26 and 0.99 in plants irrigated with 100, 85, 70 and 55% field capacity, respectively. They also reported that the amount of main constituent of the oil of *Ocimum basilicum* such as linalool, methyl chavicol, 1,8-cineole were affected by water stress.

Water deficit reduced content of essential oil and phenolic compounds of *Rosmarinus officinalis* (Solanis *et al.*, 1996), essential oil content of *Matricaria chamomilla* L. (Kerekes, 1962) and yield of essential oil of *Cymbopogon sp.* (Chaterjee *et al.*, 1995).

Pirzad *et al.* (2006) measured essential oil content in *Matricaria chamomilla* L. under different irrigation regimes. Percentage of essential oil were 0.626, 0.754, 0.751 and 0.635 in plants irrigated with 100, 85, 70 and 55% field capacity, respectively. The highest amount of essential oil (0.754%w/w) accumulated in the flowers of plants when irrigated with 85% of field capacity. However, there was no significant difference between essential oil per cent of plants which received 85 and 70% of field capacity. The lowest amount of essential oil (0.626%w/w) belonged to the plants when irrigated with 100% field capacity. However, there was no significant difference between essential oil content of plants which received 100 and 55% of field capacity.

Pirzad *et al.* (2006) also reported about quality of essential oil that yield of main components of essential oil at irrigation regimes of 100, 85, 70 and 55% field capacity were: azulene-7-ethyl-1, 4-dimethyl (chamazulene) as an important constituent, 4.68, 6.59, 5.79 and 4.67 mg/pot, limonene, 0.33, 0.41, 0.38 and 0.24 mg/pot, bisabolol oxides A, 8.90, 6.90, 12.93 and 7.57 mg/pot, bisabolol oxides B, 4.17, 14.08, 8.07 and 4.79 mg/pot, trans- β -farnesen, 0.74, 1.57, 0.59 and 0.65 mg/pot, bisabolone oxide, 2.43, 1.99, 2.30 and 1.19 mg/pot, isobornyl isobutyrate <8-isobutyryloxy>, 3.51, 4.54, 4.08 and 3.40 mg/pot, respectively. Therefore, at 85% field capacity, higher amounts were obtained for components such as chamazulene, limonene, trans- β -farnesen, bisabolol oxides B and isobornyl isobutyrate <8-isobutyryloxy>. On the other hand, highest yield was observed for bisabolol oxide A at 70% field capacity. For bisabolone oxide, largest amounts was obtained from irrigations at 100 and 70% field capacity, respectively.

Abbaszadeh *et al.* (2008) measured essential oil content and yield in *Melissa officinalis* L. under different irrigation regimes. Percentages of essential oil were 0.1040, 0.1274, 0.1456, 0.2813 and 0.3013% in plants irrigated with 100, 80, 60, 40 and 20% field capacity, respectively. Essential oil yield was highest in treatment with 60% F.C. (12.970 kg/ha) and followed by 40, 80, 100 and 20% F.C. with 8.704, 7.681, 6.732 and 3.974 kg/ha respectively. They also observed positive correlation coefficient between percentage of oil with proline content and oil yield.

Safikhani *et al.* (2007) conducted a survey on the effect of drought stress on percentage and yield of essential oil and physiological characteristics of *Deracocephalum moldavica* L. As per the results, effect of drought stress on essential oil percent and yield was significant ($p=1\%$). Essential oil content was increased as drought stress was increased in two seasons. Highest essential oil content obtained from 40% F.C. treatment with 0.2392 % and lowest oil content obtained from 100% F.C. with 0.195%. Although between 40 and 60% F.C. treatments were not significantly different. Also in oil yield, 60% F.C. treatment showed highest oil yield with 8.914 kg/ha followed by 100 and 40% F.C. treatments with 7.272 and 6.528 kg/ha, respectively.

Drought stress increases the essential oil percentage in medicinal and aromatic plants, because in case of stress, more metabolites are produced in the plants and the chemicals are prevented from oxidization in the cells. However, essential oil yield is reduced under drought stress, because of the interaction between the amounts of the essential oil percentage and shoot yield. Stress increases the essential oil percentage but shoot yield decreases by the drought stress, therefore essential oil yield gets reduces (Aliabadi *et al.*, 2009).

The effect of water stress on essential oil was studied in excised leaves of Palmarosa (*Cymbopogon martini* var. Motia) and Java citronella (*C. winterianus*).

Essential oil percentage was increased under water stress and essential oil yield was decreased under this condition (Fatima *et al.*, 2006).

An experiment was carried out to study the influence of water deficit stress on essential oil of balm. The results of this experiment showed that essential oil yield was reduced under water deficit stress but essential oil percentage was increased under stress (Aliabadi *et al.*, 2009).

Khalid (2006) evaluated the influence of water stress on essential oil of two species of an herb plant that is *Ocimum basilicum* L. and *O. americanum* L. For both the species under water stress, essential oil percentage and the main constituents of essential oil increased. Seventy five percent field water capacity resulted in highest yield of herb and essential oil for both the species.

Also, three parsley cultivars (plain-leafed, curly-leafed and turnip rooted) were grown under condition, of 35-40 and 45-60% water deficit in order to evaluate the effect of stress on essential oil yield and composition. Water stress increased the yield of essential oil (on a fresh weight basis) from leaves of plain-leafed and curly-leafed, but not turnip-rooted, parsley. However, in one meter square basis, foliage oil yield increased significantly only in curly-leafed parsley. Water stress also caused changes in the relative contribution of certain aroma constituents of the essential oils (principally 1,3,8-p-menthatriene, myristicin, terpinolene+p-cymenene), but these changes varied between cultivars. The oil of roots was low and water deficit stress had relatively little effect on the root oil composition. It is concluded that because the biomass of plants subjected to water deficit is reduced, it is possible to increase the plant density of plain-leafed or curly-leafed parsley, thereby further increasing the yield of oil per square meter. However, the application of water deficit stress to parsley essential oil production must also take into account likely changes in oil composition, which in turn relate to the cultivar (Petropoulos *et al.*, 2007).

Rahmani *et al.* (2008) showed that drought stress had significant effect on oil yield and percentage of *Calendula officinalis* L. Their results showed that highest oil yield was achieved under non-drought conditions and highest oil percentage was achieved under drought conditions.

Ardekani *et al.* (2007) reported from their studies that effect of water stress levels were significant on essential oil yield and content of *Melissa officinalis* L.). Increase in oil content was directly related to increase in water stress levels. Highest oil obtained from 20% F.C. treatment. On the other hand, highest oil yield was seen in 60% F.C. treatment. Oil yield was same in 100, 80 and 40 F.C. treatments.

Also, Bettaieb *et al.* (2009) investigated the effect of water deficit on fatty acids and essential oil yield and composition of *Salvia officinalis* aerial parts. Drought decreased significantly the foliar fatty acid content and the double bond index degree. Moderate deficit increased the essential oil yield (expressed as g/100g on the basis of dry weight) and the main essential oil constituents were camphor, α -thujone and 1,8-cineole which showed an increasing under moderate water deficit.

A study in Iran estimated the influence of soil water stress of essential oil content of Iranian *Satureja hortensis* L. The accumulation of oil increased significantly under severe water stress at the flowering stage, when the mean leaf water potential decreased from -0.5 to -1.6 MPa. This treatment affected the quantity of the essential oils more than moderate water stress during the vegetative and flowering stages. The main oil constituents are carvacrol and γ -terpinene. The amount of carvacrol increased under moderate stress, while γ -terpinene content decreased under moderate and severe water stress treatments (Baher *et al.*, 2002).

In the study of chicory, water supply was determined with irrigation as per water evaporation from evaporation pan (50, 100 and 150 mm water evaporation). Drought stress significantly increased the essential oil percentage and compounds such as: kaempferol content of chicory and the non-drought stress treatment significantly increased essential oil yield of plants (Taheri *et al.*, 2008).

Also, water stress had significant effect on flowering shoot yield, essential oil yield and percentage of coriander, highest upon characteristics were achieved under without stress conditions and highest oil percentage was achieved under water stress conditions (Aliabadi *et al.*, 2008).

Munnu Singh (2000) investigated influence of irrigation levels (1.60, 0.80, 0.50, 0.40 and 0.30 IW:CPE ratio) along with control (no irrigation) on herb and oil yield of *Cymbopogon flexuosus*. Growth, herbage and oil yield were also influenced by the irrigation level. Optimum herb yield and oil yield were obtained at 0.80 and 0.50 IW: CPE ratio, respectively.

Water stress resulted in significant reductions in total assimilatory area, fresh and dry matter and essential oil yield of Japanese mint. Some changes in essential oil composition were observed (Misra and Srivastava, 2000).

Singh-Sangwan *et al.* (1994) indicated that the level of essential oils was maintained or enhanced under drought conditions. The major oil constituents, geraniol and citral increased substantially in two lemon grass species (*Cymbopogon nardus* and *C. pendulus*). Significant induction in catalytic activity of PEP carboxylase under water stress was one of the consistent metabolic response of the aromatic grasses. Activity of geraniol dehydrogenase was also modulated under moisture stress.

Soil moisture regimes maintained at 1.2 IW:CPE (irrigation water:cumulative pan evaporation) ratio significantly increased the essential oil

yield of *Mentha arvensis* L. as compared with that of 0.9 IW:CPE ratio. The increase in essential oil due to 1.5 and 1.2 IW:CPE ratios was recorded to the extent of 23.5% and 15.5% respectively, over the irrigation given at 0.9 IW:CPE ratio. The quality of essential oil in terms of its major constituent, menthol, improved slightly with 1.2 IW:CPE ratio as compared to 0.9 and 1.5 IW:CPE ratios at first and second harvest of the crop (Dasha Ram *et al.*, 2006).

Under drought conditions, oil yield increased to 1.77 and 1.01% under MWD and SWD, respectively. Both MWD and SWD improved essential oil yield of sage (Bettaieb *et al.*, 2009). A similar result has been reported earlier on other plant species cultivated under the same conditions, e.g. Mexican oregano (*Lippia berlandieri* Schauer) (Dunford and Vazquez, 2005). Conversely, water deficit decreased oil yield of rosemary (*Rosmarinus officinalis* L.) and anise [(*Pimpinella anisum* L.) (Zehtab-Salmasi *et al.*, 2001)]. It has been suggested that under stress, a higher density of oil glands due to reduction in leaf area resulted in an elevated oil accumulation (Simon *et al.*, 1992). In addition, the stimulation of essential oil production under water stress could be due to the fact that plants produce high terpene concentration under environmental stress condition because of low allocation of carbon to the growth, suggesting a trade-off between growth and defence (Turtola *et al.*, 2003). The contents of ketones (camphor, α -thujone) and ether (1.8-cineole), as compared to the control, increased up to 267.44 and 452.12%, respectively under moderate stress (Bettaieb *et al.*, 2009).

At the balsamic period, significantly higher amounts of monoterpenes per unit mass were formed in water-stressed leaves of spearmint and rosemary with respect to irrigated controls. However, because of plant biomass reduction, water stress reduced the total yield of monoterpenes (Delfine *et al.*, 2005).

Water stress is known to increase the amount of secondary metabolites in plants, for example, artemisinin in *Artemisia* (Charles *et al.*, 1993) and betulinic

acid, quercetin and rutin in *Hypericum brasiliense* (de Abreu and Mazzafera, 2005). Accumulation of secondary metabolites is known as a defense mechanism of plants and plants can respond and adapt to the water stress by altering their cellular metabolism to invoke various defence mechanisms (Gulen and Eris, 2004). The survival of plants under such a stressful condition depends on the plant's ability to perceive the stimulus, generate and transmit the signals, and to initiate various physiological and chemical changes (Bohnert and Jensen, 1996 and Shinozaki and Yamaguchi-Shinozaki, 1997).

In the chloroplasts of the plant cells, protection against oxidative damage is provided by both enzymatic and non-enzymatic antioxidants (Asada, 1999) and thus the antioxidant concentration may therefore increase under a water stress condition in plants (Eskling *et al.*, 1997) which may also be able to increase the secondary metabolite concentrations in plant tissues (Zobayed *et al.*, 2007).

Zobayed *et al.* (2007) reported in the leaf tissues of *Hypericum perforatum* grown under a water stress condition, both hypericin and pseudohypericin concentration reduced with time and on twelfth day of the treatment, the concentration was significantly lower than that of the control; in contrast, the hyperforin concentration increased significantly and the value was nearly double after twelve days of the treatment. Under water stress condition, the hyperforin concentration was about seventy fold higher than the total hypericins concentration in the leaf tissues; in case of control it was only ten to twelve times higher. The results also indicate that the major secondary metabolite, hyperforin concentration of sixty two day old plants was three to four folds higher than the previously reported values for one to two years old field-grown plants.

Farooqi *et al.* (2005) reported that in *Cymbopogon martini*, *C. winterianus* and their cultivars, relative oil amount decreased under drought, while oil biosynthesis increased. Oil concentration increased significantly under drought in

C. winterianus while peroxidase activity increased in *C. martinii*. Amount of geraniol increased under drought stress in *C. martinii* while citronellal and geraniol accumulation decreased in *C. winterianus*. Ameliorative effects of chlormequat chloride and IAA were observed in drought stressed plants of both species. Herbage yield increased significantly in chlormequat chloride and IAA treated stressed plants of *C. winterianus*, while oil concentration increased in *C. martinii*. Ameliorative effect of IAA in increasing oil yield was significant in drought stressed plants of both the species. Changes in various morpho-physiological traits indicated that chlormequat chloride and IAA can partially alleviate the detrimental effect of drought in these aromatic grasses.

Like many secondary metabolites, phenolics are known to be affected by the biotic and abiotic stressors. The phenolic content of the plant's leaves and seeds have been associated with these benefits (Beckman, 2000).

Godoy-HG and Vargas (1991) reported in *Catharanthus roseus*, exposure of the cell to an osmotic stress caused a marked increment (32%) in the total alkaloid content. Ahmed and El Hassen (2001) reported that increasing of water interval resulted in a marked increment in alkaloid content and yield in leaves and roots.

Among the treatments, andrographolide content in the leaves was highest in severely water stressed plants. Dry matter yield was lower under mild and severe water stress conditions even under closer spacing, but the loss of andrographolide yield was partly compensated by its higher content. In *Andrographis paniculata*, increased accumulation of andrographolide in leaves of mild and severe water stressed plants compared to well watered control may be attributed to the response of stress signalling (Saravanan *et al.*, 2009).

A field experiment was conducted to determine ambrosin and damsine in different plant organs throughout the first two years of plant age by El-Mergawi and Mahassen Sidky (2007). Ambrosin concentration was slightly affected by water stress, but damsine decreased in leaves and increased in flowers. Water stress had a depressive effect on the amount of ambrosin and damsine accumulated per plant.

Dea Baričević Alenka Zupančič (2002) conducted research on the impact of drought stress and/or nitrogen fertilization on the yield and secondary metabolites content of medicinal and aromatic plants (MAP). In fenugreek (*Trigonella foenumgraecum* L.), the maximal yield of diosgenin was achieved in plants grown under an optimal irrigation regime (35% depletion of available soil water). Drought stressed seeds of cv. Margaret contained less diosgenin than irrigated plants (0.123%, dw). In deadly nightshade (*Atropa belladonna* L.), the content of tropane alkaloids was determined. The results of the plant treatment responses showed that the maximal yield of tropane alkaloids (hyoscyamine: 54 mg/plant; scopolamine: 7 mg/plant) was achieved in plants grown under an optimal irrigation regime (35% depletion of available soil water) accompanied with a total nitrogen supply of 0.37 g/pot. By contrast, the maximal content of alkaloids was achieved with 95% depletion of available soil water and a nitrogen supply of 1.60 g/pot.

Cultivars of *Cymbopogon martinii* and *C. winterianus* differed considerably in their response to water stress. Oil yield decreased while oil biogenesis increased in the different genotypes under water stress. Water stress induced a wide variation in essential oil composition, protein content and in activities of PEP carboxylase and nitrate reductase in the different genotypes (Fatima *et al.*, 2002).

No change in solasodine content of fruits was observed in either *Solanum* species or in leaves of *S. laciniatum* when exposed to drought conditions.

However, since yield of leaves and fruits of *S. laciniatum* was severely reduced, solasodine content per plant was low (Yaniv *et al.*, 1983). Similar observations were reported by Mann *et al.* (1980) for *S. laciniatum* and for *S. aviculare*. *S. khasianum* seems to be an exception; indeed, since the production of fruits was not affected by drought, the yield of solasodine per plant remained constant (Yaniv *et al.*, 1983).

Shalaby *et al.* (1983) reported that in *Ammi visnaga*, the percentage of the total chromones as well as khellin and visnagin in the fruits were not affected by the irrigation treatments. However, it was found that the yield of the active constituents per feddan was raised by irrigation especially when plants were irrigated at 30 days.

Silymarin levels have been documented to be affected by water availability. Hammouda *et al.* (1993) showed that silymarin levels were higher in plants grown at 60% field capacity compared to wild harvested plants.

Belitz and Sams (2007) showed that in *Silybum marianum*, primary blooms, taxifolin concentrations were significantly affected with the highest concentration (0.89 mg/g) in the 200 ml/day water treatment and the lowest concentration (0.47 mg/g) was found in the 650 ml/day water treatment. The other treatments did not differ significantly from each other and had an average taxifolin concentration of 0.64 mg/g. Different water treatments did not significantly affect silymarin concentration in primary and secondary blooms.

2.5 Mechanism of Plant Resistance to Water Stress and Biochemical Traits

2.5.1 Plant Resistance

The ability of a plant to grow satisfactorily when exposed to periods of water stress is called drought resistance (May and Milthorpe 1962). Stress-tolerance mechanisms vary from species to species, while basic cellular responses to abiotic stress appear to be conserved among all plants (Ashraf and Harris, 2006).

If drought is defined as a purely environmental factor and tolerance is substituted for resistance, the behavior of plants with respect to drought can be classified as follows:

Drought avoidance, when plants are not subjected to meteorological drought.

Drought tolerance, by dehydration postponement or by dehydration tolerance.

These categories are not mutually exclusive and some kinds of plants, sorghum for example, can be placed in more than one category (Kramer, 1983). Varying combinations of drought avoidance and tolerance occur in higher plants (Simpson, 1981).

2.5.2 Drought Avoidance

The best known examples of drought avoidance are the short lived desert annuals that germinate, grow, flower, and produce mature seed in a few weeks after rains have wetted the surface soil (Kramer, 1983).

2.5.3 Drought Tolerance

Plant tolerance to drought results from both morphological adaptation and responses at the biochemical and genetic levels (Hemantaranjan, 2007). Plants cannot avoid the random drought characteristics of most of the humid temperate zone, but many possess adaptations that increase their tolerance. These can be classified in to two groups those that postpone dehydration and those that increase tolerance of dehydration (Kramer, 1983).

2.5.4 Dehydration Postponement

Injurious dehydration is postponed by morphological or physiological characteristics that either reduce water loss by transpiration or increase water absorption. Thick cuticle, responsive stomata, and leaf rolling reduce water loss, and deep root systems increase water absorption (Kramer, 1983).

2.5.5 Osmotic adjustment

Plants maintain their cell turgor under osmotic stress conditions by osmotic adjustment and/or by adjusting the elasticity of the cell wall. Although osmotic adjustment is well understood in plants, only limited studies suggest that plant tissues can maintain turgor at reduced water volume by physiological adjustment of cell walls (Ashraf and Harris, 2006).

The lowering of cell osmotic potential which is termed osmo-regulation or osmotic adjustment is a physiological mechanism that enables plants to tolerate water stress (Simpson, 1981). Thus, osmotic adjustment enables cell enlargement and growth to continue at water potentials that would otherwise be inhibitory. It also aids by keeping stomata open and the photosynthetic apparatus operating at lower leaf water potential than if it did not occur. Osmotic adjustment usually develops in plants that are stressed slowly, although it has been reported to occur

in response to mid day water stress. It is not detectable in all kinds of plants or in all cultivars of species (Kramer, 1983).

Osmotic stress may induce ion uptake (K^+), compartmentalization (Na^+ into vacuole), or synthesis of compatible solutes such as proline, betaine, polyols, and soluble sugars. Compatible solutes are low in molecular weight, highly soluble compounds, and nontoxic at high cellular concentrations. The compatible solutes are synthesized only when water deficit develops gradually, not as a shock (Ashraf and Harris, 2006).

As plant cells are dehydrated, the vacuole shrinks and may almost disappear but, upon rehydration, swells to its original size and shape. However, if the protoplasmic membrane is ruptured, the cell is unable to recover. For this reason, species that are able to maintain cell turgor pressure and cell configuration by osmo-regulation have increased tolerance of water stress (Simpson, 1981).

Osmotic adjustment has been shown to be positively related to seed yield in Brassica species (Kumar *et al.*, 1987).

2.5.6 Proline Production

During periods of drought, salinity and low temperature stress, plants increase their pools of free proline far in excess of the demands of protein synthesis. They do this by inducing proline biosynthetic enzymes while repressing further synthesis of catabolic enzymes. Under dehydration conditions when expression of the gene for P5CS (pyrulline 5 carboxylase synthase) is strongly induced, expression of the gene for PDH (proline dehydrogenase) is inhibited. By contrast, under rehydration conditions, when the expression of the gene for PDH is strongly induced, the expression of the gene for P5CS is inhibited. Thus, P5CS, while acts during the biosynthesis of proline, and PDH, which acts during the metabolism of proline, appear to be the rate-limiting factors under water stress.

Therefore, it is suggested that levels of proline are regulated at the level of transcription of these two enzymes during dehydration and rehydration. Moreover, it has been demonstrated that proline acts as an osmoprotectant and that overproduction of proline results in increased tolerance to osmotic stress of transgenic tobacco plants. Genetically engineered crop plants that over produce proline might, thus, acquire osmotolerance namely, the ability to tolerate environmental stress such as drought and high salinity (Hemantaranjan, 2007).

Proline accumulation may be merely the incidental result of disturbance of normal metabolic pathways. For example, it is well established that proline accumulates because water stress either stimulates its synthesis from glutamate by loss of feedback inhibition, or decreases the rate of proline oxidation, or it may decrease its incorporation into protein (Kramer, 1983).

The capacity for free proline accumulation might depend on the plant species. The same gene was introduced in rice under control of an ABA stress inducible promoter and it accumulated up to 2.5 fold more proline than control plants under stress conditions (Hemantaranjan, 2007).

2.5.7 Role of Proline

Proline protect plants from stress by (1) osmotic adjustment which helps in turgor maintenance, (2) scavenges free radicals, and buffers cellular redox potential under stress (Ashraf and Harris, 2006) (3) stabilization of the quaternary structure of proteins (Yancey *et al.*, 1982; Bohnert and Jensen, 1996) and also possess antioxidant ability (Smirnoff and Cumbes, 1989).

Alternatively, proline may protect proteins and membranes from damage by inactivating hydroxyl radicals or other highly reactive chemical species that accumulate when stress inhibits electron transfer process. Proline catabolism is capable of a high energy output and has been proposed to donate electrons to the

respiratory electron transport chain. Each molecule of proline, when oxidized, can yield 30 ATP equivalents and has been considered a primary fuel in energy intensive process, such as insect flight or pollen germination.

The role of proline catabolism has been highlighted in the field of nitrogen fixation. Plants such as soybean (*Glycine max*) synthesize high levels of proline in the host cells of nodules and bacteroids are capable of high pro-oxidizing activity, suggesting that free proline entering the bacteroids from host cells might be an important energy source for nitrogen fixation. Nodulation tests with a bacteroid PDH-deficient mutant revealed that PDH activity is essential for nodulation efficiency. Thus, increased oxidative flux of proline in bacteroids might provide an agronomically significant yield advantage (Hemantaranjan, 2007).

In Bermuda grass, for example, free proline in stressed plants was 10 to 125 times the value in control plants (Barnette and Naylor 1966). The transgenic plants of tobacco produced ten to eighteen fold more proline than the control plants and showed enhanced root biomass and flower development under drought stress (Ashraf and Harris, 2006).

Moeini Alishah *et al.* (2006) confirmed that, with decreasing amount of water, the proline accumulation increased in the leaves of *Ocimum basilicum*. The amount of proline in 50% treatment of field capacity are 1/15, 1/30, 1/35, 1/63 and 1/69, respectively time with the amount of proline in 60, 70, 80, 90 and 100% treatment of field capacity.

The increase of density of proline because of water shortage has been reported in wheat (Bajji *et al.*, 2001), mustard (Begum and Paul, 1993), Alfalfa (Irigoyen *et al.*, 1992) and *Cymbopogon winterianus* (Farooqi *et al.*, 1998).

Abbaszadeh *et al.* (2008) confirmed that effect of drought stress on total proline was significant, with decreasing amount of water, the proline accumulation

increased in the leaves of *Melissa officinalis* L. The amount of proline were 1.483, 1.493, 1.659, 1.980 and 2.122 mg/l in plant irrigated at 100, 80, 60, 40 and 20% field capacity, respectively. It could be concluded that plant accumulation of proline and soluble sugars increased tolerance and showed that moderate drought stress is beneficial for balm production.

According to the results of studies conducted by Hasani *et al.* (2004), different levels of soil water content had significant effect on measured characteristics of *Ocimum basilicum*. As the soil water content decreased, leaf water potential and RWC decreased but leaf temperature, proline and soluble sugars concentration increased. The results of this study showed that basil plant could be able to tolerate the water deficit conditions by stomatal closure and increasing of proline and soluble sugars accumulation (osmotic adjustment).

Safikhani *et al.* (2007) showed that drought stress on proline amount of *Deracocephalum moldavica* L. was significant ($p = 1\%$). Amount of proline was 0.265, 0.247 and 0.0321 mg/l in 40, 60 and 100% F.C. respectively.

The effect of water stress either in field or pot experiments led to significant increase in the total free proline (El-Sayed *et al.*, 2008). The obtained data were in agreement with Hamed *et al.* (2004) who stated that the content of free proline significantly increased under water stress of *Rosmarinus officinalis* L. as well as, *Tanacetum parthenium* maintained at 50% of field capacity was recorded higher content of free proline compared to plants grown at 90% of field capacity. Also the data obtained are in agreement with many results of Misra *et al.* (1999) on *Cymbopogon* spp. and Nik *et al.* (2004) on *Satureja hortensis*.

Fatima *et al.* (2002) reported from their studies on the effect of water stress on growth of *Cymbopogon martinii* and *C. winterianus* that proline accumulation increased in the different genotypes under water stress.

III. MATERIAL AND METHODS

The details of materials used, and the techniques adopted in the conduct of the experiment and statistical analysis of the data during the course of the study are explained in this chapter.

The one year pot and two years field investigations were conducted during November to March of 2008-2010. Seeds of *M. chamomilla* variety "Vallary" were obtained from CIMAP, Lucknow.

Location

The pot and field investigations were conducted at Sugandhavana, Medicinal and Aromatic Section, Division of Horticulture, University of Agricultural Sciences, GKVK Bangalore (Zone-5). Lab analysis was conducted at Department of Horticulture and Physiology, GKVK, Bangalore.

Bangalore is located at an altitude of 930 m above mean sea level. The climate of Bangalore is characterized as semi-arid tropical with 890 mm mean annual rainfall. The soil of the experimental plot was red sandy loam having a pH 6.3 with bulk density of 1.5 g/cc. the water holding capacity of the soil was 15.6% at -0.3 Mpa and 65% at -1.5 Mpa.

EXPERIMENTAL DETAILS

3.1 EXPERIMENT 1:(POT EXPERIMENT)

Matricaria chamomilla L. var. Vallary was planted for a year 2008-09 under three levels of moisture conditions ($W_{100}=100\%$, $W_{80}=80\%$ and $W_{60}=60\%$ of field capacity), and three mulch materials (M_0 = No mulch or control M_1 = Dry lemon grass mulch M_2 = Plastic mulch).

3.1.1 Treatments:

W₁₀₀M₀- Cultivation without mulch at 100% F.C. (Control)

W₈₀M₀- Cultivation without mulch at 80% F.C

W₆₀M₀- Cultivation without mulch at 60% F.C

W₁₀₀M₁- Dry lemon grass (spent grass dried) mulch at 100% F.C

W₈₀M₁- Dry lemon grass (spent grass dried) mulch at 80% F.C

W₆₀M₁- Dry lemon grass (spent grass dried) mulch at 60% F.C

W₁₀₀M₂- Plastic mulch at 100% F.C

W₈₀M₂- Plastic mulch at 80% F.C.

W₆₀M₂- Plastic mulch at 60% F.C.

3.1.2 Design and Lay Out

This research was based on factorial experiment through completely randomized design with 3 replications.

3.1.3 Preparations of Pots

Battery containers measuring 60 cm in length, 20 cm width and 20 cm depth with a capacity to hold 20 kg of soil were used for the experiment. To facilitate easy handling and lifting of pots, holes were drilled and plastic ropes were tied to lift the pots. Each container was filled with 20 kg red loamy soil and sufficient farmyard manure (FYM). Nine pots were maintained in each replication. At the time of planting, recommended dose of fertilizers [(150, 60, 60 kg/ha of N.P₂O₅.K₂O respectively) (Moumita Das *et al.*, 1998)] was applied.

3.1.4 Nursery Management

The nursery area was well prepared by repeated ploughing and brought to a fine tilth during 10th Nov 2008. Well- rotten FYM was applied to the soil, and nursery-beds of convenient sizes were prepared. As the seeds are small, the seeds

were mixed with sand in the ratio of 1:4 and sown in the nursery-beds. The nursery was watered regularly. The seeds germinated in 5-7 days of sowing and the seedlings were ready for transplanting into pots by the last week of November when they were of 4 to 5 weeks old. Two seedlings of *Matricaria chamomilla* L. were transplanted in each rectangular battery containers. They were watered daily to maintain field capacity until 10 days.

3.1.5 Treatment Imposition

Water stress treatments:

For the first ten days, all containers were irrigated daily to maintain 100 per cent field capacity. When the plants reached 4-6 true-leaf stages, water stress treatments were imposed and these percentages of soil F.C. were kept at constant level by daily weighing and watering. The weight of individual containers was recorded with the help of a electronic weighing balance of 60 kg capacity. Each individual container could be brought to the balance and the weight of nearly 27 containers was completed within 45 minutes. The pots were placed under shelter to prevent moisture gain due to rain.

All the containers were grouped into three sets. One set of containers were maintained at 100% F.C., other sets of containers at 80 and 60% F.C. Containers were daily weighed once (between 8.00 to 9.30 am) to record the amount of water lost through transpiration and evaporation. After weighing, required amount of water was added to bring back the soil to F.C. For the other sets, a reference weight was calculated at 80 and 60% F.C. using 100% F.C. weight and dry soil weight as follows.

Computation of pot weight and amount of water needed for the desired soil moisture regime

Pot weight at 100% F.C. (W_{100})= $A+Q_{100}$

Pot weight at 80% F.C. (W_{80})= $A+Q_{80}$

Pot weight at 60% F.C. (W_{60})= $A+Q_{60}$

Where

A = Soil dry weight with pot

Q_{100} = Quantity of water present at 100% F.C.

Q_{80} = Quantity of water present at 80% F.C.

Q_{60} = Quantity of water present at 60% F.C.

$Q_{80} = Q_{100} \times 80/100$

$Q_{60} = Q_{100} \times 60/100$

The required amount of water (PQ) in each day in each pot was calculated as follows

$PQ_{100} = W_{100} - X_{100}$

$PQ_{80} = W_{80} - X_{80}$

$PQ_{60} = W_{60} - X_{60}$

Where

X_{100} = daily weight of pots in 100% F.C.

X_{80} = daily weight of pots in 80% F.C.

X_{60} = daily weight of pots in 60% F.C.

Mulch treatments

Plastic mulch was used on soil surface of pot before planting and lemon grass mulch was spread after planting.

3.1.6 Pinching

The plants were subjected to pinching on fifteenth days of transplanting. This treatment was imposed uniformly on all the plants.

3.1.7 Plant Protection

Not much of pest and disease problems were noticed during the crop season. However, the crop showed powdery mildew symptoms at 45 days after transplanting. Proper care was taken by spraying once with Sulphur 80 W.P. [(Sulfex) (1 g/liter)]. Aphids were also observed and monocrotophos of 1 ml/liter of water was sprayed to control the menace.

3.1.8 Weeding

Hand weeding was done as and when weeds were observed in the pots.

3.1.9 Harvesting

Flowering began from the first fortnight of February and continued till the middle of March. Fully- opened flowers were picked immediately. Individual flowers were hand picked. Four harvests were taken at 10-15 days' intervals. The last flush of flowers (5th) was allowed to set seeds on the plant itself.

3.1.10 Drying the Flowers

Drying the flowers was necessary as they had a moisture content of 60 to 85%. For drying, the harvested flowers were spread in thin layers in the shade. The flowers were dried at a temperature ranging between 22⁰C to 24⁰C. While drying, the flowers were turned once or twice.

3.1.11 Observations Recorded

- Plant height (cm)
- Shoot fresh weight (g/plant)

- Shoot dry weight(g/plant)
- Root fresh weight (g/plant)
- Root dry weight (g/plant)
- Root/shoot ratio by dry weight
- The number of flowers / plant (nos)
- Weight of 100 fresh flowers (g)
- Weight of 100 dry flowers (g)
- The yield (fresh weight of flower) (g/p)
- The yield (dry weight of flower) (g/p)
- Essential oil percentage (% v/w dry weight)
- Essential oil yield (kg/ha)
- Proline production ($\mu\text{g/g}$ fresh weight)

3.1.11.1 Plant Height

The longest shoot arising from the ground was measured from its tip and expressed in cm.

3.1.11.2 Shoot Weight (Fresh and Dry)

The separated shoot was weighed (fresh weight recorded), shade dried at room temperature to record dry weight.

3.1.11.3 Root Weight (Fresh and Dry)

After final harvest, all the pots were watered to facilitate removal of root system without damage. The soil with intact roots was removed from the pot and watered through jet hose directed to the root system to free the roots of soil. Then shoot and roots were separated and fresh weight was recorded, shade dried at room temperature to record dry weight.

3.1.11.4 Root/Shoot Dry Weight Ratio (RSR)

The ratio of root dry weight to shoot dry weight was calculated during the treatment period.

$$\text{RSR} = \frac{\text{Root dry weight (RDW)}}{\text{Shoot dry weight (SDW)}}$$

3.1.11.5 Weight of 100 fresh flowers

After harvest, 300 fresh flowers collected from each treatment were weighed separately. The weight of 100 fresh flowers was calculated by:

$$\text{Weight of 100 fresh flowers} = \frac{\text{Fresh weight of 300 flowers}}{3}$$

3.1.11.6 Weight of 100 dry flowers

After harvest, 300 flowers collected from each treatment were dried separately. After drying, they were weighed. The dried weight of 100 flowers was calculated by:

$$\text{Weight of 100 dry flowers} = \frac{\text{Dry weight of 300 flowers}}{3}$$

3.1.11.7 The Number of Flowers / Plant

Total number of flowers were accounted for each treatment, then was divided by two for finding the mean of flowers per plant.

3.1.11.8 The Yield

The harvested crop consisted of freshly gathered flower heads, with approximately = 10% of flowers containing fragments of the small flower stalks,

which were up to 30 mm long (Bottcher *et al.*, 2001). Flower heads were picked when fully developed and dried under shade (Letchamo, 1993). Totally four harvests were taken during the experiment. Sum of four harvests was the total yield (fresh and dry).

3.1.11.9 Essential Oil Percentage

Isolation of essential oil: The air-dried flowers of chamomile (30 g of the dry sample) were hydro-distilled in Clevenger apparatus of 1000 ml capacity round bottomed flask with 600 ml deionized water for 4 h (Hoelzl and Demuth, 1975; Letchamo, 1993). During distillation, the oil was deposited on the inner walls of the condenser, to solve this problem, the flow of the cooling water was frequently stopped until the temperature of the condenser rose sufficiently. The essential oil was stored in a dark glass bottle at 3⁰C for further analysis.

3.1.11.10 Essential Oil Yield

Essential oil yield was calculated by multiplication of dry flower yield and oil percentage.

3.1.11.11 Estimation of Proline

Proline was estimated as per the protocol mentioned by Sadashivam and Manickam (1996).

Principle

During selective extraction with aqueous sulphosalicylic acid, proteins are precipitated as a complex. Other interfering material are also removed presumably by absorption to the protein sulphosalicylic acid complex. Extracted proline reacted with ninhydrin in acidic conditions to form red chromophore.

Protocol

1g of the plant material (leaf) was extracted by homogenizing in 10 ml of 3% sulphosalicylic acid.



The homogenate was filtered.



2 ml of filtrate was taken and to that 2ml of glacial acetic acid and 2ml of acid ninhydrin was added.

[Acid ninhydrin: 1.25 g ninhydrin in 30 ml glacial acetic acid and 20 ml 6M ortho phosphoric acid]



This was heated in a boiling water bath for an hour



Placing the test tubes in an ice bath terminated the reaction

4 ml of toluene was added and stirred well



Toluene layer was separated using a separating funnel and warmed to room temperature.



The intensity of red color was measured at 520 nm.



Proline ($\mu\text{g/g}$ fresh weight) = $(80 \times \text{OD} \times V)/2f \times 100$

Where

V = total volume of the extract

2 = volume of aliquot taken for estimation

F = fresh weight of the sample in mg

OD = optical density

3.1.12 Statistical Analysis

Growth and yield data, as well as essential oil percentage and yield were analysed using mixed model ANOVA. First, the analysis of variance tables were obtained by AGRES Software. Then significance of treatments and corresponding effects were evaluated by LSD test. The diagrams were drawn using Excel Software 2003.

3.1.13 Determination of correlation coefficient

Growth and yield data, as well as essential oil percentage and yield were analysed by Excel Software 2003.

3.2 EXPERIMENT 2: (FIELD EXPERIMENT)

Field experiments were conducted during 2008-2009 and 2009-10. In this study *Matricaria chamomilla* was planted for 2 seasons under 3 different moisture conditions (100%, 80% and 60% of field capacity) and 3 different mulch treatments (1-No mulch or control 2- Plastic mulch 3- Dry lemon grass mulch).

3.2.1 Treatments

W₁₀₀M₀-Cultivation without mulch at 100% F.C. (with corresponding soil Ψ at a depth of 10 cm). (Control)

W₈₀M₀-Cultivation without mulch at 80% F.C. (with corresponding soil Ψ at a depth of 10 cm).

W₆₀M₀-Cultivation without mulch at 60% F.C. (with corresponding soil Ψ at a depth of 10 cm).

W₁₀₀M₁-Dry lemon grass (spent grass dried) mulch at 100% F.C. (with corresponding soil Ψ at a depth of 10 cm).

W₈₀M₁-Dry lemon grass (spent grass dried) mulch at 80% F.C. (with corresponding soil Ψ at a depth of 10 cm).

W₆₀M₁-Dry lemon grass (spent grass dried) mulch at 60% F.C. (with corresponding soil Ψ at a depth of 10 cm).

W₁₀₀M₂-Plastic mulch at 100% F.C. (with corresponding soil Ψ at a depth of 10 cm).

W₈₀M₂-Plastic mulch at 80% F.C. (with corresponding soil Ψ at a depth of 10 cm).

W₆₀M₂-Plastic mulch at 60% F.C. (with corresponding soil Ψ at a depth of 10 cm).

3.2.2 Design and Lay Out

The experiment was designed as per the split plot technique. In this experiment, water stress was the main treatment and different mulch material were sub treatments; so in plot design, different water stress levels were in sub plot and different mulch material treatments in main plot.

3.2.3 Preparation of Plots

The land was ploughed once followed by properly levelling and flat beds of convenient size (1.5 m length and 1.2 m width) were made. At the time of the final harrowing, FYM or compost at 20-25 t/ha was applied and mixed well into the soil.

3.2.4 Crop Management

Preparation of nursery and sowing seeds were taken up as in the pot experiment. The seedlings were ready for transplanting into the main field when they were 4 to 5 weeks old. The seedlings of *Matricaria chamomilla* L. were sown

in the gross plot of 1.5 m length and 1.2 m width. The pinching treatment was also imposed as per the pot experiment.

3.2.5 Treatment Imposition

Water stress

The method for determining adequate irrigation time was based on the measurement of soil moisture by WP4 Dewpoint potentiometer. During the experimental period, soil samples at depth 10 cm were collected using soil augur and water potential was recorded using a Dew Point Potentiometer (model WP4, version 1.3, Decagon Devices, Inc., Washington).

Around 0.5 kg field soil sample was collected and placed in the oven at 70°C for 24 hours. Three plastic cups were punctured by 3-4 holes in their bottom. Then they were weighed and filled up with an amount of 100 g dried soil and were poured with water upto saturation of the soil. Plastic cups were covered with plastic (protection again evaporation) and left for 24 hours for gravity water to come out. Thereafter soil with 100% field capacity was ready to measure the soil water content (g) and potential (MPa).

To measure the quantity of water present at 100%, 80% and 60% F.C.; the following formula was used:

$$Q_{100} = WS_{100} - A$$

$$Q_{80} = Q_{100} \times 80/100$$

$$Q_{60} = Q_{100} \times 60/100$$

Where

Q_{100} = Quantity of water present at 100% F.C.

Q_{80} = Quantity of water present at 80% F.C.

Q_{60} = Quantity of water present at 60% F.C.

WS_{100} = Weight of soil in 100 F.C. (g)

A = Soil dry weight (100g) with plastic cup

To measure the soil water potential (MPa) at 100%, 80% and 60% F.C. One small sample of soil with 100 F.C. was placed in WP4 and read, this number is soil water potential in 100 F.C.

Two plastic cups of 100% F.C. were left for a few days, daily they were weighed till they reached to actual quantity of water at 80% and 60% F.C.

$$WP_{80} = A + Q_{80}$$

$$WP_{60} = A + Q_{60}$$

Where

WP_{80} = Weight of plastic cup in 80% F.C.

WP_{60} = Weight of plastic cup in 60% F.C.

When the water quantity reached to 80% and 60% F.C., small sample of soil from each plastic cup as placed in WP4 and read, those numbers were soil water potential in 80% and 60% F.C. The readings of water potential (MPa) in 100%, 80% and 60% F.C. were used as critical levels for different water stress treatment in 100%, 80% and 60% F.C. in field respectively.

Mulching

In this experiment, three mulch treatments were used viz., M_0 = No mulch or control M_1 = Dry lemon grass mulch M_2 = Plastic mulch. After tillage, mulches were laid in strips to cover the whole plot and then anchored using U-shaped wire pins. Plants were planted into holes punched into the plastic mulch.

In lemon grass, after planting of chamomile seedlings, spent material of lemon grass (around 10 cm length) was spread on soil surface in between the spaces of plants.

Plant protection, weeding, harvesting and drying were taken as mention in pot experiment.

3.2.6 Observations Recorded

- Plant height (cm)
- Shoot fresh weight (g/plant)
- Shoot dry weight(g/plant)
- Root fresh weight (g/plant)
- Root dry weight (g/plant)
- Root/shoot ratio by dry weight
- The number of flowers / plant (nos)
- Weight of 100 dry flowers (g)
- The yield (fresh weight of flower) (g/p)
- The yield (dry weight of flower) (g/p)
- Essential oil percentage (% v/w dry weight)
- Essential oil yield (kg/ha)
- Essential oil quality (percentage of main components)
- Main components of essential oil yield (kg/ha)
- Proline production (µg/g fresh wt)

The plant height, shoot fresh and dry weight, root fresh and dry weight, root/shoot dry weight ratio (R/SR), the number of flower per plant, the weight of 100 dry flowers, fresh and dry flower yield, essential oil percentage and yield and proline production were measured as mentioned in the pot experiment. The statistical analysis was carried out as per Sundararaj *et al.* 1972.

3.2.7 Gas Chromatography (GC)

GC analysis of the oils was performed on a Perkin-Elmer GC 8500. Using a fused silica capillary column (25m x 0.32 mm i.d. film thickness 0.25 μ m) coated with dimethyl siloxane (BP-1). Oven temperature was programmed at 60-220°C at 5°C/min, then held isothermal at 220°C for 10 mins injector temperature, 250°C; detector temperature, 300°C; carrier gas, nitrogen at a linear velocity of 8 psi inlet pressure; split ratio, 1:80.

GC-MS

The GC MS data were obtained on a Shimadzu QP-2000 instrument. GC conditions were: 60-250 °C at 10 °C/min, with an internal hold time of 5 min: carrier gas, Helium at a flow rate of 2 ml/min. A fused silica capillary column HP-5 was used (25m x 0.25 mm i.d. film thickness 0.25 μ m). MS conditions were: EI mode, 70 eV; ion source temperature, 250°C.

Identification of Compounds

Compounds were identified by comparing the retention indices of the peaks on the BP-1 column with literature values. Final confirmations of constituents were made computer matching of the mass spect of peaks with the Wiley and NIST libraries and with published data (Ramaswamy 1988, Adams 1989). The relative amounts of the individual components are based on peak areas obtained without FID response factor correction. The retention indices were obtained from gas chromatograms by logarithmic interpolation between bracketing n-alkanes. A homologous series of n-alkanes (C8-C23; Poly Science Inc., Niles, USA) were used as standards.

IV. EXPERIMENTAL RESULTS

Results of one year pot experiment and two years field experiments are presented in this chapter. The results of the present investigation are discussed under the following heading:

4.1 EXPERIMENT 1: (POT EXPERIMENT)

4.1.1 Morphological Characters

4.1.2 Biomass Yield

4.1.3 Essential Oil Quantity

4.1.4 Proline Production

4.1.5 Correlation coefficients

4.2 EXPERIMENT 2: (FIELD EXPERIMENTS)

4.2.1 Morphological Characters

4.1.2 Biomass Yield

4.1.3 Essential Oil Quantity

4.2.4 Essential Oil Quality

4.2.5 Proline Production

4.2.6 Correlation coefficients

4.1 EXPERIMENT 1: (POT EXPERIMENT)

4.1.1 Morphological Characters

The various morphological characters such as plant height (cm), shoot fresh weight (g/plant), shoot dry weight (g/plant), root fresh weight (g/plant), root dry weight (g/plant), root/shoot dry weight ratio, number of flowers per plant, weight of 100 fresh flowers (g) and weight of 100 dry flowers (g) in *Matricaria chamomilla* L. var. Vallary recorded at different water stress levels and mulching types for pot experiment are presented in Tables 1-3 and Figures 1 and 2.

4.1.1.1 Plant Height (cm)

The data pertaining to plant height recorded among different water stress levels and mulching types for the pot experiment are presented in Table 1. Treatments W_{80} and W_{100} recorded significantly maximum plant height and were *on par* (102 and 100.3 cm, respectively). Minimum plant height was recorded in W_{60} (88.7 cm).

The results on mulching types and the interaction between water stress levels and mulching types recorded no significant influence on plant height.

4.1.1.2 Shoot Fresh Weight (g/plant)

The data pertaining to shoot fresh weight recorded among different water stress levels and mulching types for the pot experiment are presented in Table 1. Significantly maximum shoot fresh weight per plant in water stress treatments was recorded with W_{100} (367.7 g/plant) and minimum shoot fresh weight was recorded in W_{60} (317.7 g/plant).

The results on mulching types recorded significant influence on shoot fresh weight. Plastic mulch (M_2) recorded maximum shoot fresh weight (348.7 g/plant). Lemon grass mulch (M_1) recorded minimum shoot fresh weight (341.7 g/plant).

Results of the interaction between water stress levels and mulching types showed that $W_{100}M_2$ (375 g/plant) recorded significantly maximum shoot fresh weight per plant when compared to other treatments. Treatments $W_{60}M_0$ and $W_{60}M_1$ and $W_{60}M_2$ (315, 318 and 320 g/plant, respectively) recorded minimum shoot fresh weight per plant and were *on par*.

4.1.1.3 Shoot Dry Weight (g/plant)

The data pertaining to shoot dry weight recorded among different water stress levels and mulching types for the pot experiment are presented in Table 1.

Table 1. Effect of water stress levels and mulch types on plant height, shoot fresh weight and shoot dry weight in *Matricaria chamomilla* L. var. Vallary on the pot experiment

Sub treatments	Main treatments											
	Plant height (cm)				Shoot fresh weight (g/plant)				Shoot dry weight (g/plant)			
	W ₁₀₀	W ₈₀	W ₆₀	Mean	W ₁₀₀	W ₈₀	W ₆₀	Mean	W ₁₀₀	W ₈₀	W ₆₀	Mean
M ₀	110	105	85	100.0	368	350	315	344.3	68.25	60.63	51.98	60.29
M ₁	97	101	90	96.0	360	347	318	341.7	66.97	62.02	53.11	60.70
M ₂	94	100	91	95.0	375	351	320	348.7	68.80	63.40	53.44	61.88
Mean	100.3	102.0	88.7	97.0	367.7	349.3	317.7	344.9	68.01	62.02	52.84	60.96
Statistical information												
	S.Em±	CD@5%	F-test		S.Em±	CD@5%	F-test		S.Em±	CD@5%	F-test	
Water stress (W)	2.86	8.50	*		1.16	3.43	*		0.21	0.61	*	
Mulching (M)	-	-	NS		1.16	3.43	*		-	-	NS	
Interaction WxM	-	-	NS		2.0	5.94	*		0.36	1.06	*	

*= Significantly different at 5% level of probability; NS= Non Significant

Main treatments

W₁₀₀=100% F.C. or control

W₈₀=80% F.C.

W₆₀=60% F.C.

Sub treatments

M₀= No mulch or control

M₁= Dry lemon grass mulch

M₂= Plastic mulch

Significantly maximum shoot dry weight per plant in water stress treatments was recorded with W_{100} (68.01 g/plant) and minimum shoot dry weight was recorded in W_{100} (52.84 g/plant). Types of mulching had no significant influence on shoot dry weight.

Results of the interaction between water stress levels and mulching types showed that treatments $W_{100}M_2$ (68.80 g/plant) and $W_{100}M_0$ (68.25 g/plant) recorded significantly high shoot dry weight per plant and were *on par*. Minimum shoot dry weight was recorded in $W_{60}M_0$ (51.98 g/plant).

4.1.1.4 Root Fresh Weight (g/plant)

The data pertaining to root fresh weight recorded among different water stress levels and mulching types from the pot experiment are presented in Table 2. Significantly maximum root fresh weight in water stress treatments was recorded with W_{100} (44.74 g/plant) and minimum root fresh weight was recorded in W_{60} (35.80 g/plant). The results on mulching types recorded significant influence on root fresh weight. Treatment M_0 (Without mulch) recorded maximum root fresh weight (41.04 g/plant). Minimum root fresh weight was recorded in plastic mulch [(M_2) (40.17 g/plant)].

Results of the interaction between water stress levels and mulching types showed that $W_{100}M_2$ (45.14 g/plant) was *on par* with $W_{100}M_0$ and $W_{100}M_1$ (44.65 and 44.44 g/plant) gave significantly high root fresh weight when compared to other treatments. Minimum root fresh weight was recorded in $W_{60}M_2$ (33.24 g/plant).

4.1.1.5 Root Dry Weight (g/plant)

The various observations made on the root dry weight among different water stress levels and mulching types for pot experiment are tabulated and are presented in Table 2 and Figure 1. Significantly maximum root dry weight in

Table 2. Effect of water stress levels and mulch types on root fresh weight, root dry weight and root/shoot dry weight ratio in *Matricaria chamomilla* L. var. Vallary on the pot experiment

Sub treatments	Main treatments											
	Root fresh weight (g/plant)				Root dry weight (g/plant)				Root/shoot dry weight ratio			
	W ₁₀₀	W ₈₀	W ₆₀	Mean	W ₁₀₀	W ₈₀	W ₆₀	Mean	W ₁₀₀	W ₈₀	W ₆₀	Mean
M ₀	44.65	41.29	37.19	41.04	14.75	13.63	12.22	13.53	0.216	0.225	0.235	0.225
M ₁	44.44	40.64	36.96	40.68	14.20	13.70	12.76	13.55	0.212	0.221	0.240	0.224
M ₂	45.14	42.13	33.24	40.17	14.58	13.86	11.83	13.42	0.211	0.219	0.221	0.217
Mean	44.74	41.35	35.80	40.63	14.51	13.73	12.27	13.50	0.213	0.222	0.232	0.222
Statistical information												
	S.Em±	CD@5%	F-test		S.Em±	CD@5%	F-test		S.Em±	CD@5%	F-test	
Water stress (W)	0.175	0.52	*		0.58	0.17	*		0.0005	0.0014	*	
Mulching (M)	0.175	0.52	*		-	-	NS		0.0005	0.0014	*	
Interaction WxM	0.304	0.90	*		0.099	0.30	*		0.0008	0.0024	*	

*= Significantly different at 5% level of probability; NS= Non Significant

Main treatments

W₁₀₀=100% F.C. or control

W₈₀=80% F.C.

W₆₀=60% F.C.

Sub treatments

M₀= No mulch or control

M₁= Dry lemon grass mulch

M₂= Plastic mulch

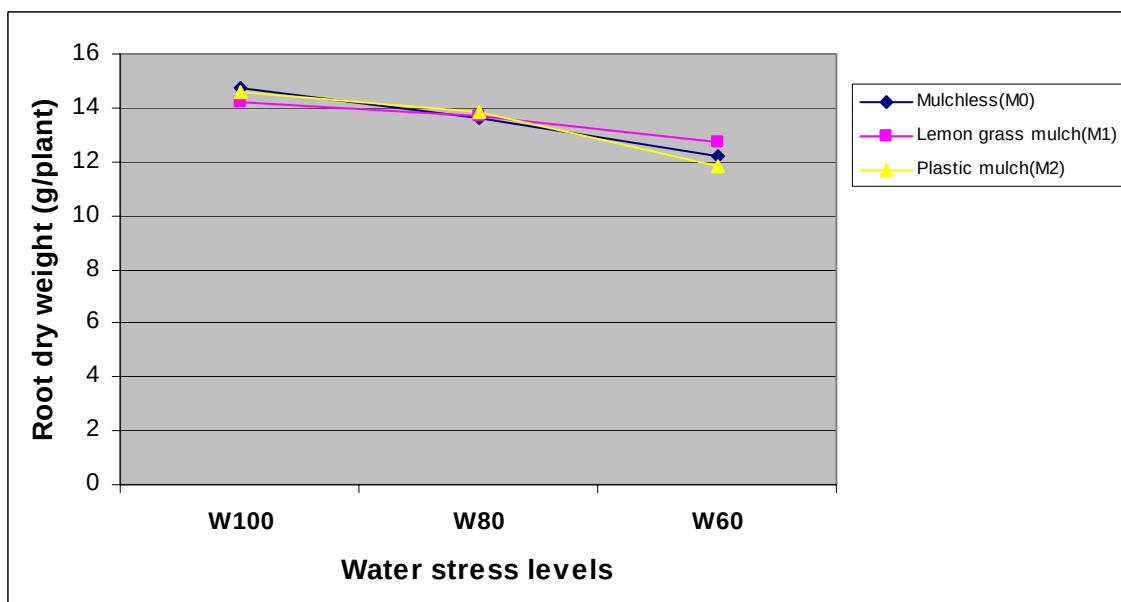


Fig. 1. Interaction effect of water stress levels and mulch types on root dry weight of *Matricaria chamomilla* L. var. Vallary of the pot experiment

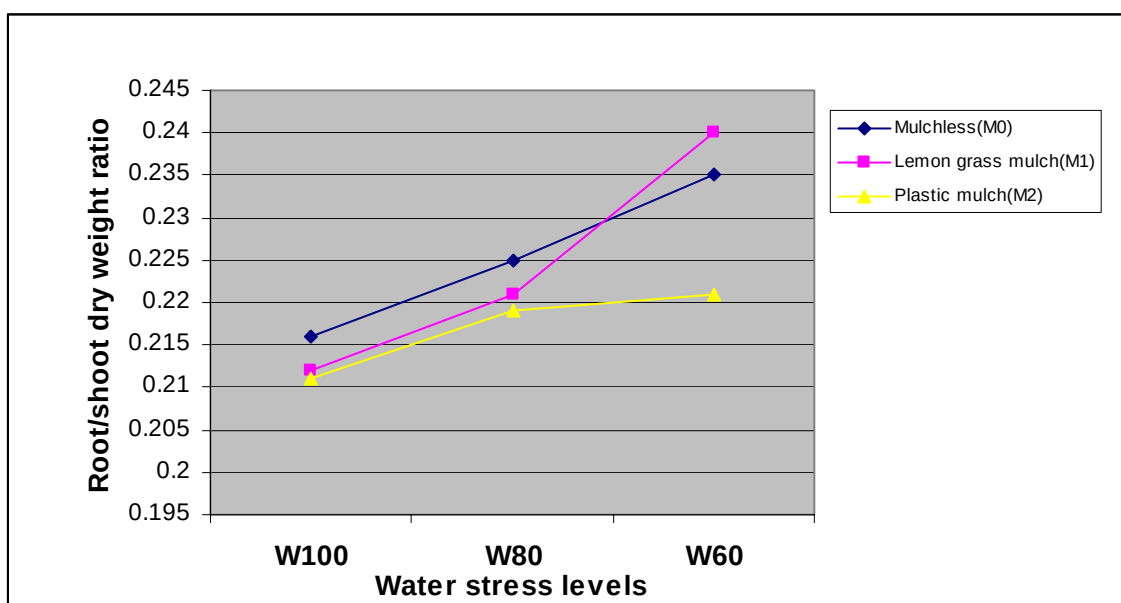


Fig. 2. Interaction effect of water stress levels and mulch types on root/shoot dry weight ratio of *Matricaria chamomilla* L. var. Vallary of the pot experiment

water stress treatments was recorded with W_{100} (14.51 g/plant) and minimum root dry weight was recorded in W_{60} (12.27 g/plant). The results on mulching types did not show any significant influence on root dry weight.

Results of the interaction between water stress levels and mulching types showed that $W_{100}M_0$ (14.75 g/plant) was *on par* with $W_{100}M_2$ (14.58 g/plant) gave significantly high root dry weight when compared to other treatments. Minimum root dry weight was recorded in $W_{60}M_2$ (11.83 g/plant).

Figure 1 clearly indicate that in water stress level of W_{100} , highest root dry weight, was obtained under the treatment without mulch (M_0) condition. While in water stress levels W_{80} and W_{60} highest root dry weight was obtained with plastic mulch (M_2) and lemon grass mulch (M_1), respectively.

4.1.1.6 Root/Shoot Dry Weight Ratio

The various observations made on the root/shoot dry weight ratio among different water stress levels and mulching types for pot experiment are tabulated and are presented in Table 1 and Figure 2.

Significantly maximum root/shoot dry weight ratio in water stress treatments was recorded with W_{60} (0.232) and minimum root/shoot dry weight ratio was recorded in W_{100} (0.213). The results on mulching types recorded significant influence on root/shoot dry weight ratio. Treatment M_0 (Without mulch) recorded maximum root/shoot dry weight ratio (0.225) and minimum root/shoot dry weight ratio (0.217) was recorded in plastic mulch (M_2).

Results of the interaction between water stress levels and mulching types showed that $W_{60}M_1$ (0.240) gave significantly high root/shoot dry weight ratio when compared to other treatments. Minimum root/shoot dry weight ratio was recorded in $W_{100}M_2$ (0.211).

Figure 2 clearly indicate that in water stress levels W_{100} , W_{80} highest root/shoot dry weight ratio was obtained under the treatment without mulch (M_0) condition. While in water stress level W_{60} highest root/shoot dry weight ratio was obtained with lemon grass mulch (M_1).

4.1.1.7 Number of Flowers per Plant

The data pertaining to number of flowers per plant recorded among different water stress levels and mulching types for the pot experiment are presented in Table 3. Treatments W_{60} and W_{80} recorded significantly maximum number of flowers per plant in water stress treatments and were *on par* (1173.5 and 1071.1, respectively). Minimum number of flowers per plant was recorded in W_{100} (757.2).

The results on mulching types and the interaction between water stress levels and mulching types recorded not significant influence on number of flowers per plant.

4.1.1.8 Weight of 100 fresh flowers (g)

The data pertaining to weight of 100 fresh flowers recorded among different water stress levels and mulching types for the pot experiment are presented in Table 3. Treatments W_{100} and W_{80} recorded significantly high 100 fresh flowers in water stress treatments and were *on par* (9.44 and 9.11 g, respectively). Minimum weight of 100 fresh flowers was recorded in W_{60} (6.81 g).

The results on mulching types and the interaction between water stress levels and mulching types recorded did not show any significant influence on weight of 100 fresh flowers.

Table 3. Effect of water stress levels and mulch types on number of flowers per plant, weight of 100 fresh flowers and weight of 100 dry flowers in *Matricaria chamomilla* L. var. Vallary on the pot experiment

Sub treatments	Main treatments											
	Number of flowers per plant				Weight of 100 fresh flowers (g)				Weight of 100 dry flowers (g)			
	W ₁₀₀	W ₈₀	W ₆₀	Mean	W ₁₀₀	W ₈₀	W ₆₀	Mean	W ₁₀₀	W ₈₀	W ₆₀	Mean
M ₀	867.2	1153.9	1011.1	1010.7	9.35	8.14	6.35	7.95	1.65	1.79	1.64	1.70
M ₁	765.6	956.9	1185.7	969.4	9.53	10.09	7.04	8.89	1.76	2.22	1.57	1.85
M ₂	638.9	1102.4	1323.8	1021.7	9.44	9.10	7.04	8.53	1.76	1.91	1.46	1.71
Mean	757.2	1071.1	1173.5	1000.6	9.44	9.11	6.81	8.45	1.72	1.97	1.56	1.75
Statistical information												
	S.Em±	CD@5%	F-test		S.Em±	CD@5%	F-test		S.Em±	CD@5%	F-test	
Water stress (W)	79.17	235.2	*		0.33	0.97	*		0.11	0.33	*	
Mulching (M)	-	-	NS		-	-	NS		-	-	NS	
Interaction WxM	-	-	NS		-	-	NS		-	-	NS	

*= Significantly different at 5% level of probability; NS= Non Significant

Main treatments

W₁₀₀=100% F.C. or control

W₈₀=80% F.C.

W₆₀=60% F.C.

Sub treatments

M₀= No mulch or control

M₁= Dry lemon grass mulch

M₂= Plastic mulch

4.1.1.9 Weight of 100 dry flowers (g)

The results of the weight of 100 dry flowers pertaining to different water stress levels and mulching types for the pot experiment are tabulated in Table 3. Treatments W₈₀ and W₁₀₀ recorded significantly high 100 dry flowers in water stress treatments and were *on par* (1.97 and 1.72 g, respectively). Minimum weight of 100 dry flowers was recorded in W₆₀ (1.56 g).

The results on mulching types and the interaction between water stress levels and mulching types recorded non significant influence on weight of 100 dry flowers.

4.1.2 Biomass Yield

The various observations made on the biomass yield of fresh flower yield (g/plant) and dry flower yield (g/plant) in *Matricaria chamomilla* L. var. Vallary recorded at different water stress levels and mulching types for the pot experiment are tabulated and are presented in Table 4 and Figure 3.

4.1.2.1 Fresh Flower Yield (g/plant)

The data pertaining to fresh flower yield recorded among different water stress levels and mulching types for the pot experiment are presented in Table 4. Significantly maximum fresh flower yield per plant in water stress treatments was recorded with W₈₀ (95.87 g/plant) and minimum fresh flower yield was recorded in W₆₀ (69.93 g/plant) during the first year. The results on mulching types recorded significant influence on fresh flower yield per plant. Lemon grass mulch (M₁) recorded maximum fresh flower yield (83.67 g/plant). Treatments without mulch (M₀) and plastic mulch (M₂) recorded minimum fresh flower yield and were *on par* (77.17 and 77.87 g/plant, respectively).

Table 4. Effect of water stress levels and mulch types on fresh flower yield and dry flower yield in *Matricaria chamomilla* L. var. Vallary on the pot experiment

Sub treatments	Main treatments							
	Fresh flower yield (g/plant)				Dry flower yield (g/plant)			
	W ₁₀₀	W ₈₀	W ₆₀	Mean	W ₁₀₀	W ₈₀	W ₆₀	Mean
M ₀	82.4	94.1	55.0	77.17	14.0	20.7	15.7	16.78
M ₁	78.2	96.8	76.0	83.67	13.3	21.0	18.3	17.56
M ₂	58.1	96.7	78.8	77.87	11.0	20.3	18.0	16.40
Mean	72.90	95.87	69.93	79.57	12.78	20.67	17.33	16.96
Statistical information								
	S.Em±	CD@5%	F-test		S.Em±	CD@5%	F-test	
Water stress (W)	0.45	1.35	*		0.4	1.18	*	
Mulching (M)	0.45	1.35	*		-	-	NS	
Interaction WxM	0.79	2.33	*		0.69	2.05	*	

*= Significantly different at 5% level of probability; NS= Non Significant

Main treatments

W₁₀₀=100% F.C. or control

W₈₀=80% F.C.

W₆₀=60% F.C.

Sub treatments

M₀= No mulch or control

M₁= Dry lemon grass mulch

M₂= Plastic mulch

Results of the interaction between water stress levels and mulching types showed that treatments $W_{80}M_1$ (96.8 g/plant) and $W_{80}M_2$ (96.7 g/plant) recorded significantly high fresh flower yield per plant and were *on par*. Minimum fresh flower yield was recorded in $W_{60}M_0$ (55.0 g/plant).

4.1.2.2 Dry Flower Yield (g/plant)

The various observations made on the dry flower yield among different water stress levels and mulching types for pot experiment are tabulated and are presented in Table 4 and Figure 3. Significantly maximum dry flower yield per plant in water stress treatments was recorded with W_{80} (20.67 g/plant) and minimum dry flower yield was recorded in W_{100} (12.78 g/plant). The results on mulching types recorded did not show any significant influence on dry flower yield per plant.

Results of the interaction between water stress levels and mulching types showed that treatments $W_{80}M_1$, $W_{80}M_0$ and $W_{80}M_2$ recorded significantly high dry flower yield per plant and were *on par* (21.0, 20.7 and 20.3 g/plant, respectively). Minimum dry flower yield was recorded in $W_{100}M_2$ (11.0 g/plant).

Figure 3 clearly indicate that in water stress level W_{100} , highest dry flower yield was obtained under the treatment without mulch (M_0) condition. While in water stress levels W_{80} and W_{60} highest dry flower yield was obtained with lemon grass mulch (M_1).

4.1.3 Essential Oil Quantity

The data pertaining to the essential oil quantity such as essential oil percentage and yield (kg/ha) in *Matricaria chamomilla* L. var. Vallary recorded at different water stress levels and mulching types for pot experiment are tabulated and are presented in Table 5 and Figures 4 and 5.

4.1.3.1 Essential Oil Percentage (% v/w dry weight)

The observations recorded on essential oil percentage under different water stress levels and mulching types for pot experiment are presented in Table 5 and Figure 4. Treatments W_{80} and W_{60} recorded significantly high essential oil percentage in water stress treatments and were *on par* (0.783 and 0.777 % v/w dry weight). Minimum essential oil percentage was recorded in W_{100} (0.703 % v/w dry weight). The results on mulching types and the interaction between water stress levels and mulching types recorded no significant influence on essential oil percentage.

Figure 4 clearly indicate that in water stress level W_{100} , highest essential oil percentage was obtained under the treatment without mulch (M_0) condition. While in water stress levels W_{80} essential oil percentage was equal between different mulching types. In water stress levels W_{60} highest essential oil percentage was obtained with lemon grass mulch (M_1) which was equal with plastic mulch (M_2).

4.1.3.2 Essential Oil Yield (kg/ha)

The observations recorded on essential oil yield under different water stress levels and mulching types for pot experiment are presented in Table 5 and Figure 5. Significantly maximum essential oil yield in water stress treatments was recorded with W_{80} (16.19 kg/ha) and minimum essential oil yield was recorded in W_{100} (8.99 kg/ha). The results on mulching types recorded did not show any significant influence on root dry weight.

Results of the interaction between water stress levels and mulching types showed that treatments $W_{80}M_1$, $W_{80}M_0$ and $W_{80}M_2$ recorded significantly essential oil yield and were *on par* (16.39, 16.11 and 16.06 kg/ha). Minimum essential oil yield was recorded in $W_{100}M_2$ (7.68 kg/ha).

Table 5. Effect of water stress levels and mulch types on essential oil percentage, essential oil yield and proline production in *Matricaria chamomilla* L. var. Vallary on the pot experiment

Sub treatments	Main treatments											
	Essential oil percentage (v/w DW)				Essential oil yield (kg/ha)				Proline production(µg/g fresh weight)			
	W ₁₀₀	W ₈₀	W ₆₀	Mean	W ₁₀₀	W ₈₀	W ₆₀	Mean	W ₁₀₀	W ₈₀	W ₆₀	Mean
M ₀	0.71	0.78	0.77	0.753	9.92	16.11	12.05	12.70	106.8	163.2	240.4	170.1
M ₁	0.70	0.78	0.78	0.753	9.37	16.39	14.30	13.35	100.9	148.3	238.8	162.7
M ₂	0.70	0.78	0.78	0.757	7.68	16.06	14.05	12.60	96.4	156.9	224.3	159.2
Mean	0.703	0.783	0.777	0.754	8.99	16.19	13.47	12.88	101.4	156.1	234.5	164.0
Statistical information												
	S.Em±	CD@5%	F-test		S.Em±	CD@5%	F-test		S.Em±	CD@5%	F-test	
Water stress (W)	0.008	0.024	*		0.32	0.95	*		5.01	14.87	*	
Mulching (M)	-	-	NS		-	-	NS		-	-	NS	
Interaction WxM	-	-	NS		0.56	1.65	*		-	-	NS	

*= Significantly different at 5% level of probability; NS= Non Significant

Main treatments

W₁₀₀=100% F.C. or control

W₈₀=80% F.C.

W₆₀=60% F.C.

Sub treatments

M₀= No mulch or control

M₁= Dry lemon grass mulch

M₂= Plastic mulch

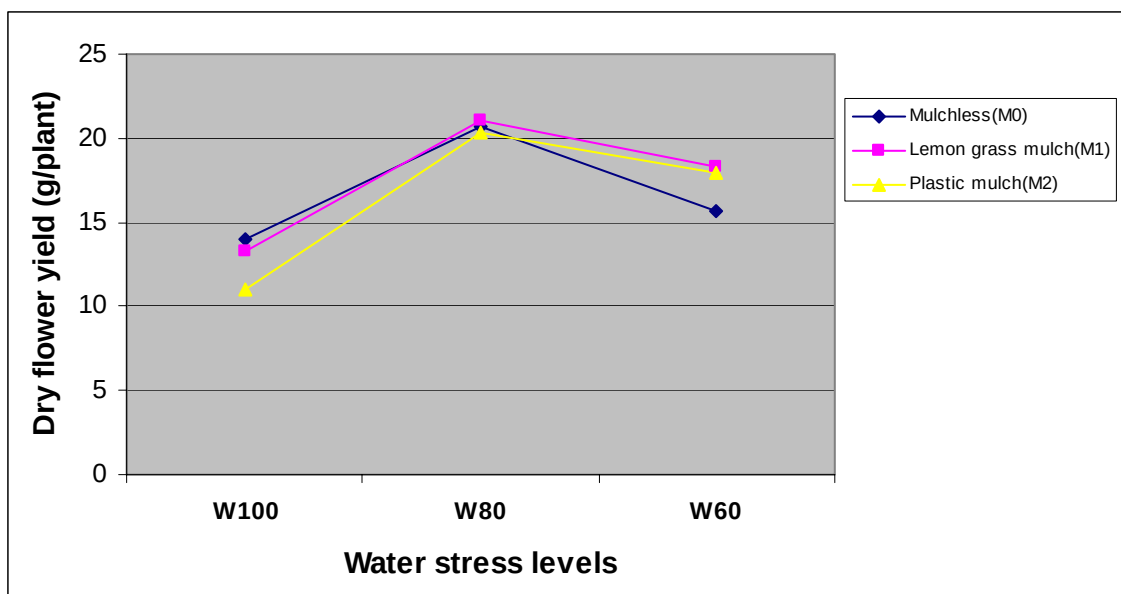


Fig. 3. Interaction effect of water stress levels and mulch types on dry flower yield of *Matricaria chamomilla* L. var. Vallary of the pot experiment

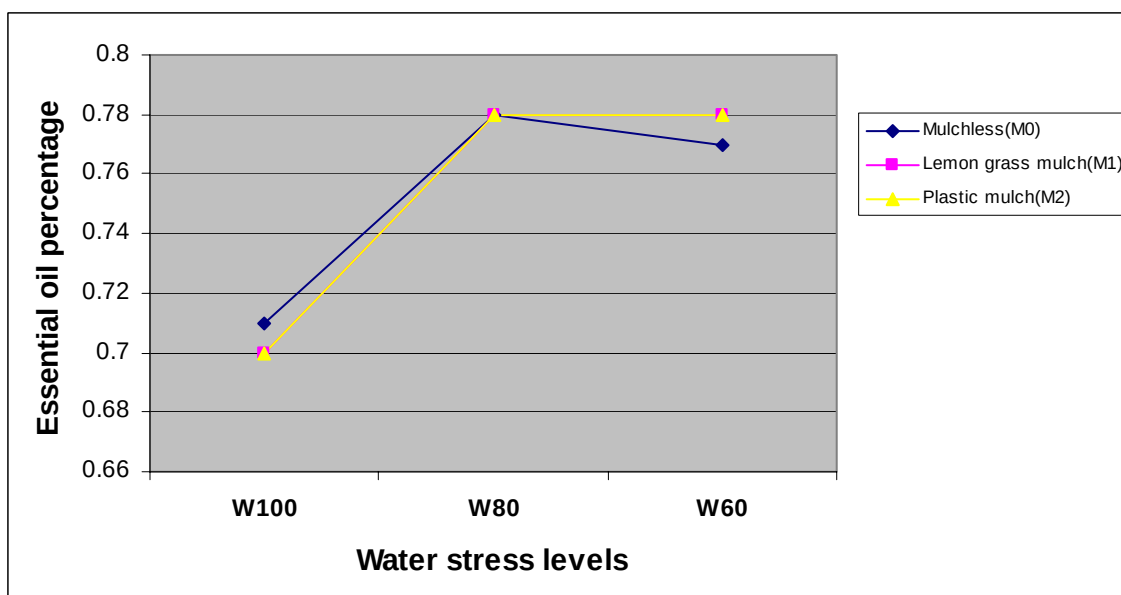


Fig. 4. Interaction effect of water stress levels and mulch types on essential oil percentage (v/w) of *Matricaria chamomilla* L. var. Vallary of the pot experiment



Plate 9. Treatment without mulch (M_0) in the field experiment (25 days after transplanting)



Plate 10. Treatment lemon grass mulch (M_1) in the field experiment (25 days after transplanting)

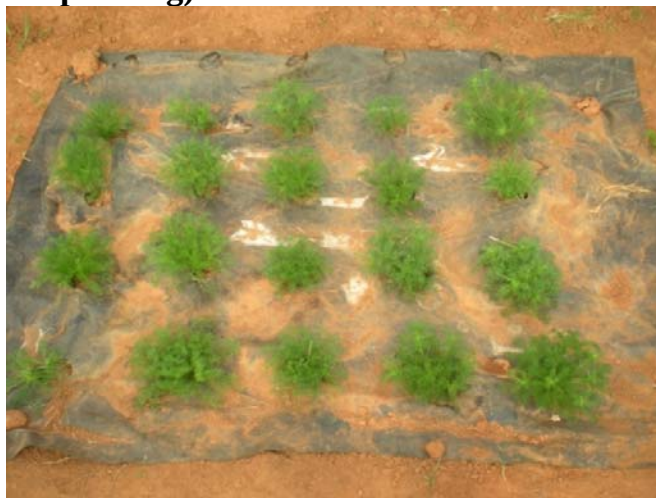


Plate 11. Treatment plastic mulch (M_2) in the field experiment (25 days after transplanting)



Plate 12. First flowering - forty days after transplanting



Plate 13. Second flowering - fifty five days after transplanting



Plate 14. Third flowering - seventy five days after transplanting



Plate 15. Optimum stage for harvest



Plate 16. Harvesting of *Matricaria chamomilla* L. var. Vallary (Hand picking of fully- opened flowers)



Plate 17. Fresh flowers after harvest



Plate 18. Shade drying of harvested flowers



Plate 19. Distillation of chamomile essential oil by Clevenger apparatus

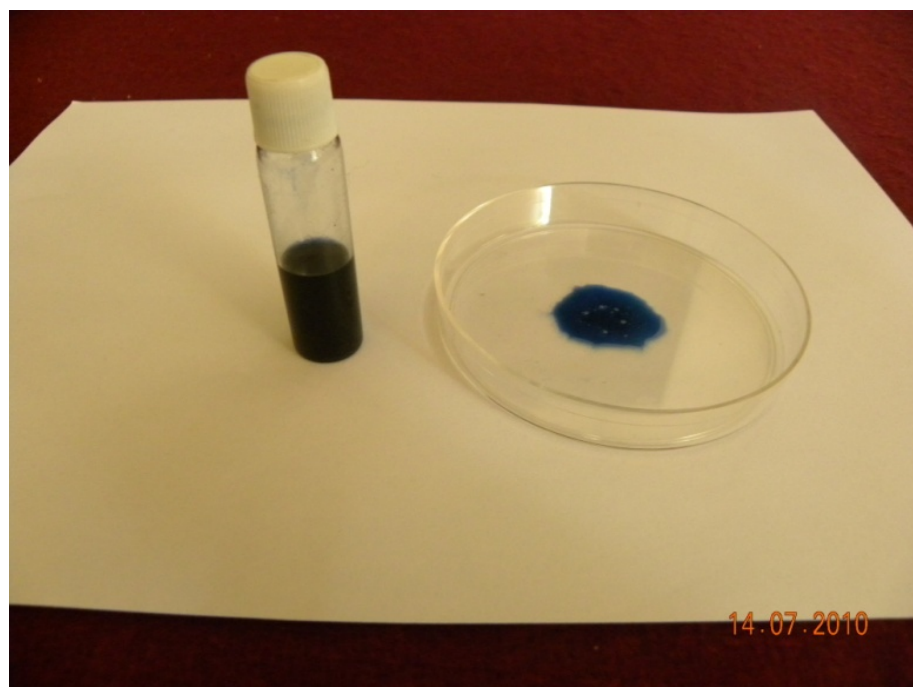


Plate 20. Azure coloured chamomile essential oil

Figure 5 clearly indicate that in water stress level W_{100} , highest essential oil yield was obtained under the treatment without mulch (M_0) condition. While in water stress levels W_{80} and W_{60} highest essential oil yield was obtained with lemon grass mulch (M_1).

4.1.4 Proline Production

The various observations made on the proline production ($\mu\text{g/g}$ fresh weight) in *Matricaria chamomilla* L. var. Vallary recorded at different water stress levels and mulching types for the pot experiment are tabulated and are presented in Table 5 and Figure 6.

4.1.4.1 Proline Production ($\mu\text{g/g}$ fresh weight)

Significantly maximum proline production in water stress treatments was recorded in W_{60} (234.5 $\mu\text{g/g}$ fresh weight) and minimum proline production was recorded in W_{100} (101.4 $\mu\text{g/g}$ fresh weight). The results on mulching types and the interaction between water stress levels and mulching types recorded did not show any significant influence on proline production.

Figure 4 clearly indicate that in different water stress levels (W_{100} , W_{80} and W_{60}), highest proline production was obtained under the treatment without mulch (M_0) condition.

4.1.5 Correlation coefficients

The observations recorded on correlation coefficients between some of the yield and growth parameters in *Matricaria chamomilla* L. var. Vallary under different water stress levels and mulching types for the pot experiment are presented in Table 6.

As per results, correlation coefficients between dry flower yield and essential oil percentage, essential oil yield and root/shoot dry weight ratio showed

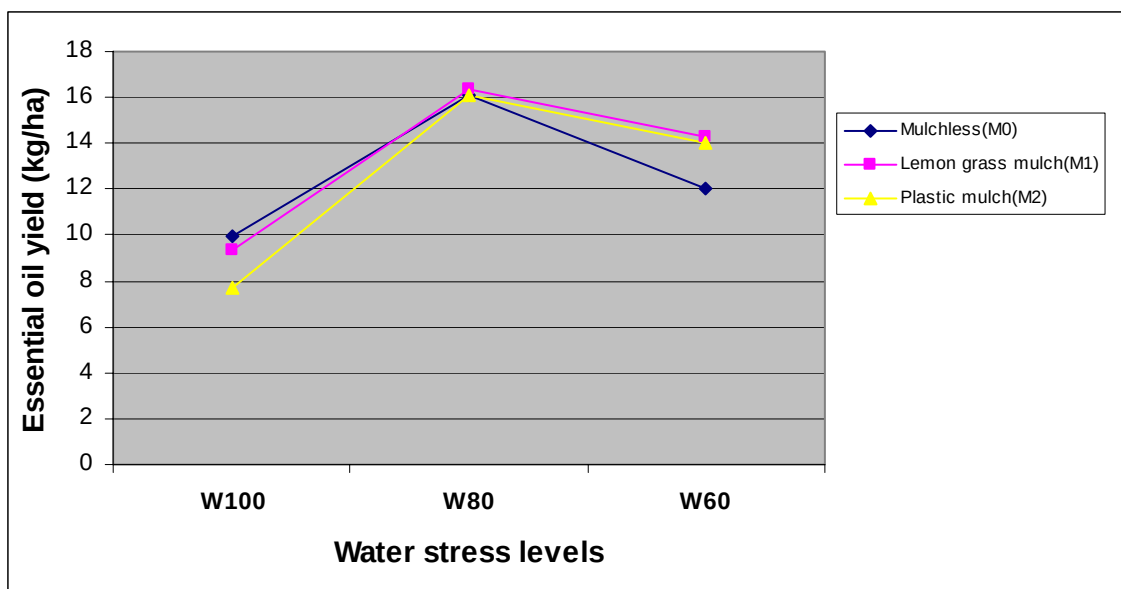


Fig. 5. Interaction effect of water stress levels and mulch types on essential oil yield of *Matricaria chamomilla* L. var. Vallary of the pot experiment

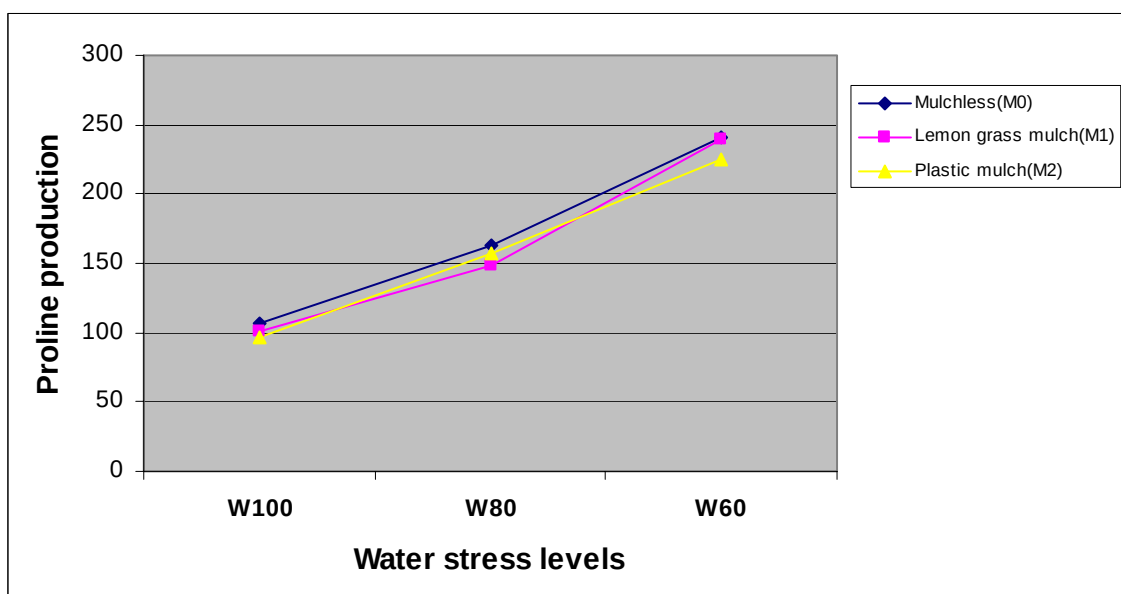


Fig. 6. Interaction effect of water stress levels and mulch types on proline production ($\mu\text{g/g}$ fresh weight) of *Matricaria chamomilla* L. var. Vallary of the pot experiment

positive correlation and correlation coefficients were +0.76, +0.99 and +0.39, respectively. Moreover essential oil yield showed positive correlation coefficients with essential oil percentage, root/shoot dry weight ratio and proline production which correlation coefficients were +0.84, +0.42 and +0.50, respectively. Essential oil percentage showed positive correlation coefficients with root/shoot dry weight ratio (+0.54). Also positive linear correlation was found between proline production and root/shoot dry weight ratio (+0.85).

Table 6. Correlation coefficients between growth and yield parameters of treatments under water stress and mulching conditions of *Matricaria chamomilla* L. var. Vallary on pot experiment.

Parameters	Essential Oil percentage	Essential oil yield	Root/shoot DW ratio
Dry flower yield	+0.76	+0.99	+0.39
Essential Oil percentage	-	-	+0.54
Essential Oil yield	+0.84	-	+0.42
Proline	+0.64	+0.50	+0.85

4.2 EXPERIMENT 2: (FIELD EXPERIMENTS)

4.2.1 Morphological Characters

The various morphological characters such as plant height (cm), shoot fresh weight (g/plant), shoot dry weight (g/plant), root fresh weight (g/plant), root dry weight (g/plant), root/shoot dry weight ratio, number of flowers per plant and weight of 100 dry flowers (g) in *Matricaria chamomilla* L. var. Vallary recorded at different water stress levels and mulching types for the first and second years and mean of them are presented in Tables 7-14 and Figures 7-10.

4.2.1.1 Plant Height (cm)

The observations recorded on plant height in *Matricaria chamomilla* L. var. Vallary under different water stress levels and mulching types for the first and second years and mean of two years are presented in Table 7.

Significantly maximum plant height in water stress treatments was recorded with W_{80} (80.3, 77.3 and 78.8 cm in the first and second years and mean of them, respectively), and minimum plant height was recorded in W_{60} (62.0, 63.0 and 62.5 cm in the first and second years and mean of them, respectively).

The results on mulching types recorded significant influence on plant height. Without mulch (M_0) with 73.7 and 72.8 cm in the first year and mean of two years, respectively and also lemon grass mulch (M_1) with 72.3 cm in the second year recorded maximum plant height. Also without mulch (M_0) was *on par* with lemon grass mulch (M_1) in the first and second years and mean of two years. Plastic mulch (M_2) recorded minimum plant height (72.7, 71.3 and 72.0 cm in the first and second years and mean of them, respectively) which was *on par* with lemon grass mulch (M_1) in the first year.

Results of the interaction between water stress levels and mulching types showed that $W_{80}M_2$ gave significantly maximum plant height (82, 78 and 80 cm in the first and second years and mean of them, respectively) when compared to other treatments but was *on par* with $W_{80}M_1$ (78 and 79 cm) in the second year and mean of two years. Minimum plant height was recorded in $W_{60}M_2$ (60, 62 and 61 cm in the first and second years and mean of them, respectively), which was *on par* with $W_{60}M_1$ (63 cm) in the second year.

The main point is, in the mean of two years, these amounts of plant height in W_{100} were obtained approximately with 42, 34 and 28 irrigations by without mulch (M_0), lemon grass mulch (M_1) and plastic mulch (M_2), respectively during

Table 7. Effect of water stress levels and mulch types on plant height in *Matricaria chamomilla* L. var. Vallary on first and second years and their mean of field experiment

Sub treatments	Plant height (cm)											
	Main treatments											
	First year ¹				Second year ²				Mean of two years ³			
	W ₁₀₀	W ₈₀	W ₆₀	Mean	W ₁₀₀	W ₈₀	W ₆₀	Mean	W ₁₀₀	W ₈₀	W ₆₀	Mean
M ₀	78	79	64	73.7	76	76	64	72.0	77	77 ⁺	64 ^x	72.8
M ₁	77	80	62	73.0	76	78	63	72.3	76	79 ⁺⁺	62 ^{xx}	72.7
M ₂	76	82	60	72.7	74	78	62	71.3	75	80 ⁺⁺⁺	61 ^{xxx}	72.0
Mean	77.0	80.3	62.0	73.1	75.3	77.3	63.0	71.9	76.2	78.8	62.5	72.5
Statistical information												
	S.Em±	CD@5%	F-test		S.Em±	CD@5%	F-test		S.Em±	CD@5%	F-test	
Water stress (W)	0.157	0.484	*		0.351	1.083	*		0.215	0.663	*	
Mulching (M)	0.192	0.756	*		0.111	0.436	*		0.147	0.577	*	
Interaction WxM	0.272	0.839	*		0.609	1.875	*		0.373	1.148	*	

*= Significantly different at 5% level of probability; 1- First year= 2008-2009; 2- Second year= 2009-2010; 3- Mean= mean of first and second years; +Plant height after approximately 25 irrigation through 3 month crop growth; ++ Plant height after approximately 20 irrigation only; +++ Plant height after approximately 17 irrigation only; x Plant height after approximately 17 irrigation only; xx Plant height after approximately 12 irrigation only; xxx Plant height after approximately 9 irrigation only.

Main treatments

W₁₀₀=100% F.C. or control

W₈₀=80% F.C.

W₆₀=60% F.C.

Sub treatments

M₀= No mulch or control

M₁= Dry lemon grass mulch

M₂= Plastic mulch

the growth. Also the amounts of plant height in W_{80} were obtained approximately with 25, 20 and 17 irrigations by without mulch (M_0), lemon grass mulch (M_1) and plastic mulch (M_2), respectively during the growth. The amounts of plant height in W_{60} were obtained approximately with 17, 12 and 9 irrigations by without mulch (M_0), lemon grass mulch (M_1) and plastic mulch (M_2), respectively during the growth.

4.2.1.2 Shoot Fresh Weight (g/plant)

The observations recorded on shoot fresh weight in *Matricaria chamomilla* L. var. Vallary under different water stress levels and mulching types for the first and second years and mean of them are presented in Table 8. Data in Table (8) showed that water stress levels had significant effect on the shoot fresh weight of plants. The shoot fresh weight was significantly higher for the plants irrigated at 100% F.C. (402, 372 and 386 g/plant in the first and second years and mean of them, respectively). Minimum shoot fresh weight was recorded in W_{60} (313, 331 and 322 g/plant in the first and second years and mean of them, respectively).

The results on mulching types recorded significant influence on shoot fresh weight. Without mulch (M_0) with 373 and 364 g/plant in the first year and mean of two years and on the other hand lemon grass mulch (M_1) with 357 g/plant in the second year recorded maximum shoot fresh weight. Also without mulch (M_0) was *on par* with lemon grass mulch (M_1) in the first year and mean of two years. Plastic mulch (M_2) recorded minimum shoot fresh weight (361, 343 and 352 g/plant in the first and second years and mean of them, respectively).

Results of the interaction between water stress levels and mulching types showed that $W_{100}M_0$ (406 g/plant) in the first year, $W_{100}M_1$ (375 g/plant) in the second year and $W_{100}M_0$ and $W_{100}M_1$ (389 g/plant) gave significantly maximum shoot fresh weight when compared to other treatments but $W_{100}M_0$ and $W_{100}M_1$ were *on par* in the first and second years and also were equal in mean of two

Table 8. Effect of water stress levels and mulch types on shoot fresh weight in *Matricaria chamomilla* L. var. Vallary on first and second years and their mean of field experiment

Sub treatments	Shoot fresh weight (g/plant)											
	Main treatments											
	First year ¹				Second year ²				Mean of two years ³			
	W ₁₀₀	W ₈₀	W ₆₀	Mean	W ₁₀₀	W ₈₀	W ₆₀	Mean	W ₁₀₀	W ₈₀	W ₆₀	Mean
M ₀	406	392	320	373	372	358	336	355	389	375	328	364
M ₁	404	397	311	371	375	361	335	357	389	379	323	363
M ₂	395	380	308	361	370	338	322	343	382	359	315	352
Mean	402	390	313	368	372	352	331	352	386	371	322	359
Statistical information												
	S.Em±	CD@5%	F-test		S.Em±	CD@5%	F-test		S.Em±	CD@5%	F-test	
Water stress (W)	0.97	2.991	*		0.69	2.111	*		0.56	1.736	*	
Mulching (M)	0.97	3.812	*		0.19	0.756	*		0.40	1.578	*	
Interaction WxM	1.68	5.181	*		1.19	3.655	*		0.98	3.007	*	

*= Significantly different at 5% level of probability; 1- First year= 2008-2009; 2- Second year= 2009-2010; 3- Mean= mean of first and second years

Main treatments

W₁₀₀=100% F.C. or control

W₈₀=80% F.C.

W₆₀=60% F.C.

Sub treatments

M₀= No mulch or control

M₁= Dry lemon grass mulch

M₂= Plastic mulch

years. Minimum shoot fresh weight was recorded in $W_{60}M_2$ (308, 322 and 315 g/plant in the first and second years and mean of them, respectively), which was *on par* with $W_{60}M_1$ (311 g/plant) in the first year.

The main point is, in the mean of two years, these amounts of shoot fresh weight in W_{100} were obtained approximately with 42, 34 and 28 irrigations by without mulch (M_0), lemon grass mulch (M_1) and plastic mulch (M_2), respectively during the growth. Also the amounts of shoot fresh weight in W_{80} were obtained approximately with 25, 20 and 17 irrigations by without mulch (M_0), lemon grass mulch (M_1) and plastic mulch (M_2), respectively during the growth. The amounts of shoot fresh weight in W_{60} were obtained approximately with 17, 12 and 9 irrigations by without mulch (M_0), lemon grass mulch (M_1) and plastic mulch (M_2), respectively during the growth.

4.2.1.3 Shoot Dry Weight (g/plant)

The observations recorded on shoot dry weight in *Matricaria chamomilla* L. var. Vallary under different water stress levels and mulching types for the first and second years and mean of them are presented in Table 9. Significantly maximum shoot dry weight in water stress treatments was recorded with W_{100} (69.60, 64.74 and 67.17 g/plant in the first and second years and mean of them, respectively), and minimum shoot dry weight was recorded in W_{60} (61.69, 59.22 and 60.45 g/plant in the first and second years and mean of them, respectively).

The results on mulching types recorded significant influence on shoot dry weight. Lemon grass mulch (M_1) with 65.94 and 63.60 and 64.77 g/plant in the first and second years and mean of them, respectively recorded maximum shoot dry weight. Also lemon grass mulch (M_1) was *on par* under the treatment without mulch (M_0) in the first year. Plastic mulch (M_2) recorded minimum shoot dry weight (64.49, 61.31 and 62.90 g/plant in the first and second years and mean of them, respectively).

Table 9. Effect of water stress levels and mulch types on shoot dry weight in *Matricaria chamomilla* L. var. Vallary on first and second years and their mean of field experiment

Sub treatments	Shoot dry weight (g/plant)											
	Main treatments											
	First year ¹				Second year ²				Mean of two years ³			
	W ₁₀₀	W ₈₀	W ₆₀	Mean	W ₁₀₀	W ₈₀	W ₆₀	Mean	W ₁₀₀	W ₈₀	W ₆₀	Mean
M ₀	69.43	66.25	61.76	65.81	63.61	63.20	61.93	62.91	66.52	64.73	61.85	64.37
M ₁	70.24	66.30	61.27	65.94	65.85	64.65	60.29	63.60	68.05	65.48	60.78	64.77
M ₂	69.13	62.32	62.03	64.49	64.75	63.76	55.43	61.31	66.94	63.04	58.73	62.90
Mean	69.60	64.96	61.69	65.41	64.74	63.87	59.22	62.61	67.17	64.42	60.45	64.01
Statistical information												
	S.Em±	CD@5%	F-test		S.Em±	CD@5%	F-test		S.Em±	CD@5%	F-test	
Water stress (W)	0.171	0.526	*		0.125	0.384	*		0.097	0.299	*	
Mulching (M)	0.176	0.689	*		0.034	0.135	*		0.072	0.283	*	
Interaction W×M	0.296	0.911	*		0.216	0.666	*		0.168	0.518	*	

*= Significantly different at 5% level of probability; 1- First year= 2008-2009; 2- Second year= 2009-2010; 3- Mean= mean of first and second years

Main treatments

W₁₀₀=100% F.C. or control

W₈₀=80% F.C.

W₆₀=60% F.C.

Sub treatments

M₀= No mulch or control

M₁= Dry lemon grass mulch

M₂= Plastic mulch

Results of the interaction between water stress levels and mulching types showed that $W_{100}M_1$ gave significantly maximum shoot dry weight (70.24, 65.85 and 68.05 g/plant in the first and second years and mean of them, respectively) when compared to other treatments but was *on par* with $W_{100}M_0$ (69.43 g/plant) in the first year. Minimum shoot dry weight in the first year was recorded in $W_{60}M_0$ (61.76 g/plant) which was *on par* with $W_{60}M_1$ (61.27 g/plant), also in the second year and mean of two years $W_{60}M_2$ (55.43 and 58.73 g/plant, respectively) showed minimum shoot dry weight.

The main point is, in the mean of two years, these amounts of shoot dry weight in W_{100} were obtained approximately with 42, 34 and 28 irrigations by without mulch (M_0), lemon grass mulch (M_1) and plastic mulch (M_2), respectively during the growth. Also the amounts of shoot dry weight in W_{80} were obtained approximately with 25, 20 and 17 irrigations by without mulch (M_0), lemon grass mulch (M_1) and plastic mulch (M_2), respectively during the growth. The amounts of shoot dry weight in W_{60} were obtained approximately with 17, 12 and 9 irrigations by without mulch (M_0), lemon grass mulch (M_1) and plastic mulch (M_2), respectively during the growth.

4.2.1.4 Root Fresh Weight (g/plant)

The observations recorded on root fresh weight in *Matricaria chamomilla* L. var. Vallary under different water stress levels and mulching types for the first and second years and mean of them are presented in Table 10. Significantly maximum root fresh weight in water stress treatments was recorded with W_{100} (43.67, 46.18 and 44.93 g/plant in the first and second years and mean of them, respectively) and minimum root fresh weight was recorded in W_{60} (38.37, 32.87 and 35.62 g/plant in the first and second years and mean of them, respectively).

The results on mulching types recorded significant influence on root fresh weight. Lemon grass mulch (M_1) recorded maximum root fresh weight (41.92,

Table 10. Effect of water stress levels and mulch types on root fresh weight in *Matricaria chamomilla* L. var. Vallary on first and second years and their mean of field experiment

Sub treatments	Root fresh weight (g/plant)											
	Main treatments											
	First year ¹				Second year ²				Mean of two years ³			
	W ₁₀₀	W ₈₀	W ₆₀	Mean	W ₁₀₀	W ₈₀	W ₆₀	Mean	W ₁₀₀	W ₈₀	W ₆₀	Mean
M ₀	44.48	42.22	38.73	41.81	46.70	38.69	35.37	40.25	45.59	40.46	37.05	41.03
M ₁	43.42	43.27	39.06	41.92	46.77	40.31	35.52	40.87	45.09	41.80	37.29	41.39
M ₂	43.12	43.45	37.31	41.29	45.08	40.70	27.72	37.83	44.10	42.08	32.52	39.57
Mean	43.67	42.98	38.37	41.67	46.18	39.90	32.87	39.65	44.93	41.44	35.62	40.66
Statistical information												
	S.Em±	CD@5%	F-test		S.Em±	CD@5%	F-test		S.Em±	CD@5%	F-test	
Water stress (W)	0.108	0.333	*		0.083	0.256	*		0.06	0.185	*	
Mulching (M)	0.112	0.441	*		0.018	0.069	*		0.05	0.190	*	
Interaction WxM	0.187	0.576	*		0.144	0.443	*		0.104	0.321	*	

*= Significantly different at 5% level of probability; 1- First year= 2008-2009; 2- Second year= 2009-2010; 3- Mean= mean of first and second years

Main treatments

W₁₀₀=100% F.C. or control

W₈₀=80% F.C.

W₆₀=60% F.C.

Sub treatments

M₀= No mulch or control

M₁= Dry lemon grass mulch

M₂= Plastic mulch

40.87 and 41.39 g/plant in the first and second years and mean of them, respectively) which was *on par* under the treatment without mulch (M_0) in first year. Plastic mulch (M_2) recorded minimum root fresh weight (41.29, 37.83 and 39.57 g/plant in the first and second years and mean of them, respectively).

Results of the interaction between water stress levels and mulching types showed that $W_{100}M_0$ (44.48 and 45.59 g/plant in the first year and mean of two years, respectively) and $W_{100}M_1$ (46.77 g/plant in the second year) gave significantly maximum root fresh weight when compared to other treatments but $W_{100}M_1$ was *on par* with $W_{100}M_0$ (46.70 g/plant) in the second year. Minimum root fresh weight was recorded in $W_{60}M_2$ (37.31, 27.72 and 32.52 g/plant in the first and second years and mean of them, respectively).

The main point is, in the mean of two years, these amounts of root fresh weight in W_{100} were obtained approximately with 42, 34 and 28 irrigations by without mulch (M_0), lemon grass mulch (M_1) and plastic mulch (M_2), respectively during the growth. Also the amounts of root fresh weight in W_{80} were obtained approximately with 25, 20 and 17 irrigations by without mulch (M_0), lemon grass mulch (M_1) and plastic mulch (M_2), respectively during the growth. The amounts of root fresh weight in W_{60} were obtained approximately with 17, 12 and 9 irrigations by without mulch (M_0), lemon grass mulch (M_1) and plastic mulch (M_2), respectively during the growth.

4.2.1.5 Root Dry Weight (g/plant)

The observations recorded on root dry weight in *Matricaria chamomilla* L. var. Vallary under different water stress levels and mulching types for the first and second years and mean of them are presented in Table 11 and Figures 7 and 8. Significantly maximum root dry weight in water stress treatments was recorded with W_{100} (14.88, 13.87 and 14.38 g/plant in the first and second years and mean of them, respectively) and minimum root dry weight was recorded in W_{60} (14.12,

Table 11. Effect of water stress levels and mulch types on root dry weight in *Matricaria chamomilla* L. var. Vallary on first and second years and their mean of field experiment

Sub treatments	Root dry weight (g/plant)											
	Main treatments											
	First year ¹				Second year ²				Mean of two years ³			
	W ₁₀₀	W ₈₀	W ₆₀	Mean	W ₁₀₀	W ₈₀	W ₆₀	Mean	W ₁₀₀	W ₈₀	W ₆₀	Mean
M ₀	15.21	14.53	14.33	14.69	13.50	13.45	13.32	13.42	14.36	13.99	13.83	14.06
M ₁	15.15	14.89	14.32	14.79	14.15	13.92	13.41	13.83	14.65	14.41	13.87	14.31
M ₂	14.29	13.74	13.70	13.91	13.95	13.81	12.85	13.54	14.12	13.78	13.28	13.73
Mean	14.88	14.39	14.12	14.46	13.87	13.73	13.19	13.60	14.38	14.06	13.66	14.03
Statistical information												
	S.Em±	CD@5%	F-test		S.Em±	CD@5%	F-test		S.Em±	CD@5%	F-test	
Water stress (W)	0.084	0.225	*		0.03	0.091	*		0.038	0.117	*	
Mulching (M)	-	-	NS		0.007	0.027	*		0.041	0.159	*	
Interaction WxM	0.126	0.389	*		0.051	0.158	*		0.066	0.203	*	

*= Significantly different at 5% level of probability; NS= Non Significant; 1- First year= 2008-2009; 2- Second year= 2009-2010; 3- Mean= mean of first and second years

Main treatments

W₁₀₀=100% F.C. or control

W₈₀=80% F.C.

W₆₀=60% F.C.

Sub treatments

M₀= No mulch or control

M₁= Dry lemon grass mulch

M₂= Plastic mulch

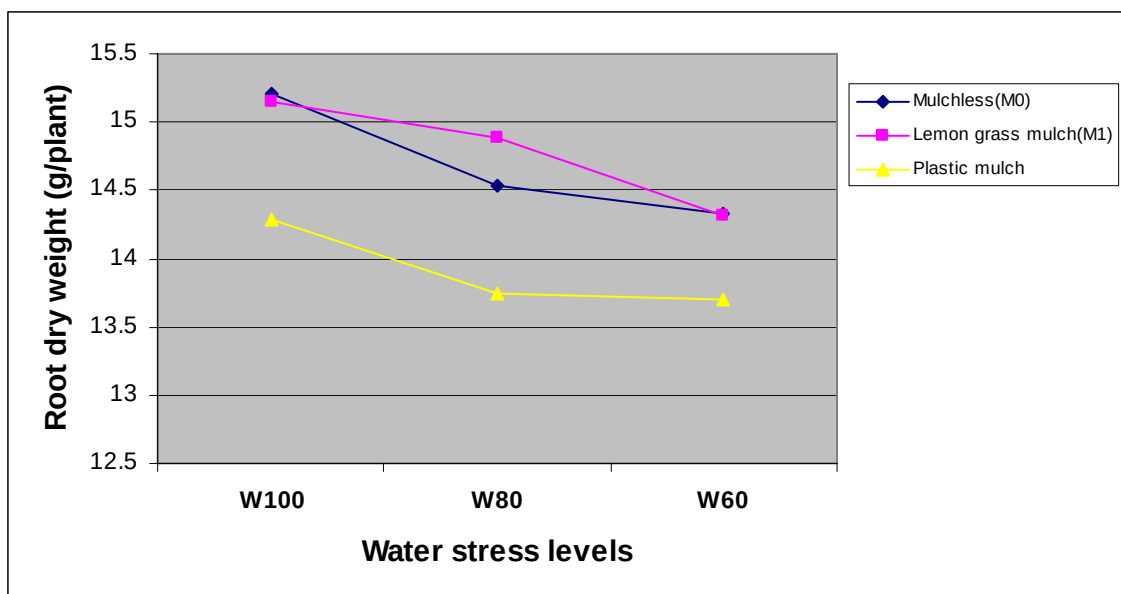


Fig. 7. Interaction effect of water stress levels and mulch types on root dry weight of *Matricaria chamomilla* L. var. Vallary on first year of field experiment

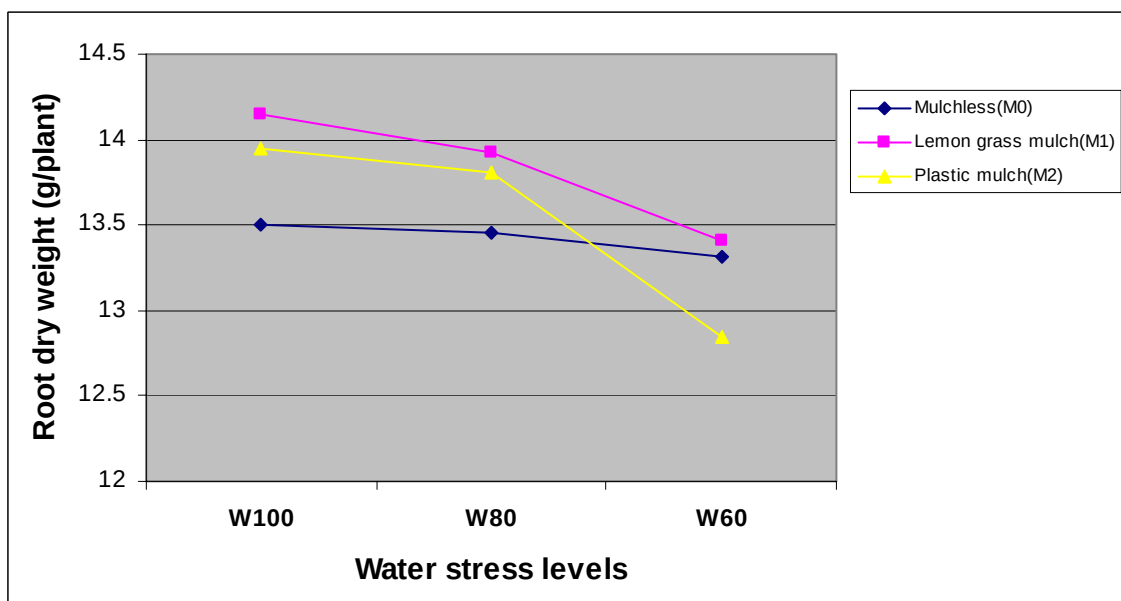


Fig. 8. Interaction effect of water stress levels and mulch types on root dry weight of *Matricaria chamomilla* L. var. Vallary on second year of field experiment

13.19 and 13.66 g/plant in the first and second years and mean of them, respectively).

The results on mulching types recorded significant influence on root dry weight in the second year and mean of two years data. But it was not significant in first year. Lemon grass mulch (M_1) recorded maximum root dry weight (13.83, 14.31 g/plant in the second year and mean of two years, respectively). Without mulch (M_0) and plastic mulch (M_2) recorded minimum root dry weight (13.42 and 13.73 g/plant in the second year and mean of two years, respectively).

Results of the interaction between water stress levels and mulching types showed that $W_{100}M_0$ (15.21g/plant in the first year), $W_{100}M_1$ (14.15 and 14.65 g/plant in the second year and mean of two years, respectively) gave significantly maximum root dry weight when compared to other treatments but $W_{60}M_0$ was *on par* with $W_{100}M_1$ and $W_{80}M_1$ (15.15 and 14.89 g/plant) in the first year. Minimum root dry weight was recorded in $W_{60}M_2$ (13.70, 12.85 and 13.28 g/plant in the first and second years and mean of them, respectively).

Figures 7 and 8 clearly indicate that in water stress level W_{100} , highest root dry weight, was obtained under the treatment M_0 (Without mulch) condition in the first year and lemon grass mulch (M_1) in the second year. While in water stress levels W_{80} and W_{60} , highest root dry weight was obtained with lemon grass mulch (M_1).

The main point is, in the mean of two years, these amounts of root dry weight in W_{100} were obtained approximately with 42, 34 and 28 irrigations by without mulch (M_0), lemon grass mulch (M_1) and plastic mulch (M_2), respectively during the growth. Also the amounts of root dry weight in W_{80} were obtained approximately with 25, 20 and 17 irrigations by without mulch (M_0), lemon grass mulch (M_1) and plastic mulch (M_2), respectively during the growth. The amounts

of root dry weight in W_{60} were obtained approximately with 17, 12 and 9 irrigations by without mulch (M_0), lemon grass mulch (M_1) and plastic mulch (M_2), respectively during the growth.

4.2.1.6 Root/Shoot Dry Weight Ratio

The observations recorded on root/shoot dry weight ratio in *Matricaria chamomilla* L. var. Vallary under different water stress levels and mulching types for the first and second years and mean of them are presented in Table 12 and Figures 9 and 10. Significantly maximum root/shoot dry weight ratio in water stress treatments was recorded with W_{60} (0.2289, 0.2227 and 0.2260 in the first and second years and mean of them, respectively) and minimum root/shoot dry weight ratio was recorded in W_{100} (0.2138, 0.2142 and 0.2141 in the first and second years and mean of them, respectively).

The results on mulching types recorded significant influence on root/shoot dry weight ratio. Lemon grass mulch (M_1) recorded maximum root/shoot dry weight ratio (0.2243 and 0.2209 in the first year and mean of two years, respectively) but, plastic mulch (M_2) recorded maximum root/shoot dry weight ratio (0.2208) in the second year. Plastic mulch (M_2) recorded minimum root/shoot dry weight ratio (0.2157 and 0.2183 in the first year and mean of two years, respectively).

Results of the interaction between water stress levels and mulching types showed that $W_{60}M_1$ (0.2337 and 0.2209) in the first year and mean of two years, respectively and $W_{60}M_2$ (0.2318) in the second year gave significantly maximum root/shoot dry weight ratio when compared to other treatments. Minimum root/shoot dry weight ratio was recorded in $W_{100}M_2$ (0.2067 and 0.2109) in the first year and mean of two years, respectively and in $W_{100}M_0$ (0.2122) in the second year.

Table 12. Effect of water stress levels and mulch types on root/shoot dry weight ratio in *Matricaria chamomilla* L. var. Vallary on first and second years and their mean of field experiment

Sub treatments	Root/shoot dry weight ratio											
	Main treatments											
	First year ¹				Second year ²				Mean of two years ³			
	W ₁₀₀	W ₈₀	W ₆₀	Mean	W ₁₀₀	W ₈₀	W ₆₀	Mean	W ₁₀₀	W ₈₀	W ₆₀	Mean
M ₀	0.2191	0.2193	0.2320	0.2232	0.2122	0.2128	0.2151	0.2133	0.2159	0.2161	0.2236	0.2184
M ₁	0.2157	0.2246	0.2337	0.2243	0.2149	0.2153	0.2224	0.2175	0.2153	0.2201	0.2282	0.2209
M ₂	0.2067	0.2205	0.2209	0.2157	0.2154	0.2166	0.2318	0.2208	0.2109	0.2186	0.2261	0.2183
Mean	0.2138	0.2215	0.2289	0.2211	0.2142	0.2150	0.2227	0.2172	0.2141	0.2183	0.2260	0.2192
Statistical information												
	S.Em±	CD@5%	F-test		S.Em±	CD@5%	F-test		S.Em±	CD@5%	F-test	
Water stress (W)	0.00006	0.00020	*		0.00002	0.00009	*		0.00003	0.00008	*	
Mulching (M)	0.00006	0.00024	*		0.00003	0.00008	*		0.00003	0.00012	*	
Interaction WxM	0.00011	0.00034	*		0.00005	0.00015	*		0.00004	0.00013	*	

*= Significantly different at 5% level of probability; 1- First year= 2008-2009; 2- Second year= 2009-2010; 3- Mean= mean of first and second years

Main treatments

W₁₀₀=100% F.C. or control

W₈₀=80% F.C.

W₆₀=60% F.C.

Sub treatments

M₀= No mulch or control

M₁= Dry lemon grass mulch

M₂= Plastic mulch

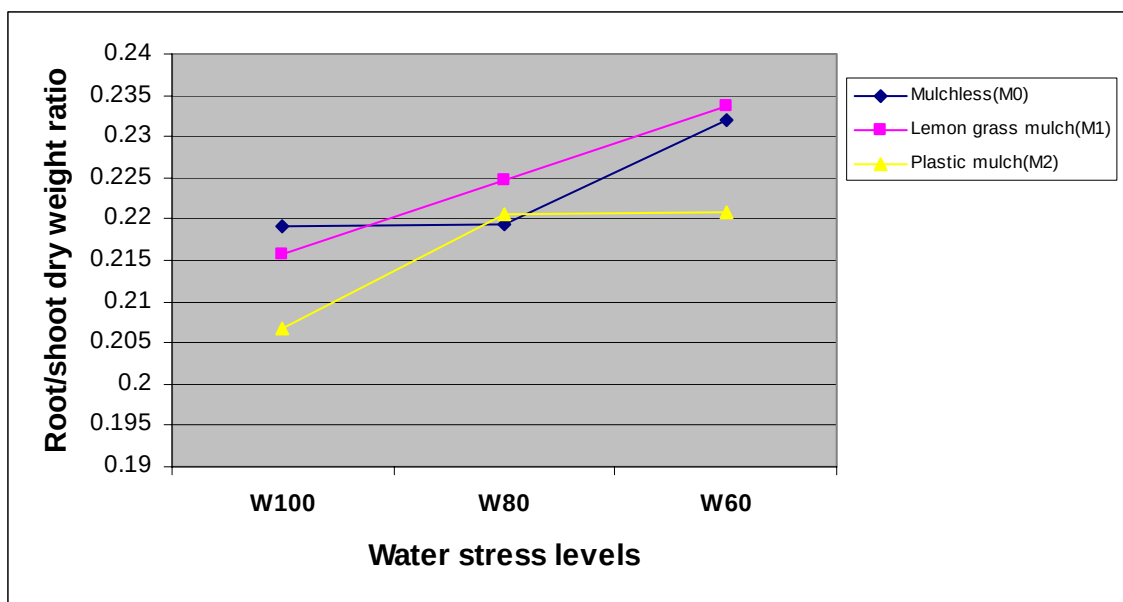


Fig. 9. Interaction effect of water stress levels and mulch types on root/shoot dry weight ratio of *Matricaria chamomilla* L. var. Vallary on first year of field experiment

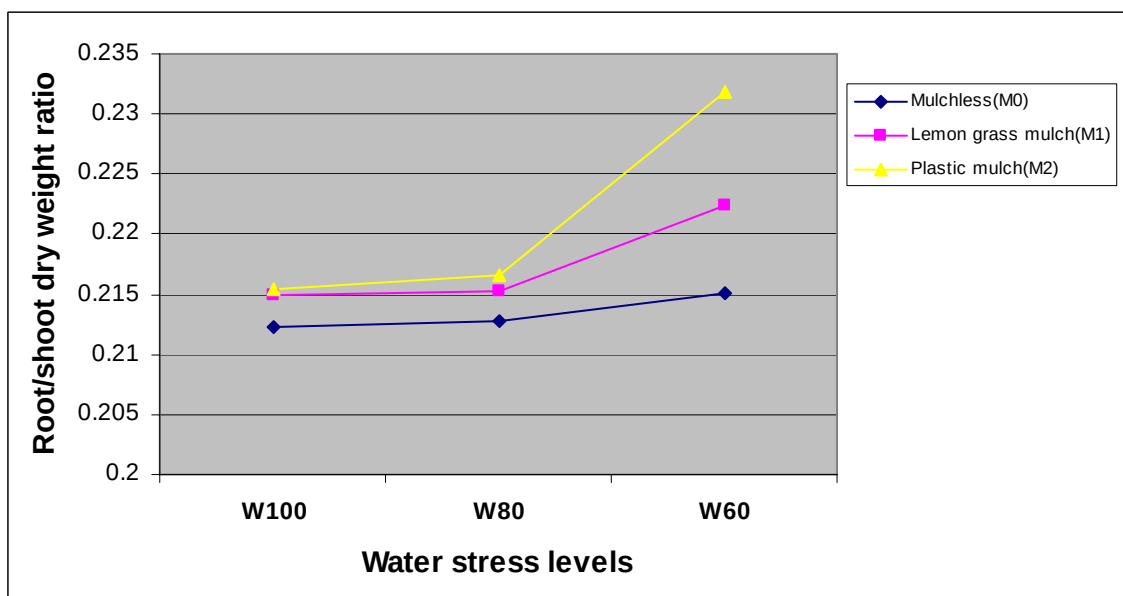


Fig. 10. Interaction effect of water stress levels and mulch types on root/shoot dry weight ratio of *Matricaria chamomilla* L. var. Vallary on second year of field experiment

Further, results detected in Figures 9 and 10 showed that in water stress level W_{100} , highest root/shoot dry weight ratio in the first year was obtained under the treatment without mulch (M_0) condition and also in second year highest root/shoot dry weight ratio was obtained with plastic mulch (M_2). While in water stress level W_{80} and W_{60} highest root/shoot dry weight ratio was obtained with lemon grass mulch (M_1) in the first year and plastic mulch (M_2) in the second year.

The main point is, in the mean of two years, these amounts of root/shoot dry weight ratio in W_{100} were obtained approximately with 42, 34 and 28 irrigations by without mulch (M_0), lemon grass mulch (M_1) and plastic mulch (M_2), respectively during the growth. Also the amounts of root/shoot dry weight ratio in W_{80} were obtained approximately with 25, 20 and 17 irrigations by without mulch (M_0), lemon grass mulch (M_1) and plastic mulch (M_2), respectively during the growth. The amounts of root/shoot dry weight ratio in W_{60} were obtained approximately with 17, 12 and 9 irrigations by without mulch (M_0), lemon grass mulch (M_1) and plastic mulch (M_2), respectively during the growth.

4.2.1.7 Number of Flowers per Plant

The data pertaining to number of flowers per plant in *Matricaria chamomilla* L. var. Vallary recorded among different water stress levels and mulching types for the first and second years and mean of them are presented in Table 13. Significantly maximum number of flowers per plant in water stress treatments was recorded with W_{60} (1037.5), W_{80} (920.9) and W_{60} (960.1) in the first and second years and mean of them, respectively. Minimum number of flowers per plant was recorded in W_{100} (980.4, 828.6 and 904.5 in the first and second years and mean of them, respectively).

The results on mulching types recorded did not show any significant influence on number of flowers per plant in the first year but it showed significant

Table 13. Effect of water stress levels and mulch types on number of flower per plant in *Matricaria chamomilla* L. var. Vallary on first and second years and their mean of field experiment.

Sub treatments	Number of flowers per plant											
	Main treatments											
	First year ¹				Second year ²				Mean of two years ³			
	W ₁₀₀	W ₈₀	W ₆₀	Mean	W ₁₀₀	W ₈₀	W ₆₀	Mean	W ₁₀₀	W ₈₀	W ₆₀	Mean
M ₀	981	988	1038	1002.7	836	933	901	890.3	909	961	970	946.5
M ₁	977	1000	1032	1003.1	836	932	894	887.8	907	966	963	945.5
M ₂	983	994	1042	1006.4	812	897	852	853.9	898	946	947	930.2
Mean	980.4	994.2	1037.5	1004.1	828.6	920.9	882.6	877.4	904.5	957.5	960.1	940.7
Statistical information												
	S.Em±	CD@5%	F-test		S.Em±	CD@5%	F-test		S.Em±	CD@5%	F-test	
Water stress (W)	3.31	10.206	*		0.68	2.106	*		1.73	5.316	*	
Mulching (M)	-	-	NS		0.45	1.763	*		1.22	4.776	NS	
Interaction WxM	-	-	NS		1.18	3.648	*		-	-	NS	

*= Significantly different at 5% level of probability; NS= Non Significant; 1- First year= 2008-2009; 2- Second year= 2009-2010; 3- Mean= mean of first and second years

Main treatments

W₁₀₀=100% F.C. or control

W₈₀=80% F.C.

W₆₀=60% F.C.

Sub treatments

M₀= No mulch or control

M₁= Dry lemon grass mulch

M₂= Plastic mulch

influence in the second year and mean of them. Without mulch (M_0) recorded maximum number of flowers per plant (890.3 and 946.5 in the second year and mean of them, respectively) and plastic mulch (M_2) recorded minimum number of flowers per plant (853.9 and 930.2 in the second year and mean of them, respectively).

The water stress levels x mulches interactions were not also significant on number of flowers per plant in the first year and mean of two years, respectively, but it was significant in the second year. $W_{80}M_0$ (933) gave significant maximum number of flowers per plant which was *on par* with $W_{80}M_1$ (932) and minimum number of flowers per plant obtain from $W_{100}M_2$ (812) in the second year.

The main point is, in the mean of two years, these amounts of number of flowers per plant in W_{100} were obtained approximately with 42, 34 and 28 irrigations by without mulch (M_0), lemon grass mulch (M_1) and plastic mulch (M_2), respectively during the growth. Also the amounts of number of flowers per plant in W_{80} were obtained approximately with 25, 20 and 17 irrigations by without mulch (M_0), lemon grass mulch (M_1) and plastic mulch (M_2), respectively during the growth. The amounts of number of flowers per plant in W_{60} were obtained approximately with 17, 12 and 9 irrigations by without mulch (M_0), lemon grass mulch (M_1) and plastic mulch (M_2), respectively during the growth.

4.2.1.8 Weight of 100 dry flowers (g)

The data pertaining to weight of 100 dry flowers in *Matricaria chamomilla* L. var. Vallary recorded among different water stress levels and mulching types for the first and second years and mean of them are presented in Table 14.

Significantly maximum weight of 100 dry flowers in water stress treatments was recorded with W_{80} (1.92, 1.92 and 1.92 g in the first and second years and mean of them, respectively), which was *on par* with W_{100} . Minimum

Table 14. Effect of water stress levels and mulch types on weight of 100 dry flowers in *Matricaria chamomilla* L. var. Vallary on first and second years and their mean of field experiment.

Sub treatments	Weight of 100 dry flowers (g)											
	Main treatments											
	First year ¹				Second year ²				Mean of two years ³			
	W ₁₀₀	W ₈₀	W ₆₀	Mean	W ₁₀₀	W ₈₀	W ₆₀	Mean	W ₁₀₀	W ₈₀	W ₆₀	Mean
M ₀	1.92	1.92	1.82	1.89	1.92	1.92	1.80	1.88	1.92	1.92	1.81	1.88
M ₁	1.92	1.92	1.83	1.89	1.93	1.94	1.82	1.90	1.92	1.93	1.82	1.89
M ₂	1.91	1.93	1.84	1.89	1.90	1.91	1.80	1.87	1.90	1.92	1.82	1.88
Mean	1.92	1.92	1.83	1.89	1.92	1.92	1.80	1.88	1.92	1.92	1.82	1.89
Statistical information												
	S.Em±	CD@5%	F-test		S.Em±	CD@5%	F-test		S.Em±	CD@5%	F-test	
Water stress (W)	0.009	0.290	*		0.005	0.0141	*		0.007	0.021	*	
Mulching (M)	-	-	NS		0.001	0.0044	*		-	-	NS	
Interaction WxM	-	-	NS		-	-	NS		-	-	NS	

*= Significantly different at 5% level of probability; NS= Non Significant; 1- First year= 2008-2009; 2- Second year= 2009-2010; 3- Mean= mean of first and second years

Main treatments

W₁₀₀=100% F.C. or control

W₈₀=80% F.C.

W₆₀=60% F.C.

Sub treatments

M₀= No mulch or control

M₁= Dry lemon grass mulch

M₂= Plastic mulch

weight of 100 dry flowers was recorded in W_{60} (1.83, 1.80 and 1.82 g in the first and second years and mean of them, respectively).

The results on mulching types recorded significant influence on weight of 100 dry flowers in the second year and not significant influence in the first year and mean of two years. Lemon grass mulch (M_1) recorded maximum weight of 100 dry flowers in the second year (1.90 g) and plastic mulch (M_2) recorded minimum weight of 100 dry flowers (1.87 g). The water stress levels x mulches interactions were not also significant on weight of 100 dry flowers in the first and second years and mean of them, respectively.

The main point is, in the mean of two years, these amounts of weight of 100 dry flowers in W_{100} were obtained approximately with 42, 34 and 28 irrigations by without mulch (M_0), lemon grass mulch (M_1) and plastic mulch (M_2), respectively during the growth. Also the amounts of weight of 100 dry flowers in W_{80} were obtained approximately with 25, 20 and 17 irrigations by without mulch (M_0), lemon grass mulch (M_1) and plastic mulch (M_2), respectively during the growth. The amounts of weight of 100 dry flowers in W_{60} were obtained approximately with 17, 12 and 9 irrigations by without mulch (M_0), lemon grass mulch (M_1) and plastic mulch (M_2), respectively during the growth.

4.2.2 Biomass Yield

The various observations made on the biomass yield such as fresh flower yield (g/plant), dry flower yield (g/plant) and dry flower yield (kg/ha) in *Matricaria chamomilla* L. var. Vallary recorded at different water stress levels and mulching types for the first and second years and mean of them are tabulated and are presented in Tables 15-18 and Figures 11 and 12.

4.2.2.1 Fresh Flower Yield (g/plant)

The observations recorded on fresh flower yield per plant in *Matricaria chamomilla* L. var. Vallary under different water stress levels and mulching types for the first and second years and mean of them are presented in Table 15. Significantly maximum fresh flower yield per plant in water stress treatments was recorded with W₈₀ (100.92, 90.80 and 95.86 g/plant in the first and second years and mean of them, respectively) and minimum fresh flower yield was recorded in W₆₀ (98.54 g/plant) W₁₀₀ (86.23 g/plant) and W₆₀ (92.49 g/plant) in the first and second years and mean of them, respectively.

The results on mulching types recorded significant influence on fresh flower yield per plant. Lemon grass mulch (M₁) recorded maximum fresh flower yield (99.97, 88.73 and 94.35 g/plant in the first and second years and mean of them, respectively) and plastic mulch (M₂) recorded minimum fresh flower yield (99.20, 86.77 and 92.99 g/plant in the first and second years and mean of them, respectively).

Results of the interaction between water stress levels and mulching types showed that W₈₀M₁ gave significantly maximum fresh flower yield per plant (101.05, 91.90 and 96.48 g/plant in the first and second years and mean of them, respectively) when compared to other treatments but was *on par* with W₈₀M₀ (100.90 g/plant) in the first year. Minimum fresh flower yield was recorded in W₆₀M₂ (97.84, 84.80 and 91.32 g/plant in the first and second years and mean of them, respectively), which was *on par* with W₁₀₀M₂ (85.10 g/plant) in the second year.

The main point is, in the mean of two years, these amounts of fresh flower yield per plant in W₁₀₀ were obtained approximately with 42, 34 and 28 irrigations by without mulch (M₀), lemon grass mulch (M₁) and plastic mulch (M₂), respectively during the growth. Also the amounts of fresh flower yield per plant in

Table 15. Effect of water stress levels and mulch types on fresh flower yield (g/plant) in *Matricaria chamomilla* L. var. Vallary on first and second years and their mean of field experiment.

Sub treatments	Fresh flower yield (g/plant)											
	Main treatments											
	First year ¹				Second year ²				Mean of two years ³			
	W ₁₀₀	W ₈₀	W ₆₀	Mean	W ₁₀₀	W ₈₀	W ₆₀	Mean	W ₁₀₀	W ₈₀	W ₆₀	Mean
M ₀	99.80	100.90	98.85	99.85	86.70	90.10	87.10	87.97	93.91	95.50	92.98	93.91
M ₁	99.20	101.05	98.93	99.97	86.90	91.90	87.40	88.73	93.41	96.48	93.17	94.35
M ₂	98.97	100.80	97.84	99.20	85.10	90.40	84.80	86.77	92.04	95.60	91.32	92.99
Mean	99.56	100.92	98.54	99.67	86.23	90.80	86.43	87.82	92.90	95.86	92.49	93.75
Statistical information												
	S.Em±	CD@5%	F-test		S.Em±	CD@5%	F-test		S.Em±	CD@5%	F-test	
Water stress (W)	0.03	0.093	*		0.096	0.295	*		0.045	0.137	*	
Mulching (M)	0.04	0.155	*		0.069	0.273	*		0.029	0.114	*	
Interaction WxM	0.052	0.161	*		0.166	0.510	*		0.077	0.237	*	

*= Significantly different at 5% level of probability; 1- First year= 2008-2009; 2- Second year= 2009-2010; 3- Mean= mean of first and second years

Main treatments

W₁₀₀=100% F.C. or control

W₈₀=80% F.C.

W₆₀=60% F.C.

Sub treatments

M₀= No mulch or control

M₁= Dry lemon grass mulch

M₂= Plastic mulch

W₈₀ were obtained approximately with 25, 20 and 17 irrigations by without mulch (M₀), lemon grass mulch (M₁) and plastic mulch (M₂), respectively during the growth. The amount of fresh flower yield per plant in W₆₀ were obtained approximately with 17, 12 and 9 irrigations by without mulch (M₀), lemon grass mulch (M₁) and plastic mulch (M₂), respectively during the growth.

4.2.2.2 Fresh Flower Yield (kg/ha)

The observations recorded on fresh flower yield (kg/ha) in *Matricaria chamomilla* L. var. Vallary under different water stress levels and mulching types for the first and second years and mean of them are presented in Table 16. Significantly maximum fresh flower yield (kg/ha) in water stress treatments was recorded with W₈₀ (11213, 10089 and 10651 kg/ha in the first and second years and mean of them, respectively) and minimum fresh flower yield was recorded in W₆₀ (10949 kg/ha) W₁₀₀ (9581 kg/ha) and W₆₀ (10277 kg/ha) in the first and second years and mean of them, respectively.

The results on mulching types recorded significant influence on fresh flower yield (kg/ha). Lemon grass mulch (M₁) recorded maximum fresh flower yield (11108, 9859 and 10483 kg/ha in the first and second years and mean of them, respectively) and plastic mulch (M₂) recorded minimum fresh flower yield (11022, 9641 and 10332 kg/ha in the first and second years and mean of them, respectively).

Results of the interaction between water stress levels and mulching types showed that W₈₀M₁ gave significantly maximum fresh flower yield (11228, 10211 and 10720 kg/ha in the first and second years and mean of them, respectively) when compared to other treatments but was *on par* with W₈₀M₀ (11211 kg/ha) in the first year. Minimum fresh flower yield was recorded in W₆₀M₂ (10871, 9422 and 10147 kg/ha in the first and second years and mean of them, respectively), which was *on par* with W₁₀₀M₂ (9455 kg/ha) in the second year.

Table 16. Effect of water stress levels and mulch types on fresh flower yield (kg/ha) in *Matricaria chamomilla* L. var. Vallary on first and second years and their mean of field experiment

Sub treatments	Fresh flower yield (kg/ha)											
	Main treatments											
	First year ¹				Second year ²				Mean of two years ³			
	W ₁₀₀	W ₈₀	W ₆₀	Mean	W ₁₀₀	W ₈₀	W ₆₀	Mean	W ₁₀₀	W ₈₀	W ₆₀	Mean
M ₀	11088	11211	10983	11094	9633	10011	9678	9774	10434	10611	10331	10434
M ₁	11022	11228	10992	11108	9655	10211	9711	9859	10379	10720	10352	10483
M ₂	10997	11199	10871	11022	9455	10044	9422	9641	10227	10622	10147	10332
Mean	11062	11213	10949	11074	9581	10089	9603	9758	10322	10651	10277	10417
Statistical information												
	S.Em±	CD@5%	F-test		S.Em±	CD@5%	F-test		S.Em±	CD@5%	F-test	
Water stress (W)	3.3	10.42	*		9.2	29	*		4.9	15.3	*	
Mulching (M)	5.4	17.36	*		10	30.6	*		4.2	12.8	*	
Interaction WxM	5.8	18.03	*		18.6	57.1	*		8.8	26.5	*	

*= Significantly different at 5% level of probability; 1- First year= 2008-2009; 2- Second year= 2009-2010; 3- Mean= mean of first and second years

Main treatments

W₁₀₀=100% F.C. or control

W₈₀=80% F.C.

W₆₀=60% F.C.

Sub treatments

M₀= No mulch or control

M₁= Dry lemon grass mulch

M₂= Plastic mulch

The main point is, in the mean of two years, these amounts of fresh flower yield (kg/ha) in W_{100} were obtained approximately with 42, 34 and 28 irrigations by without mulch (M_0), lemon grass mulch (M_1) and plastic mulch (M_2), respectively during the growth. Also the amounts of fresh flower yield (kg/ha) in W_{80} were obtained approximately with 25, 20 and 17 irrigations by without mulch (M_0), lemon grass mulch (M_1) and plastic mulch (M_2), respectively during the growth. The amounts of fresh flower yield (kg/ha) in W_{60} were obtained approximately with 17, 12 and 9 irrigations by without mulch (M_0), lemon grass mulch (M_1) and plastic mulch (M_2), respectively during the growth.

4.2.2.3 Dry Flower Yield (g/plant)

The observations recorded on dry flower yield per plant in *Matricaria chamomilla* L. var. Vallary under different water stress levels and mulching types for the first and second years and mean of them are presented in Table 17 and Figures 11 and 12. Significantly maximum dry flower yield per plant in water stress treatments was recorded with W_{80} (19.25, 17.70 and 18.48 g/plant in the first and second years and mean of them, respectively), and minimum dry flower yield was recorded in W_{60} (18.57 g/plant) W_{100} (15.88 g/plant) and W_{60} (17.26 g/plant) in the first and second years and mean of them, respectively.

The results on mulching types recorded significant influence on dry flower yield per plant. Lemon grass mulch (M_1) recorded maximum dry flower yield (19.01, 16.84 and 17.93 g/plant in the first and second years and mean of them, respectively) and plastic mulch (M_2) recorded minimum dry flower yield (18.64, 15.96 and 17.29 g/plant in the first and second years and mean of them, respectively).

Results of the interaction between water stress levels and mulching types showed that $W_{80}M_1$ gave significantly maximum dry flower yield per plant (19.40, 18.09 and 18.75 g/plant in the first and second years and mean of them,

Table 17. Effect of water stress levels and mulch types on dry flower yield (g/plant) in *Matricaria chamomilla* L. var. Vallary on first and second years and their mean of field experiment.

Sub treatments	Dry flower yield (g/plant)											
	Main treatments											
	First year ¹				Second year ²				Mean of two years ³			
	W ₁₀₀	W ₈₀	W ₆₀	Mean	W ₁₀₀	W ₈₀	W ₆₀	Mean	W ₁₀₀	W ₈₀	W ₆₀	Mean
M ₀	18.84	19.17	18.90	18.97	16.07	17.92	16.22	16.74	17.46	18.56	17.56	17.86
M ₁	18.75	19.40	18.89	19.01	16.15	18.09	16.27	16.84	17.45	18.75	17.58	17.93
M ₂	18.77	19.19	17.92	18.64	15.43	17.10	15.35	15.96	17.10	18.14	16.63	17.29
Mean	18.79	19.25	18.57	18.87	15.88	17.70	15.95	16.51	17.34	18.48	17.26	17.69
Statistical information												
	S.Em±	CD@5%	F-test		S.Em±	CD@5%	F-test		S.Em±	CD@5%	F-test	
Water stress (W)	0.032	0.098	*		0.019	0.057	*		0.016	0.048	*	
Mulching (M)	0.023	0.088	*		0.006	0.023	*		0.012	0.045	*	
Interaction WxM	0.055	0.169	*		0.032	0.988	*		0.27	0.834	*	

*= Significantly different at 5% level of probability; 1- First year= 2008-2009; 2- Second year= 2009-2010; 3- Mean= mean of first and second years

Main treatments

W₁₀₀=100% F.C. or control

W₈₀=80% F.C.

W₆₀=60% F.C.

Sub treatments

M₀= No mulch or control

M₁= Dry lemon grass mulch

M₂= Plastic mulch

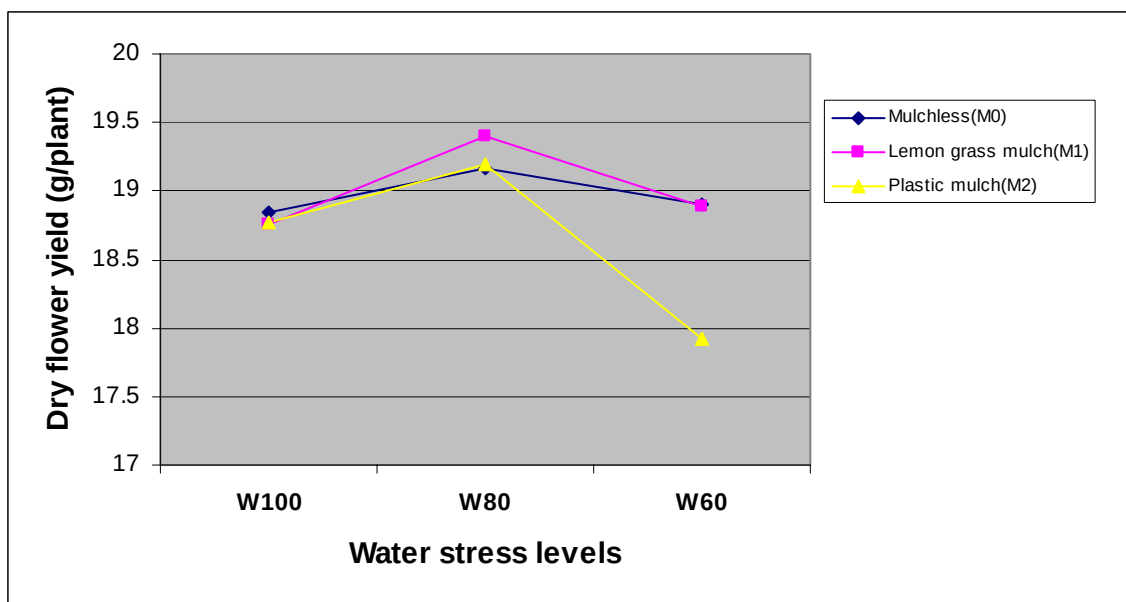


Fig. 11. Interaction effect of water stress levels and mulch types on dry flower yield (g/plant) of *Matricaria chamomilla* L. var. Vallary on first year of field experiment

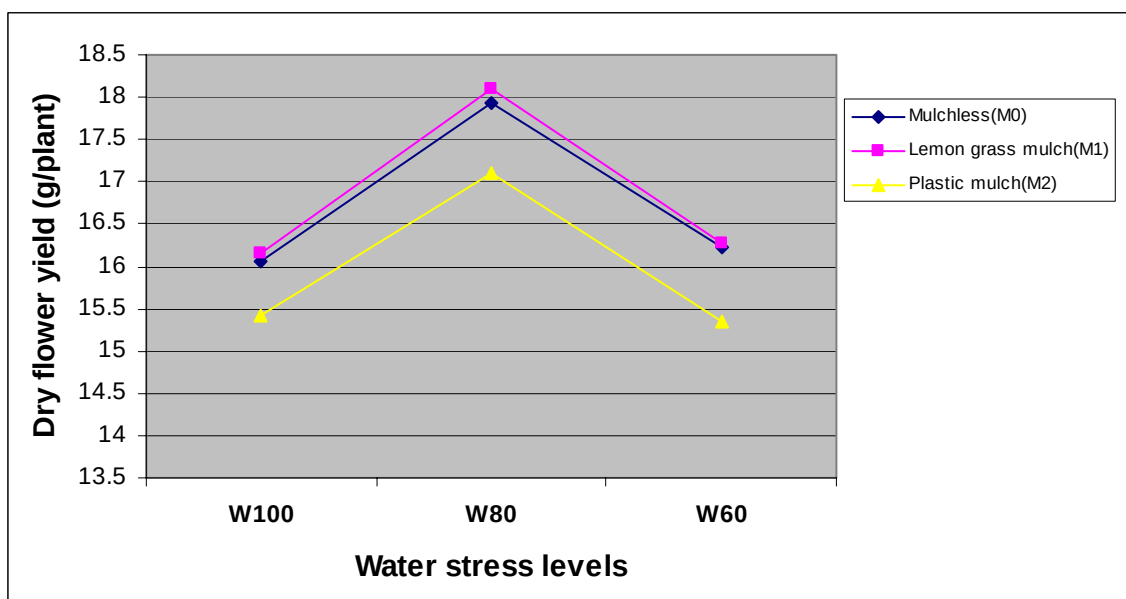


Fig. 12. Interaction effect of water stress levels and mulch types on dry flower yield (g/plant) of *Matricaria chamomilla* L. var. Vallary on second year of field experiment

respectively) when compared to other treatments. Minimum dry flower yield was recorded in $W_{60}M_2$ (17.92, 15.35 and 16.63 g/plant in the first and second years and mean of them, respectively) which was *on par* with $W_{100}M_2$ (15.43 g/plant) in the second year.

Figures 11 and 12 clearly indicate that in water stress level W_{100} , highest dry flower yield, was obtained under the treatment without mulch (M_0) condition. While in water stress level W_{80} , highest dry flower yield was obtained with lemon grass mulch (M_1). In water stress level W_{60} , highest dry flower yield was obtained under the treatment without mulch (M_0).

The main point is, in the mean of two years, these amounts of dry flower yield per plant in W_{100} were obtained approximately with 42, 34 and 28 irrigations by without mulch (M_0), lemon grass mulch (M_1) and plastic mulch (M_2), respectively during the growth. Also the amounts of dry flower yield per plant in W_{80} were obtained approximately with 25, 20 and 17 irrigations by without mulch (M_0), lemon grass mulch (M_1) and plastic mulch (M_2), respectively during the growth. The amounts of dry flower yield per plant in W_{60} were obtained approximately with 17, 12 and 9 irrigations by without mulch (M_0), lemon grass mulch (M_1) and plastic mulch (M_2), respectively during the growth.

4.2.2.4 Dry Flower Yield (kg/ha)

The observations recorded on dry flower yield (kg/ha) in *Matricaria chamomilla* L. var. Vallary under different water stress levels and mulching types for the first and second years and mean of them are presented in Table 18. Significantly maximum dry flower yield (kg/ha) in water stress treatments was recorded with W_{80} (2139, 1967 and 2053 kg/ha in the first and second years and mean of them, respectively) and minimum dry flower yield (kg/ha) was recorded in W_{60} (2063 kg/ha) W_{100} (1764 kg/ha) and W_{60} (1917 kg/ha) in the first and second years and mean of them, respectively.

Table 18. Effect of water stress levels and mulch types on dry flower yield (kg/ha) in *Matricaria chamomilla* L. var. Vallary on first and second years and their mean of field experiment

Sub treatments	Dry flower yield (kg/ha)											
	Main treatments											
	First year ¹				Second year ²				Mean of two years ³			
	W ₁₀₀	W ₈₀	W ₆₀	Mean	W ₁₀₀	W ₈₀	W ₆₀	Mean	W ₁₀₀	W ₈₀	W ₆₀	Mean
M ₀	2093	2130	2100	2107	1785	1993	1802	1860	1939	2061	1951	1984
M ₁	2083	2155	2098	2112	1794	2010	1807	1870	1938	2082	1953	1991
M ₂	2085	2132	1991	2069	1714	1900	1705	1773	1900	2016	1848	1921
Mean	2087	2139	2063	2096	1764	1967	1771	1834	1926	2053	1917	1966
Statistical information												
	S.Em±	CD@5%	F-test		S.Em±	CD@5%	F-test		S.Em±	CD@5%	F-test	
Water stress (W)	3.5	10.9	*		2.0	6.3	*		1.8	5.4	*	
Mulching (M)	2.9	9.8	*		0.66	2.6	*		1.3	5.1	*	
Interaction WxM	6.1	18.7	*		3.5	10.9	*		3.0	9.3	*	

*= Significantly different at 5% level of probability; 1- First year= 2008-2009; 2- Second year= 2009-2010; 3- Mean= mean of first and second years

Main treatments

W₁₀₀=100% F.C. or control

W₈₀=80% F.C.

W₆₀=60% F.C.

Sub treatments

M₀= No mulch or control

M₁= Dry lemon grass mulch

M₂= Plastic mulch

The results on mulching types recorded significant influence on dry flower yield (kg/ha). Lemon grass mulch (M_1) recorded maximum dry flower yield (2112, 1870 and 1991 kg/ha in the first and second years and mean of them, respectively) which was *on par* under the treatment without mulch (M_0) in the first year. Plastic mulch (M_2) recorded minimum dry flower yield (2069, 1773 and 1921 kg/ha in the first and second years and mean of them, respectively).

Results of the interaction between water stress levels and mulching types showed that $W_{80}M_1$ gave significantly maximum dry flower yield (2155, 2010 and 2082 kg/ha in the first and second years and mean of them, respectively) when compared to other treatments. Minimum dry flower yield was recorded in $W_{60}M_2$ (1991, 1705 and 1848 kg/ha in the first and second years and mean of them, respectively) which was *on par* with $W_{100}M_2$ (15.43 kg/ha) in the second year.

The main point is, in the mean of two years, these amounts of dry flower yield (kg/ha) in W_{100} were obtained approximately with 42, 34 and 28 irrigations by without mulch (M_0), lemon grass mulch (M_1) and plastic mulch (M_2), respectively during the growth. Also the amounts of dry flower yield (kg/ha) in W_{80} were obtained approximately with 25, 20 and 17 irrigations by without mulch (M_0), lemon grass mulch (M_1) and plastic mulch (M_2), respectively during the growth. The amounts of dry flower yield (kg/ha) in W_{60} were obtained approximately with 17, 12 and 9 irrigations by without mulch (M_0), lemon grass mulch (M_1) and plastic mulch (M_2), respectively during the growth.

4.2.3 Essential Oil Quantity

The data pertaining to the essential oil quantity as essential oil percentage and yield (kg/ha) in *Matricaria chamomilla* L. var. Vallary recorded at different water stress levels and mulching types for the first and second years and mean of them are tabulated and are presented in Tables 19 and 20 and Figures 13-16.

4.2.3.1 Essential Oil Percentage (% v/w dry weight)

The observations recorded on essential oil percentage in *Matricaria chamomilla* L. var. Vallary under different water stress levels and mulching types for the first and second years and mean of them are presented in Table 19 and Figures 13 and 14. Significantly maximum essential oil percentage in water stress treatments was recorded in W₆₀ (0.743, 0.770 and 0.757 percent v/w dry weight in the first and second years and mean of them, respectively), and minimum essential oil percentage was recorded in W₁₀₀ (0.687, 0.710 and 0.698 percent v/w dry weight in the first and second years and mean of them, respectively).

The results on mulching types recorded significant influence on essential oil percentage in the second year but it was not significant in first year and mean of two year. Lemon grass mulch (M₁) recorded maximum essential oil percentage (0.753 percent) in the second year which was *on par* under the treatment without mulch [(M₀) (0.750 percent v/w dry weight)]. Plastic mulch (M₂) recorded minimum essential oil percentage (0.743 percent v/w dry weight) in the second year. Results of the interaction between water stress levels and mulching types showed not significant effect on essential oil percentage.

Figures 13 and 14 clearly indicate that in water stress level W₁₀₀, highest essential oil percentage in the first year was obtained under the treatments without mulch (M₀) and lemon grass mulch (M₁) condition but in the second year, it was same between different mulch types. While in water stress level W₈₀, highest essential oil percentage was obtained with lemon grass mulch (M₁) and plastic mulch (M₂) in the first year and with lemon grass mulch (M₁) and without mulch (M₀) in the second year. In water stress level W₆₀, highest essential oil percentage was obtained under the treatment without mulch (M₀) in the first year and with lemon grass mulch (M₁) in the second years.

Table 19. Effect of water stress levels and mulch types on essential oil percentage in *Matricaria chamomilla* L. var. Vallary on first and second years and their mean of field experiment

Sub treatments	Essential oil percentage (v/w dry weight)											
	Main treatments											
	First year ¹				Second year ²				Mean of two years ³			
	W ₁₀₀	W ₈₀	W ₆₀	Mean	W ₁₀₀	W ₈₀	W ₆₀	Mean	W ₁₀₀	W ₈₀	W ₆₀	Mean
M ₀	0.69	0.73	0.75	0.723	0.71	0.77	0.77	0.750	0.70	0.75	0.76	0.737
M ₁	0.69	0.74	0.74	0.723	0.71	0.77	0.78	0.753	0.70	0.75	0.76	0.738
M ₂	0.68	0.74	0.74	0.720	0.71	0.76	0.76	0.743	0.69	0.75	0.75	0.732
Mean	0.687	0.736	0.743	0.722	0.710	0.767	0.770	0.749	0.698	0.752	0.757	0.736
Statistical information												
	S.Em±	CD@5%	F-test		S.Em±	CD@5%	F-test		S.Em±	CD@5%	F-test	
Water stress (W)	0.0031	0.0097	*		0.003	0.0077	*		0.0022	0.0066	*	
Mulching (M)	-	-	NS		0.002	0.0075	*		-	-	NS	
Interaction WxM	-	-	NS		-	-	NS		-	-	NS	

*= Significantly different at 5% level of probability; NS= Non Significant; 1- First year= 2008-2009; 2- Second year= 2009-2010; 3- Mean= mean of first and second years

Main treatments

W₁₀₀=100% F.C. or control

W₈₀=80% F.C.

W₆₀=60% F.C.

Sub treatments

M₀= No mulch or control

M₁= Dry lemon grass mulch

M₂= Plastic mulch

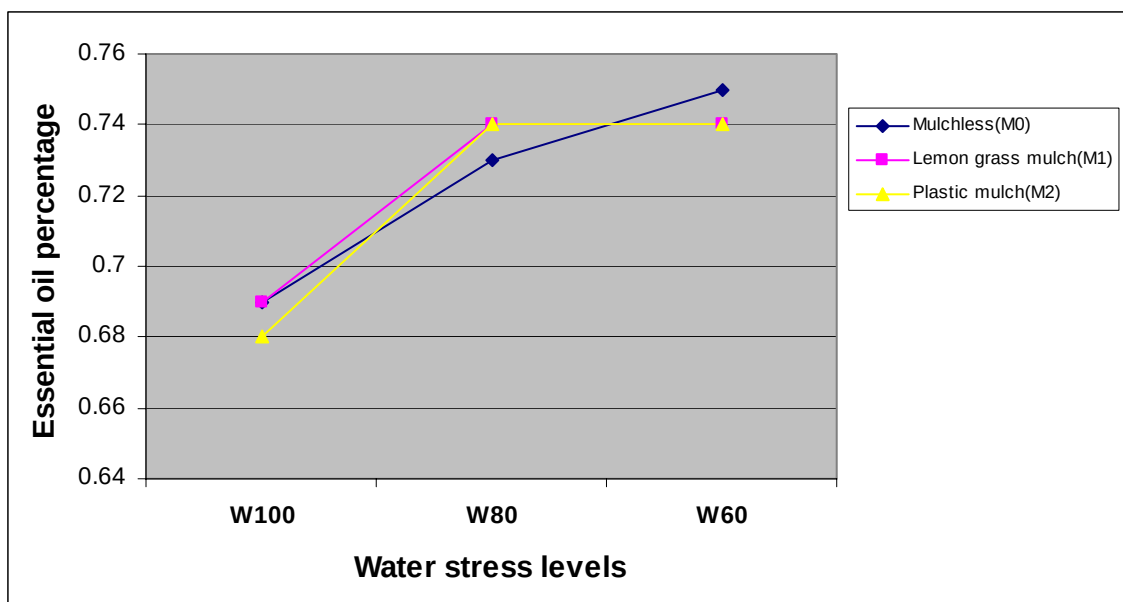


Fig. 13. Interaction effect of water stress levels and mulch types on essential oil percentage (v/w) of *Matricaria chamomilla* L. var. Vallary on first year of field experiment

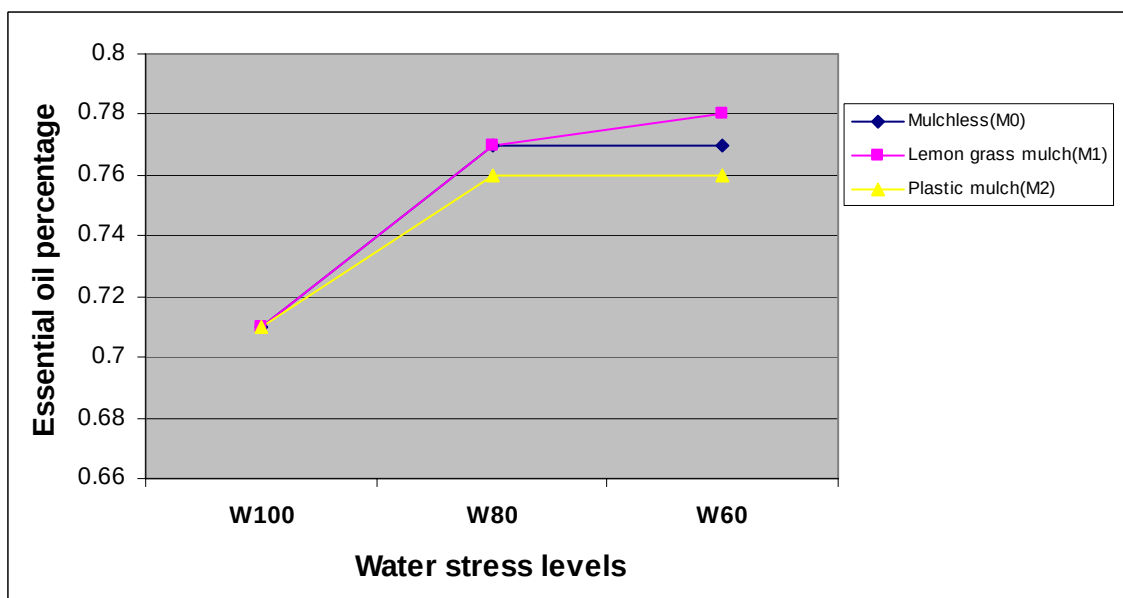


Fig. 14. Interaction effect of water stress levels and mulch types on essential oil percentage (v/w) of *Matricaria chamomilla* L. var. Vallary on second year of field experiment

The main point is, in the mean of two years, these amounts of essential oil percentage in W₁₀₀ were obtained approximately with 42, 34 and 28 irrigations by without mulch (M₀), lemon grass mulch (M₁) and plastic mulch (M₂), respectively during the growth. Also the amounts of essential oil percentage in W₈₀ were obtained approximately with 25, 20 and 17 irrigations by without mulch (M₀), lemon grass mulch (M₁) and plastic mulch (M₂), respectively during the growth. The amounts of essential oil percentage in W₆₀ were obtained approximately with 17, 12 and 9 irrigations by without mulch (M₀), lemon grass mulch (M₁) and plastic mulch (M₂), respectively during the growth.

4.2.3.2 Essential Oil Yield (kg/ha)

The observations recorded on essential oil yield in *Matricaria chamomilla* L. var. Vallary under different water stress levels and mulching types for the first and second years and mean of them are presented in Table 20 and Figures 15 and 16. Significantly maximum essential oil yield in water stress treatments was recorded with W₈₀ (14.19, 13.58 and 13.88 kg/ha in the first and second years and mean of them, respectively), and minimum essential oil yield was recorded in W₁₀₀ (12.90, 11.28 and 12.09 kg/h in the first and second years and mean of them, respectively).

The results on mulching types recorded significant influence on essential oil yield. Lemon grass mulch (M₁) recorded maximum essential oil yield (13.75, 12.70 and 13.23 kg/ha in the first and second years and mean of them, respectively) which was *on par* under the treatment without mulch [(M₀) (13.72, 12.57 and 13.15 kg/ha in the first and second years and mean of them, respectively)]. Plastic mulch (M₂) recorded minimum essential oil yield (13.41, 11.87 and 12.64 kg/ha in the first and second years and mean of them, respectively).

Table 20. Effect of water stress levels and mulch types on essential oil yield in *Matricaria chamomilla* L. var. Vallary on first and second years and their mean of field experiment.

Sub treatments	Essential oil yield (kg/ha)											
	Main treatments											
	First year ¹				Second year ²				Mean of two years ³			
	W ₁₀₀	W ₈₀	W ₆₀	Mean	W ₁₀₀	W ₈₀	W ₆₀	Mean	W ₁₀₀	W ₈₀	W ₆₀	Mean
M ₀	13.0	13.99	14.18	13.72	11.41	13.82	12.49	12.57	12.20	13.91	13.33	13.15
M ₁	12.94	14.36	13.98	13.75	11.47	13.93	12.69	12.70	12.20	14.14	13.33	13.23
M ₂	12.76	14.20	13.26	13.41	10.96	12.99	11.67	11.87	11.86	13.60	12.46	12.64
Mean	12.90	14.19	13.81	13.63	11.28	13.58	12.28	12.38	12.09	13.88	13.04	13.01
Statistical information												
	S.Em±	CD@5%	F-test		S.Em±	CD@5%	F-test		S.Em±	CD@5%	F-test	
Water stress (W)	0.069	0.213	*		0.043	0.133	*		0.032	0.098	*	
Mulching (M)	0.060	0.234	*		0.035	0.139	*		0.045	0.176	*	
Interaction WxM	0.120	0.369	*		0.075	0.231	*		0.055	0.170	*	

*= Significantly different at 5% level of probability; 1- First year= 2008-2009; 2- Second year= 2009-2010; 3- Mean= mean of first and second years

Main treatments

W₁₀₀=100% F.C. or control

W₈₀=80% F.C.

W₆₀=60% F.C.

Sub treatments

M₀= No mulch or control

M₁= Dry lemon grass mulch

M₂= Plastic mulch

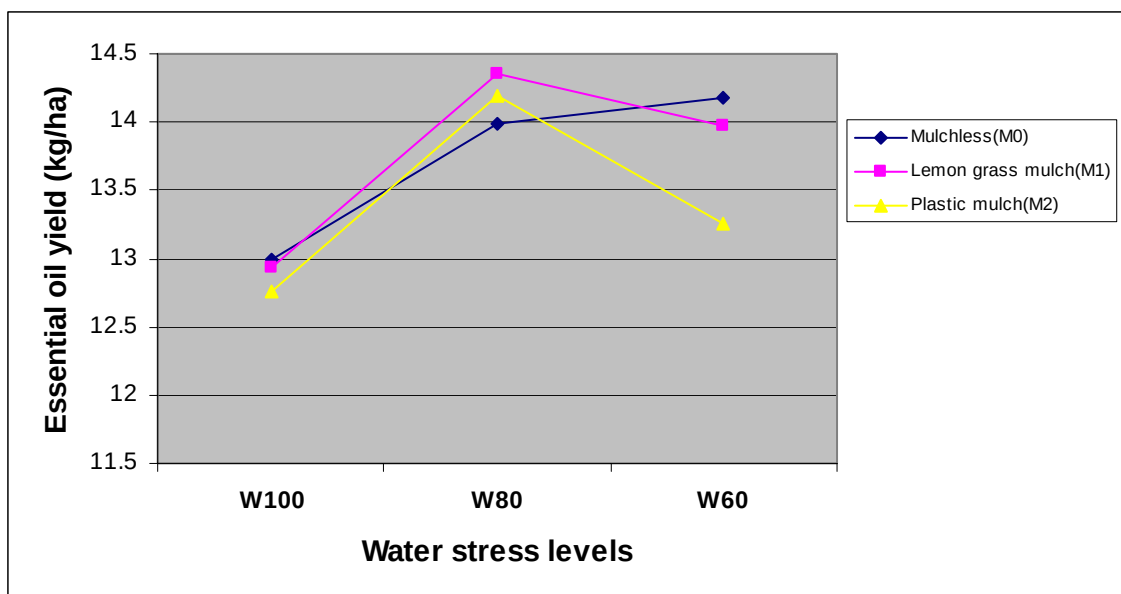


Fig. 15. Interaction effect of water stress levels and mulch types on essential oil yield of *Matricaria chamomilla* L. var. Vallary on first year of field experiment

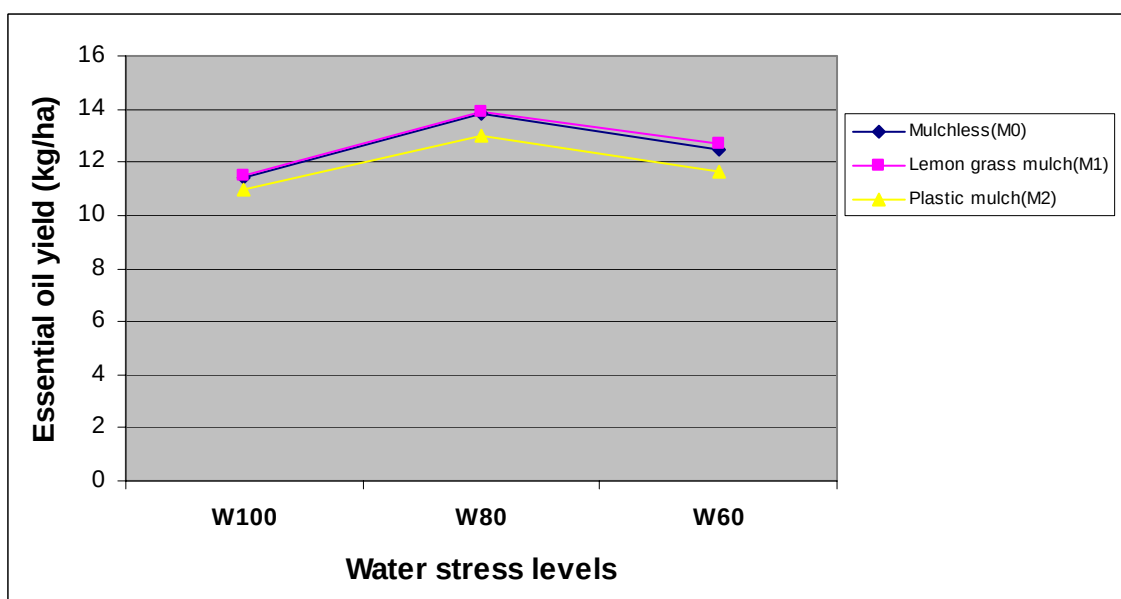


Fig. 16. Interaction effect of water stress levels and mulch types on essential oil yield of *Matricaria chamomilla* L. var. Vallary on second year of field experiment

Results of the interaction between water stress levels and mulching types showed that $W_{80}M_1$ gave significantly maximum essential oil yield (14.36, 13.93 and 14.14 kg/ha in the first and second years and mean of them, respectively) when compared to other treatments but was *on par* with $W_{80}M_2$, $W_{60}M_0$ and $W_{80}M_0$ (14.20, 14.18 and 13.99 kg/ha) in the first year and also with $W_{80}M_0$ (13.82 kg/ha) in the second year. Minimum essential oil yield was recorded in $W_{100}M_2$ (12.76, 10.96 and 11.86 kg/ha in the first and second years and mean of them, respectively), which was *on par* with $W_{100}M_1$ and $W_{100}M_0$ (12.94 and 13.0 kg/ha) in the first year.

Further, results presented in Figures 15 and 16 showed that in water stress level W_{100} , highest essential oil yield was obtained under the treatments without mulch (M_0) and lemon grass mulch (M_1) condition in the first and second year, respectively. While in water stress level W_{80} , highest essential oil yield was obtained with lemon grass mulch (M_1) in the first and second years. In water stress level W_{60} , highest essential oil yield was obtained under the treatment without mulch (M_0) in the first year and with lemon grass mulch (M_1) in the second year.

The main point is, in the mean of two years, these amounts of essential oil yield in W_{100} were obtained approximately with 42, 34 and 28 irrigations by without mulch (M_0), lemon grass mulch (M_1) and plastic mulch (M_2), respectively during the growth. Also the amounts of essential oil yield in W_{80} were obtained approximately with 25, 20 and 17 irrigations by without mulch (M_0), lemon grass mulch (M_1) and plastic mulch (M_2), respectively during the growth. The amounts of essential oil yield in W_{60} were obtained approximately with 17, 12 and 9 irrigations by without mulch (M_0), lemon grass mulch (M_1) and plastic mulch (M_2), respectively during the growth.

4.2.4 Essential Oil Quality

The essential oil composition and yield of essential oil of main components (kg/ha) of *Matricaria chamomilla* L. var. Vallary obtained at different water stress levels and mulch types in the first and second years and mean of them of field experiment are shown in Tables 21- 25.

4.2.4.1 Essential Oil Composition

The main constituents of the essential oil were identified as α -Bisabolol oxide B, α -Bisabolone oxide A, α -Bisabolol, Chamazulene, α -Bisabolol oxide A and (Z)-En-yn-dicycloether (Sashidhara *et al.*, 2006; Syamasundar *et al.*, 2002; Moumita Das *et al.*, 1998; Honcariv and Repack, 1979).

Results of the interaction between water stress levels and mulching types in the first year (Table 21) showed the maximum percentage of α -Bisabolol oxide B in W₆₀M₂ (5.9%), α -Bisabolone oxide A in W₈₀M₁ (3.91%), α -Bisabolol in W₁₀₀M₀ (21.06%), Chamazulene in W₈₀M₂ (4.04%), α -Bisabolol oxide A in W₆₀M₂ (64.32%) and (Z)-En-yn-dicycloether in W₆₀M₁ (10.49%) compared to other treatments. Minimum percentage of α -Bisabolol oxide B in W₁₀₀M₀ (3.09%), α -Bisabolone oxide A in W₆₀M₀ (0.23%), α -Bisabolol in W₆₀M₂ (5.21%), Chamazulene in W₈₀M₀ (1.82%), α -Bisabolol oxide A in W₁₀₀M₀ (49.32%) and (Z)-En-yn-dicycloether in W₈₀M₁ (7.16%) compared to other treatments.

Results of the interaction between water stress levels and mulching types in the first year (Table 23) showed the maximum percentage of α -Bisabolol oxide B in W₆₀M₁ (6.57%), α -Bisabolone oxide A in W₈₀M₂ (5.2%), α -Bisabolol in W₁₀₀M₁ (24.55%), Chamazulene in W₆₀M₁ (4.66%), α -Bisabolol oxide A in W₆₀M₀ (65.94%) and (Z)-En-yn-dicycloether in W₆₀M₂ (11.66%) compared to other treatments. Minimum percentage of α -Bisabolol oxide B in W₁₀₀M₂ (2.96 %), α -Bisabolone oxide A in W₆₀M₀ (0.79%), α -Bisabolol in W₆₀M₂ (3.22%),

Table 21. Effect of water stress levels and mulch types on essential oil composition (area percentage) in *Matricaria chamomilla* L. var. Vallary on first year of field experiment.

Compounds	Treatments								
	W ₁₀₀ M ₀	W ₁₀₀ M ₁	W ₁₀₀ M ₂	W ₈₀ M ₀	W ₈₀ M ₁	W ₈₀ M ₂	W ₆₀ M ₀	W ₆₀ M ₁	W ₆₀ M ₂
Artemisia ketone	0.41	0.39	0.43	0.37	0.44	0.46	0.52	0.45	0.43
Linalool	0.12	0.19	-	-	0.40	0.22	0.14	-	0.20
Camphore	0.58	0.64	0.75	0.72	0.68	0.81	0.66	0.67	0.59
Borneol	-	0.11	-	-	-	-	-	-	-
(E)- β -Farnesene	3.11	2.97	3.34	3.37	3.32	3.88	3.22	3.18	3.57
Germacrene D	0.74	0.83	0.76	0.90	0.61	0.99	0.79	0.65	0.81
Bicyclogermacrene	0.40	0.39	0.50	0.40	0.50	0.40	0.40	0.56	0.42
(E,E)- α -Farnesene	0.13	0.08	0.09	0.11	0.35	0.07	0.09	-	0.07
δ -Cadinene	-	-	0.13	-	0.19	-	-	-	-
Spathulenol	0.29	0.33	0.42	0.21	0.40	0.25	0.28	0.22	0.35
Caryophyllene oxide	-	-	-	-	-	0.14	0.16	-	0.14
Tau-Cadinol	0.43	0.47	0.35	0.38	0.69	0.51	0.70	0.57	0.62
β -Eudesmol	1.32	1.67	1.10	1.58	1.91	1.00	0.90	1.71	1.15
α -Bisabolol oxide B	3.09	3.28	3.22	3.74	3.49	3.36	5.76	4.56	5.90
α -Bisabolone oxide A	-	-	-	-	3.91	2.35	0.23	-	-
α -Bisabolol	21.06	17.25	18.11	12.62	6.45	6.04	16.09	6.35	5.21
Chamazulene	2.45	2.16	3.07	1.82	3.45	4.04	3.18	2.31	3.37
α -Bisabolol oxide A	49.32	55.30	53.91	61.47	61.69	60.58	51.64	63.3	64.32
(Z)-En-yn-dicycloether	7.32	8.45	9.12	7.47	7.16	8.53	7.60	10.49	9.11
Hexadecanoic acid (Palmitic acid)	0.24	0.30	0.27	0.31	0.33	0.35	0.26	0.31	0.29

Table 22. Effect of water stress levels and mulch types on yield of essential oil main component (kg/ha) in *Matricaria chamomilla* L. var. Vallary on first year of field experiment.

Compounds	Treatments								
	W ₁₀₀ M ₀	W ₁₀₀ M ₁	W ₁₀₀ M ₂	W ₈₀ M ₀	W ₈₀ M ₁	W ₈₀ M ₂	W ₆₀ M ₀	W ₆₀ M ₁	W ₆₀ M ₂
α -Bisabolol oxide B	0.402	0.424	0.411	0.523	0.501	0.477	0.817	0.638	0.782
α -Bisabolone oxide A	0.000	0.000	0.000	0.000	0.562	0.334	0.033	0.000	0.000
α -Bisabolol	2.738	2.232	2.311	1.766	0.926	0.858	2.282	0.888	0.691
Chamazulene	0.319	0.2795	0.392	0.255	0.495	0.574	0.451	0.323	0.447
α -Bisabolol oxide A	6.412	7.156	6.879	8.600	8.858	8.602	7.323	8.849	8.529
(Z)-En-yn-dicycloether	0.952	1.093	1.164	1.045	1.028	1.211	1.078	1.467	1.208

Table 23. Effect of water stress levels and mulch types on essential oil composition (area percentage) in *Matricaria chamomilla* L. var. Vallary on second year of field experiment.

Compounds	Treatments								
	W ₁₀₀ M ₀	W ₁₀₀ M ₁	W ₁₀₀ M ₂	W ₈₀ M ₀	W ₈₀ M ₁	W ₈₀ M ₂	W ₆₀ M ₀	W ₆₀ M ₁	W ₆₀ M ₂
Artemisia ketone	-	0.29	0.23	0.35	0.19	0.12	0.11	-	0.22
Linalool	-	0.09	0.05	0.08	0.06	0.07	-	-	0.05
Camphore	-	0.43	0.35	0.78	0.46	0.41	0.45	0.32	0.52
Borneol	-	0.22	0.16	0.13	-	0.17	0.22	-	0.21
(E)- β -Farnesene	2.63	3.58	3.22	3.84	2.81	3.30	3.68	2.74	4.13
Germacrene D	0.79	0.86	0.84	0.94	0.15	0.14	0.73	0.61	0.81
Bicyclogermacrene	0.54	0.61	0.55	0.47	0.15	0.13	0.28	0.51	0.33
(E,E)- α -Farnesene	0.15	0.12	0.21	0.21	0.12	0.13	-	0.26	-
δ -Cadinene	0.12	0.14	0.14	0.18	-	-	-	0.18	-
Spathulenol	0.24	0.38	0.30	0.35	1.47	1.40	0.24	0.53	0.21
Caryophyllene oxide	0.22	0.15	0.14	0.14	0.16	0.20	0.15	-	0.13
Tau-Cadinol	0.42	0.76	0.73	0.84	1.17	1.37	0.70	0.50	0.78
β -Eudesmol	1.70	1.60	1.50	2.24	1.80	0.70	0.55	2.23	0.54
α -Bisabolol oxide B	3.33	3.01	2.96	4.70	4.81	4.78	5.42	6.57	4.91
α -Bisabolone oxide A	-	-	-	-	2.32	5.20	0.79	3.77	0.81
α -Bisabolol	21.27	24.55	20.13	14.51	6.74	4.50	3.57	7.23	3.22
Chamazulene	2.67	2.88	2.82	2.38	2.93	3.43	2.29	4.66	2.35
α -Bisabolol oxide A	50.99	47.94	52.21	56.69	60.38	58.77	65.94	58.08	64.56
(Z)-En-yn-dicycloether	9.21	6.85	8.84	6.10	6.37	7.13	10.38	8.85	11.66
Hexadecanoic acid (Palmitic acid)	0.37	0.31	0.37	0.29	0.31	0.32	0.22	0.44	0.12

Table 24. Effect of water stress levels and mulch types on yield of essential oil composition (kg/ha) in *Matricaria chamomilla* L. var. Vallary on second year of field experiment.

Compounds	Treatments								
	W ₁₀₀ M ₀	W ₁₀₀ M ₁	W ₁₀₀ M ₂	W ₈₀ M ₀	W ₈₀ M ₁	W ₈₀ M ₂	W ₆₀ M ₀	W ₆₀ M ₁	W ₆₀ M ₂
α -Bisabolol oxide B	0.380	0.345	0.324	0.649	0.670	0.621	0.677	0.834	0.573
α -Bisabolone oxide A	0.000	0.000	0.000	0.000	0.323	0.676	0.099	0.479	0.095
α -Bisabolol	2.427	2.815	2.205	2.005	0.939	0.585	0.446	0.918	0.376
Chamazulene	0.305	0.330	0.309	0.329	0.408	0.446	0.286	0.591	0.274
α -Bisabolol oxide A	5.818	5.498	5.720	7.832	8.413	7.638	8.235	7.371	7.532
(Z)-En-yn-dicycloether	1.051	0.786	0.968	0.843	0.888	0.927	1.296	1.123	1.360

Chamazulene in W₆₀M₀ (2.29%), α -Bisabolol oxide A in W₁₀₀M₁ (47.94%) and (Z)-En-yn-dicycloether in W₈₀M₀ (6.1%) compared to other treatments.

4.2.4.2 Yield of Essential Oil Main Component (kg/ha)

Based on mean yield of essential oil per hectare and per cent of its constituents, yield of oil components per hectare was calculated (Tables 22, 24 and 25).

The results of different treatments influenced the yield of main components of essential oil in the first year (Table 22). Maximum yield of the main components such as α -Bisabolol oxide B, α -Bisabolone oxide A, α -Bisabolol, Chamazulene, α -Bisabolol oxide A and (Z)-En-yn-dicycloether obtained from W₆₀M₀ (0.817 kg/ha), W₈₀M₁ (0.562 kg/ha), W₁₀₀M₀ (2.738 kg/ha), W₈₀M₂ (0.574 kg/ha), W₈₀M₁ (8.858 kg/ha) and W₆₀M₁ (1.467 kg/ha) respectively and minimum percentage was recorded in W₁₀₀M₀ (0.402 kg/ha), W₆₀M₀ (0.033 kg/ha), W₆₀M₂ (0.691 kg/ha), W₈₀M₀ (0.255 kg/ha), W₁₀₀M₀ (6.412 kg/ha) and W₁₀₀M₀ (0.952 kg/ha) respectively.

Similarly the results of different treatments influenced the yield of main components of essential oil in the second year (Table 24). Maximum yield of the main components such as α -Bisabolol oxide B, α -Bisabolone oxide A, α -Bisabolol, Chamazulene, α -Bisabolol oxide A and (Z)-En-yn-dicycloether obtained from W₆₀M₁ (0.834 kg/ha), W₈₀M₂ (0.676 kg/ha), W₁₀₀M₁ (2.815 kg/ha), W₆₀M₁ (0.591 kg/ha), W₈₀M₁ (8.413 kg/ha) and W₆₀M₂ (1.360 kg/ha) respectively and minimum percentage was recorded in W₁₀₀M₂ (0.324 kg/ha), W₆₀M₂ (0.095 kg/ha), W₆₀M₂ (0.376 kg/ha), W₆₀M₂ (0.274 kg/ha), W₁₀₀M₁ (5.498 kg/ha) and W₁₀₀M₁ (0.786 kg/ha) respectively.

Further, the results of different treatments influenced the yield of main components of essential oil in the mean of two years also (Table 25). Maximum

yield of the main components such as α -Bisabolol oxide B, α -Bisabolone oxide A, α -Bisabolol, Chamazulene, α -Bisabolol oxide A and (Z)-En-yn-dicycloether obtained from W₆₀M₀ (0.747 kg/ha), W₈₀M₂ (0.505 kg/ha), W₁₀₀M₀ (2.582 kg/ha), W₈₀M₂ (0.510 kg/ha), W₈₀M₁ (8.636 kg/ha) and W₆₀M₁ (1.295 kg/ha) respectively and minimum percentage was recorded in W₁₀₀M₂ (0.359 kg/ha), W₆₀M₂ (0.047 kg/ha), W₆₀M₂ (0.533 kg/ha), W₈₀M₀ (0.292 kg/ha), W₁₀₀M₀ (6.115 kg/ha) and W₁₀₀M₁ (0.940 kg/ha) respectively.

Table 25. Effect of water stress levels and mulch types on yield of essential oil main composition (kg/ha) in *Matricaria chamomilla* L. var. Vallary on mean of two years of field experiment.

Compounds	Treatments								
	W ₁₀₀ M ₀	W ₁₀₀ M ₁	W ₁₀₀ M ₂	W ₈₀ M ₀	W ₈₀ M ₁	W ₈₀ M ₂	W ₆₀ M ₀	W ₆₀ M ₁	W ₆₀ M ₂
α -Bisabolol oxide B	0.399	0.385	0.359	0.586	0.586	0.549	0.747	0.736	0.678
α -Bisabolone oxide A	0.000	0.000	0.000	0.000	0.442	0.505	0.066	0.239	0.047
α -Bisabolol	2.582	2.524	2.258	1.885	0.933	0.721	1.364	0.903	0.533
Chamazulene	0.312	0.305	0.350	0.292	0.452	0.510	0.369	0.457	0.361
α -Bisabolol oxide A	6.115	6.327	6.299	8.216	8.636	8.120	7.779	8.110	8.030
(Z)-En-yn-dicycloether	1.001	0.940	1.066	0.944	0.958	1.069	1.187	1.295	1.284

4.2.5 Proline Production

The observations recorded on proline production (μ g/g fresh weight) in *Matricaria chamomilla* L. var. Vallary under different water stress levels and mulching types for the first and second years and mean of them for the field experiment are presented in Table 26 and Figures 17 and 18.

4.2.5.1 Proline Production ($\mu\text{g/g}$ fresh weight)

Significantly, maximum proline production in water stress treatments was recorded with W_{60} (192.3, 210.3 and 201.3 $\mu\text{g/g}$ fresh weight in the first and second years and mean of them, respectively), and minimum proline production was recorded in W_{100} (82.3, 107.0 and 94.7 $\mu\text{g/g}$ fresh weight in the first and second years and mean of them, respectively).

The results on mulching types recorded significant influence on proline production. plastic mulch (M_2) recorded maximum proline production (136.7, 155.3 and 146.0 $\mu\text{g/g}$ fresh weight in the first and second years and mean of them, respectively) which was *on par* with Lemon grass mulch (M_1) (132.0, 154.1 and 143.1 $\mu\text{g/g}$ fresh weight in the first and second years and mean of them, respectively). Without mulch (M_0) recorded minimum proline production (122.0, 145.3 and 133.7 $\mu\text{g/g}$ fresh weight in the first and second years and mean of them, respectively).

Results of the interaction between water stress levels and mulching types showed that $W_{60}M_2$ gave significantly maximum proline production (202, 213 and 207 $\mu\text{g/g}$ fresh weight in the first and second years and mean of them, respectively) when compared to other treatments but was *on par* with $W_{80}M_1$ (197 and 210 $\mu\text{g/g}$ fresh weight in the first and second years). Minimum proline production was recorded in $W_{100}M_0$ (80, 105 and 92 $\mu\text{g/g}$ fresh weight in the first and second years and mean of them, respectively), which was *on par* with $W_{100}M_1$ and $W_{100}M_2$ (84 and 83 $\mu\text{g/g}$ fresh weight) in the first year and with $W_{100}M_2$ (107 $\mu\text{g/g}$ fresh weight) in the second year.

Figures 17 and 18, clearly indicate that in water stress level W_{100} , highest proline production in the first and second years was obtained with lemon grass mulch (M_1) condition. While in water stress level W_{80} and W_{60} highest proline production was obtained with plastic mulch (M_2). In the different levels of water

Table 26. Effect of water stress levels and mulch types on proline production in *Matricaria chamomilla* L. var. Vallary on first and second years and their mean of field experiment.

Sub treatments	Proline production (µg/g fresh weight)											
	Main treatments											
	First year ¹				Second year ²				Mean of two years ³			
	W ₁₀₀	W ₈₀	W ₆₀	Mean	W ₁₀₀	W ₈₀	W ₆₀	Mean	W ₁₀₀	W ₈₀	W ₆₀	Mean
M ₀	80	108	178	122.0	105	123	208	145.3	92	115	193	133.7
M ₁	84	115	197	132.0	109	143	210	154.1	96	129	203	143.1
M ₂	83	125	202	136.7	107	146	213	155.3	95	135	207	146.0
Mean	82.3	116.0	192.3	130.2	107.0	137.4	210.3	151.6	94.7	126.7	201.3	140.9
Statistical information												
	S.Em±	CD@5%	F-test		S.Em±	CD@5%	F-test		S.Em±	CD@5%	F-test	
Water stress (W)	1.04	3.193	*		0.63	1.932	*		0.421	1.296	*	
Mulching (M)	1.2	4.719	*		0.44	1.708	*		0.392	1.540	*	
Interaction WxM	1.8	5.531	*		1.09	3.346	*		0.729	2.245	*	

*= Significantly different at 5% level of probability; 1- First year= 2008-2009; 2- Second year= 2009-2010; 3- Mean= mean of first and second years

Main treatments

W₁₀₀=100% F.C. or control

W₈₀=80% F.C.

W₆₀=60% F.C.

Sub treatments

M₀= No mulch or control

M₁= Dry lemon grass mulch

M₂= Plastic mulch

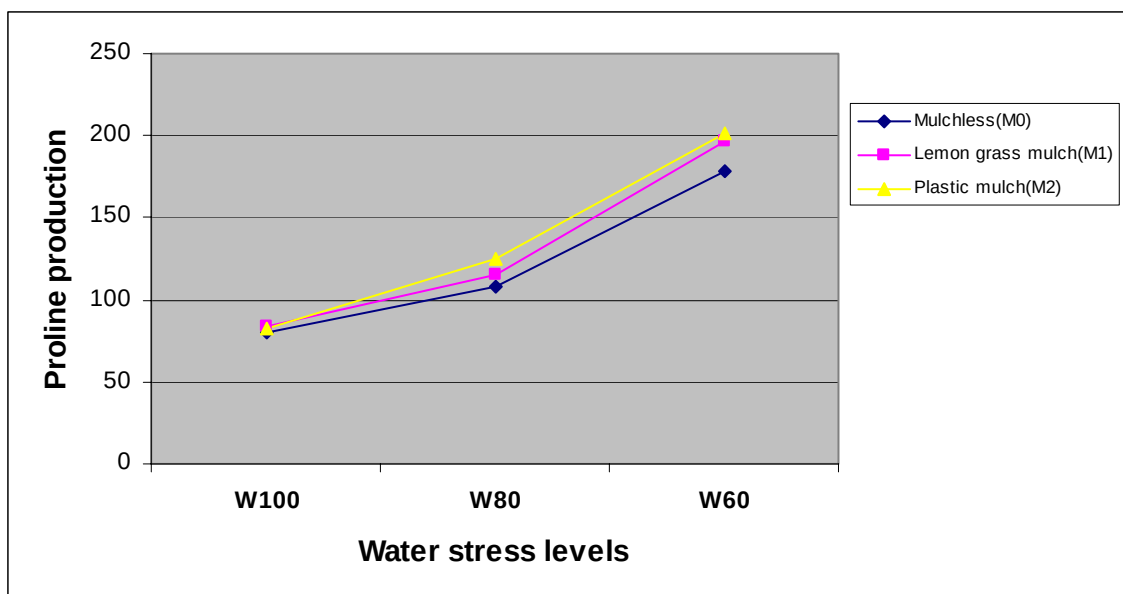


Fig. 17. Interaction effect of water stress levels and mulch types on proline production ($\mu\text{g/g}$ fresh weight) of *Matricaria chamomilla* L. var. Vallary on first year of field experiment

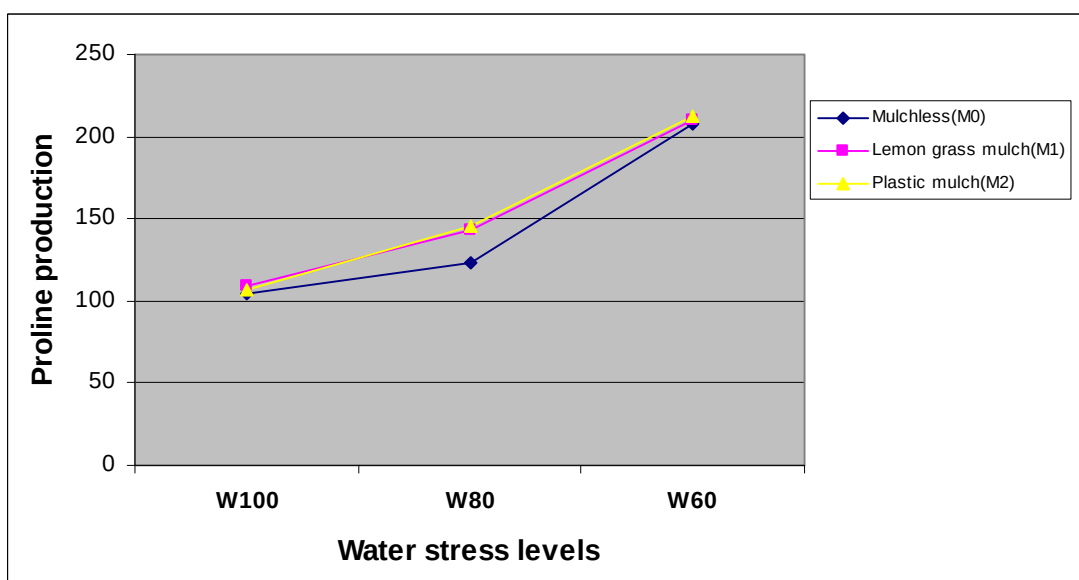


Fig. 18. Interaction effect of water stress levels and mulch types on proline production ($\mu\text{g/g}$ fresh weight) of *Matricaria chamomilla* L. var. Vallary on second year of field experiment

stress, less proline production in both the years was obtained under the treatment without mulch (M_0).

4.2.6 Correlation coefficients

The observations recorded on correlation coefficients between some of the yield and growth parameters in *Matricaria chamomilla* L. var. Vallary under different water stress levels and mulching types for the first and second years of the field experiment are presented in Table 27.

As per results, correlation coefficients between dry flower yield and essential oil percentage, essential oil yield and root/shoot dry weight ratio showed positive correlation and correlation coefficients were +0.15, +0.59 and +0.11 in the first year and +0.48, +0.91 and +0.02 in the second year, respectively. Moreover essential oil yield showed positive correlation coefficients with essential oil percentage, root/shoot dry weight ratio and proline production which correlation coefficients were +0.88, +0.43 and +0.39 in the first year and +0.79, +0.18 and +0.19 in the second year, respectively. Essential oil percentage showed positive correlation coefficients with root/shoot dry weight ratio (+0.72 and +0.43 in the first and second years, respectively). Also positive linear correlation was found between proline production and root/shoot dry weight ratio (+0.71 and +0.56 in the first and second years, respectively).

Table 27. Correlation coefficients between some of growth and yield parameters of treatments under water stress and mulching conditions of *Matricaria chamomilla* L. var. Vallary on first and second years of field experiments.

Parameters	First year			Second year		
	Essential oil percentage	Essential oil yield	Root/shoot ratio	Essential oil percentage	Essential oil yield	Root/shoot ratio
Dry flower yield	+0.15	+0.59	+0.11	+0.48	+0.91	+0.02
Essential Oil percentage	-	-	+0.72	-	-	+0.43
Essential Oil yield	+0.88	-	+0.43	+0.79	-	+0.18
Proline production	+0.73	+0.39	+0.71	+0.69	+0.19	+0.56

Discussion

V. DISCUSSION

Medicinal and aromatic crops are inherently variable in content of secondary metabolites. It is desirable to develop systems that can assure production of plants with high levels of medicinally and aromatically active compounds. Researches attempting to enhance the biological active constituents concentrations of medicinal plants used in pharmaceutical preparations must take into consideration both the parameters of chemical yield i.e., chemical concentration and dry weight.

Chamomile is fairly widespread in India as well as in other countries. Chamomile flowers contain an essential oil which is employed in a variety of therapeutic uses. It is antimicrobial, antispasmodic, antipyretic, anti-inflammatory, expectorant and diuretic (Baby *et al.*, 2007). About 120 chemical constituents have been identified in chamomile as secondary metabolites, including 28 terpenoids, 36 flavonoids and 52 additional compounds with potential pharmacological activity (Mann and Staba, 1992). Components such as α -bisabolol and cyclic ethers are antimicrobial. Chamazulen and α -bisabolol are antiseptic (Duke, 1985). The chamomile extracts was found to have the most effective antileishmanial activity (Shnitzler *et al.*, 1996).

Studies on subjecting *Matricaria chamomilla* L. var. Vallary to different water and mulch conditions revealed that environmental factor affect herb quality. Knowledge of the influence of soil water content on the morphological and biochemical characteristics could be very useful when a choice of growing site or possible agro techniques are issued for cultivation of this crop.

Published reports on how drought affects compounds of therapeutic interest are scarce, but recent work has shown that we can manipulate production

conditions to enhance the levels of metabolites. The results of the present investigation are discussed under the following heading:

5.1 Morphological Characters

5.2 Biomass Yield

5.3 Essential Oil Quantity

5.4 Essential Oil Quality

5.5 Proline Production

5.6 Correlation coefficient

5.1 MORPHOLOGICAL CHARACTERS

The results on water stress levels showed significant influence on plant height (cm), shoot fresh weight (g/plant), shoot dry weight (g/plant), root fresh weight (g/plant), root dry weight (g/plant), root/shoot dry weight ratio, number of flowers per plant and weight of 100 dry flowers (g) in both the experiments (pot and field experiments). Also shoot fresh weight (g/plant), root fresh weight (g/plant) and root/shoot dry weight ratio were significantly affected by mulching types in both the experiments however in the field experiment plant height (cm), shoot dry weight (g/plant), root dry weight (g/plant) and number of flowers per plant were significantly affected by mulching types.

Further results of the interaction between water stress levels and mulching types showed significant influence on shoot fresh weight (g/plant), shoot dry weight (g/plant), root fresh weight (g/plant), root dry weight (g/plant) and root/shoot dry weight ratio in the both experiments and on plant height (cm) in the field experiment.

5.1.1 Plant Height (cm)

In the pot experiment, maximum plant height (102 cm) was obtained with water stress at W_{80} level and was *on par* with W_{100} (100.3 cm). Minimum plant height was recorded in W_{60} (88.7 cm). However, the mulching types and interaction between water stress levels and mulching types did not have significant effect on plant height. Mulching types did not have significant effect on plant height in the pot experiment, because during the pot experiment water content of soil was kept at the constant levels depend to the level of water stress treatments (W_{100} , W_{80} , W_{60}) by daily weighing and watering for replacement of water loss. Perhaps, the constant monitoring of water in the pots might have contributed to not having any effect of mulching on the height.

In the mean of two years under field experiment, maximum plant height (78.8 cm) was obtained with water stress at W_{80} level. Minimum plant height was recorded in W_{60} (62.5 cm). Plant height was significantly affected by mulching types, as observed. Highest plant height (72.8 cm) obtained under the treatment without mulch (M_0), **because in mulch treatments especially in plastic mulch, water deficit resulted in slow development in comparison under the treatment without mulch. Hence after irrigation, mulch plots have taken longer time in reaching to optimum field capacity (FC).**

Results of the interaction between water stress levels and mulching types showed that $W_{80}M_2$ recorded significantly high plant height (80.0 cm) compared to other treatments. Least plant height (61 cm) was recorded in $W_{60}M_2$.

One of the first signs of water shortage is the decrease of turgor pressure and it results in decrease of growth and development of cell especially in stem. The growth of cell is the most important process that is affected by water stress (Moeini Alishah *et al.*, 2006).

On the other hand when plants are recovering from stress there may be a brief period during which growth exceeds that of non-stressed plants (Simpson, 1981). Rewatering stressed plants in water stress at 80% F.C. restored these parameters at values close to those plants irrigated with 100% F.C.

These results are in good agreement with the findings of *Silybum marianum* (Belitz and Sams, 2007), *Origanum majorana* (Rhizopoulou and Diamantoglou, 1991), *Cymbopogon martini* (Fatima *et al.*, 1999), *Mentha arvensis* (Misra and Srivastava, 2000), *Catharanthus roseus* (Ahmed and El Hassen, 2001), *Ocimum basilicum* (Moeini Alishah *et al.*, 2006), *Melissa officinalis* L. (Ardekani *et al.*, 2007) and *Salvia officinalis* (Bettaieb *et al.*, 2009).

5.1.2 Shoot Fresh Weight (g/plant)

In the pot experiment, maximum shoot fresh weight (367.7 g/plant) was obtained with water stress at W_{100} level. Minimum shoot fresh weight was recorded in W_{60} (317.7 g/plant). Shoot fresh weight was significantly affected by mulching types, as observed in the high shoot fresh weight (348.7 g/plant) obtained with plastic mulch (M_2) treatment. Results of the interaction between water stress levels and mulching types showed that $W_{100}M_2$ gave significantly high shoot fresh weight (375 g/plant) compared to other treatments. Least shoot fresh weight was recorded in $W_{60}M_0$ (315 g/plant).

In the mean of two years under field experiment, maximum shoot fresh weight (386 g/plant) was obtained with water stress at W_{100} level. Minimum shoot fresh weight was recorded in W_{60} (322 g/plant). Shoot fresh weight was significantly affected by mulching types, as observed in the high shoot fresh weight (364 g/plant) obtained under the treatment without mulch (M_0), **because in mulch treatments especially in plastic mulch, water deficit resulted in slow development in comparison under the treatment without mulch. Hence after**

irrigation, mulch plots have taken longer time in reaching to optimum field capacity (FC).

Results of the interaction between water stress levels and mulching types showed that $W_{100}M_0$ and $W_{100}M_1$ gave significantly high shoot fresh weight (389 g/plant) compared to other treatments. Least shoot fresh weight (315 g/plant) was recorded in $W_{60}M_2$.

In the pot and field experiments, decrease in shoot fresh weight in water stress condition could be the result of a preferential allocation of biomass production to the roots (Albouchi *et al.*, 2003) or a reduction in chlorophyll content and, consequently, photosynthesis efficiency, as reported by Viera *et al.* (1991).

In Table 8, the shoot fresh weight as a mean of two years is given. In the treatment M_0 (without mulch), the shoot fresh weight decrease from 389 to 375 g/plant at 100% to 80% F.C., respectively. In severe stress treatment (W_{60}), the shoot fresh weight in the without mulch treatment ($W_{60}M_0$) decrease further to 328 g/plant which was a reduction of 15%. With regard to the lemon grass mulch (M_1), the shoot fresh weight was almost similar at all moisture regimes. For example in $W_{100}M_1$, $W_{80}M_1$, and $W_{60}M_1$, the shoot fresh weight was 389, 379 and 323 g/plant, respectively again showing that the shoot fresh weight was similar to the without mulch (M_0) treatment all the moisture regimes. **However, it must be noted that in mildly stress condition (W_{80}) with lemon grass mulch treatment ($W_{80}M_1$), the shoot fresh weight of 379 g/plant was obtained with only 20 irrigation as compared to 25 irrigation in without mulch treatment ($W_{80}M_0$). In other words, because moisture was conserved in the lemon grass mulch treatment ($W_{80}M_1$), it required much less irrigations to give the same amount of shoot fresh weight as that without mulch ($W_{80}M_0$).**

A similar trend was observed for $W_{60}M_0$ treatment. In the $W_{60}M_1$ treatment, the shoot fresh weight was nearly similar to $W_{60}M_0$ treatment (323 and 328 g/plant, respectively). **However, the significant point to note is that, in the severe stress condition, lemon grass mulch ($W_{60}M_1$) required only 12 irrigation to give a shoot biomass of 323 g/plant as compared to 17 irrigations in the without mulch treatment ($W_{60}M_0$).** Exactly similar trend was observed with plastic mulch also.

Therefore the highlight of the study was that a major beneficial effect of the two kinds of mulches used (lemon grass mulch and plastic mulch) was revealed. The beneficial effects accrued from the lesser number of irrigation require both W_{80} and W_{60} treatments because of the significant moisture conservation.

These results are in good agreement with the findings of *Artemisia herba-alba* (Guenauoui *et al.*, 2010), *Mentha arvensis* L. (Misra and Srivastava, 2000), *Melissa officinalis* L. (Ardekani *et al.*, 2007), *Mentha arvensis* L. (Dasha Ram *et al.*, 2006), *Tribulus* species (El-Sayed *et al.*, 2008), *Salvia officinalis* (Bettaieb *et al.*, 2009), rosemary and spearmint (Delfine *et al.*, 2005), *Cymbopogon nardus* L. and *Cymbopogon pendulus* Steud. (Singh-Sangwan *et al.*, 1994), *Andrographis paniculata* (Saravanan *et al.*, 2009) and *Cymbopogon martinii* and *C. winterianus* (Farooqi *et al.*, 2005).

5.1.3 Root Fresh Weight (g/plant)

In the pot experiment, maximum root fresh weight (44.74 g/plant) was obtained with water stress at W_{100} level. Root fresh weight was significantly affected by mulching types, as observed in the high root fresh weight (41.04 g/plant) obtained under the treatment without mulch (M_0). Results of the interaction between water stress levels and mulching types showed that $W_{100}M_2$

gave significantly high root fresh weight (45.14 g/plant) compared to other treatments. Least root fresh weight was recorded in $W_{60}M_2$ (33.24 g/plant).

In the mean of two years under field experiment, maximum root fresh weight (44.93 g/plant) was obtained with water stress at W_{100} level. Root fresh weight was significantly affected by mulching types, as observed in the significantly high root fresh weight (41.39 g/plant) obtained with lemon grass mulch (M_1) treatment. Results of the interaction between water stress levels and mulching types showed that $W_{100}M_0$ gave significantly high root fresh weight (45.59 g/plant) compared to other treatments. Least root fresh weight (32.52 g/plant) was recorded in $W_{60}M_2$.

In Table 10, the root fresh weight as a mean of two years is given. In the treatment M_0 (without mulch), the root fresh weight decrease from 45.59 to 40.46 g/plant at 100% to 80% F.C., respectively. In severe stress treatment (W_{60}), the root fresh weight in the without mulch treatment ($W_{60}M_0$) decrease further to 37.05 g/plant which was a reduction of 18%. With regard to the lemon grass mulch (M_1), the root fresh weight was almost similar at all moisture regimes. For example in $W_{100}M_1$, $W_{80}M_1$, and $W_{60}M_1$, the root fresh weight was 45.09, 41.80 and 37.29 g/plant, respectively again showing that the root fresh weight was similar to the without mulch (M_0) treatment all the moisture regimes. **However, it must be noted that in mildly stress condition (W_{80}) with lemon grass mulch treatment ($W_{80}M_1$), the root fresh weight of 41.80 g/plant was obtained with only 20 irrigation as compared to 25 irrigation in without mulch treatment ($W_{80}M_0$). In other words, because moisture was conserved in the lemon grass mulch treatment ($W_{80}M_1$), it required much less irrigations to give the same amount of root fresh weight as that without mulch ($W_{80}M_0$).**

A similar trend was observed for $W_{60}M_0$ treatment. In the $W_{60}M_1$ treatment the root fresh weight was nearly similar to $W_{60}M_0$ treatment (41.39 and 41.03

g/plant, respectively). However, the significant point to note is that, in the severe stress condition, lemon grass mulch ($W_{60}M_1$) required only 12 irrigation to give a root biomass of 41.39 g/plant as compared to 17 irrigations in the without mulch treatment ($W_{60}M_0$). Exactly similar trend was observed with plastic mulch also.

Therefore the highlight of the study was that a major beneficial effect of the two kinds of mulches used (lemon grass mulch and plastic mulch) was revealed. The beneficial effects accrued from the lesser number of irrigation require both W_{80} and W_{60} treatments because of the significant moisture conservation.

The decrease in root fresh because of water stress has also been reported on *Pogostemon cablin* (Blanco) Benth. (Singh *et al.*, 2002) and *Atropa belladonna* (Baricevic *et al.*, 1999).

5.1.4 Root Dry Weight (g/plant)

In the pot experiment, maximum root dry weight (14.51 g/plant) was obtained with water stress at W_{100} level. However, the mulching types did not have significant effect on root dry weight. Results of the interaction between water stress levels and mulching types showed that $W_{100}M_0$ gave significantly high root dry weight (14.75 g/plant) compared to other treatments. Least root dry weight was recorded in $W_{60}M_2$ (11.83 g/plant).

In the mean of two years under field experiment, maximum root dry weight (14.38 g/plant) was obtained with water stress at W_{100} level. Root dry weight was significantly affected by mulching types, as observed in the high root dry weight (14.31 g/plant) obtained with lemon grass mulch (M_1) treatment. Results of the interaction between water stress levels and mulching types showed that $W_{100}M_1$

gave significantly high root dry weight (14.65 g/plant) compared to other treatments. Least root dry weight (13.28 g/plant) was recorded in W₆₀M₂.

In general, root growth is decreased or stopped by soil water stress (Kramer, 1983). In W₁₀₀ treatments, plastic mulch application decreased the root dry weight when frequency irrigation was increased. Excessive moisture reduced the effectiveness of mulches as reported by Mozumder *et al.* (2005). The decrease in root biomass (root fresh and dry weight) because of water stress has also been reported on *Pogostemon cablin* (Blanco) Benth. (Singh *et al.*, 2002) and *Atropa belladonna* (Baricevic *et al.*, 1999).

5.1.5 Root/Shoot Dry Weight Ratio

In the pot experiment, maximum root/shoot dry weight ratio (0.232) was obtained with water stress at W₆₀ level. Root/shoot dry weight ratio was significantly affected by mulching types, as observed in the high root/shoot dry weight ratio (0.225 and 0.224) obtained under the treatments without mulch (M₀) and lemon grass mulch (M₁), respectively. Results of the interaction between water stress levels and mulching types showed that W₆₀M₁ gave significantly high root/shoot dry weight ratio (0.240) compared to other treatments. Least root/shoot dry weight ratio was recorded in W₁₀₀M₂ (0.211).

In the mean of two years under field experiment, maximum root/shoot dry weight ratio (0.2260) was obtained with water stress at W₆₀ level. Root/shoot dry weight ratio was significantly affected by mulching types, as observed in the high root/shoot dry weight ratio (0.2209) obtained with lemon grass mulch (M₁) treatment. Results of the interaction between water stress levels and mulching types showed that W₆₀M₁ gave significantly high root/shoot dry weight ratio (0.2282) compared to other treatments. Least root/shoot dry weight ratio (0.2109) was recorded in W₁₀₀M₂.

An absolute increase in the amount of roots formed in mildly stressed plants, possibly because there is more effective osmotic adjustment in roots than in shoots (Sharp and Davies, 1979). It seems likely that it occurs when mild water stress inhibits shoot growth more than it inhibits photosynthesis, making a surplus of carbohydrate available for root growth (Kramer, 1983). Moreover in general, shoot growth is reduced more than the root growth because severe water deficits develop in the transpiring shoots and probably persist longer (Kramer, 1983).

Tolerant plants under water stress appear to shift carbohydrate utilization from shoot growth in to the production of additional root biomass in the early stages of adaptation. However at later stages, carbohydrate concentration may shift toward the shoots (Mathur and Wattal, 1996), accompanied by growth retardation (Ashraf and Harris, 2006).

These results are in good agreement with the findings of *Zataria multiflora*, *Ziziphora clinopodioides*, *Thymus vulgaris* and *Teucrium polium* (Kouchaki *et al.*, 2004).

5.1.6 Number of Flowers per Plant

In the pot experiment, maximum number of flowers per plant (1173.5) was obtained with water stress at W₆₀ level. However, the mulching types and interaction between water stress levels and, mulching types did not have significant effect on number of flowers per plant.

In the mean of two years under field experiment, maximum number of flowers per plant (960.1) was obtained with water stress at W₆₀ level. Number of flowers per plant was significantly affected by mulching types, as observed in the high number of flowers per plant (946.5) obtained under the treatment without mulch (M₀). However, the interaction between water stress levels and mulching types did not have significant effect on number of flowers per plant.

In water stress at 60% F.C., increase in number of flowers per plant may be due to stimulatory effect of water stress on flowering and inhibitory effect on growth and plant height. Water stress induces directly or indirectly, the products of both adverse and stimulatory effect on plants (Ashraf and Harris, 2006).

5.1.7 Weight of 100 dry flowers (g)

In the pot experiment, maximum weight of 100 dry flowers (1.97 g) was obtained with water stress at W_{80} level. However, the mulching types and interaction between water stress levels and mulching types did not have any significant effect on number of flowers per plant.

In the mean of two years under field experiment, maximum weight of 100 dry flowers (1.92 g) was obtained with water stress at W_{80} and W_{100} levels. However, the mulching types and interaction between water stress levels and mulching types did not have significant effect on number of flowers per plant.

Hundred dry flowers weight and number of flowers per plant were flower yield components. Results of weight of 100 dry flowers and number of flowers per plant showed that when weight of 100 dry flowers was less, the number of flowers per plant was high and vice versa. Under water stress condition, it is a common phenomenon that the reduction in one component of yield is compensated by an increase in another (Simpson, 1981).

5.2 BIOMASS YIELD

The results on water stress levels showed significant influence on fresh and dry flower yields in the both experiments (pot and field experiments). Also fresh and dry flower yields were significantly affected by mulching types in both the experiments except dry flower yield in the pot experiment. Moreover results of the interaction between water stress levels and mulching types showed significant influence on fresh and dry flower yields in the both experiments.

5.2.1 Fresh Flower Yield (g/plant)

In the pot experiment, maximum fresh flower yield (95.87 g/plant) was obtained with water stress at W_{80} level. Fresh flower yield was significantly affected by mulching types, as observed in the high fresh flower yield (83.67 g/plant) obtained with lemon grass mulch (M_1) treatment. Results of the interaction between water stress levels and mulching types showed that $W_{80}M_1$ gave significantly high fresh flower yield (96.8 g/plant) compared to other treatments. Least fresh flower yield was recorded in $W_{60}M_0$ (55 g/plant).

In the mean of two years under field experiment, maximum fresh flower yield (95.86 g/plant) was obtained with water stress at W_{80} level. Fresh flower yield was significantly affected by mulching types, as observed in the high fresh flower yield (94.35 g/plant) obtained with lemon grass mulch (M_1) treatment. Results of the interaction between water stress levels and mulching types showed that $W_{80}M_1$ gave significantly high fresh flower yield (96.48 g/plant) compared to other treatments. Least fresh flower yield (91.32 g/plant) was recorded in $W_{60}M_2$.

In Table 15, the fresh flower yield (g/plant) as a mean of two years is given. In the without mulch (M_0) treatment the fresh flower yield increase from 93.91 to 95.50 g/plant at 100% to 80% F.C., respectively. In severe stress treatment (W_{60}) the fresh flower yield in the without mulch treatment ($W_{60}M_0$) decrease to 92.98 g/plant. With regard to the lemon grass mulch (M_1) the fresh flower yield was almost similar at all moisture regimes. For example in $W_{100}M_1$, $W_{80}M_1$, and $W_{60}M_1$ the fresh flower yield was 93.41, 96.48 and 93.17 g/plant, respectively again showing that the fresh flower yield was similar to the without mulch (M_0) treatment all the moisture regimes. **However, it must be noted that in mildly stress condition (W_{80}) with lemon grass mulch treatment ($W_{80}M_1$), the fresh flower yield of 96.48 g/plant was obtained with only 20 irrigation as compared to 25 irrigation in without mulch treatment ($W_{80}M_0$). In other words, because**

moisture was conserved in the lemon grass mulch treatment ($W_{80}M_1$), it required much less irrigations to give the same amount of fresh flower yield as that without mulch ($W_{80}M_0$).

A similar trend was observed for $W_{60}M_0$ treatment. In the $W_{60}M_1$ treatment the fresh flower yield was nearly similar to $W_{60}M_0$ treatment (93.17 and 92.98 g/plant, respectively). **However, the significant point to note is that, in the severe stress condition, lemon grass mulch ($W_{60}M_1$) required only 12 irrigation to give a fresh flower yield of 93.17 g/plant as compared to 17 irrigations in the without mulch treatment ($W_{60}M_0$).** Exactly similar trend was observed with plastic mulch also.

Therefore the highlight of the study was that a major beneficial effect of the two kinds of mulches used (lemon grass mulch and plastic mulch) was revealed. The beneficial effects accrued from the lesser number of irrigation require both W_{80} and W_{60} treatments because of the significant moisture conservation.

5.2.2 Dry Flower Yield (g/plant)

In the pot experiment, maximum dry flower yield (20.67 g/plant) was obtained with water stress at W_{80} level. Minimum dry flower yield was recorded in W_{100} (12.78 g/plant). However, the mulching types did not have significant effect on dry flower yield. Results of the interaction between water stress levels and mulching types showed that $W_{80}M_1$ gave significantly high dry flower yield (21.0 g/plant) compared to other treatments. Least dry flower yield was recorded in $W_{100}M_2$ (11.0 g/plant).

It is an interesting fact, that the high amount of water in the soil (water stress at W_{100} level) had an adverse effect on dry flower yield. This condition may increase vegetative growth, which in turn limits flowering. In water stress at 80%

F.C., increase in dry flower yield may be due to stimulatory effect of water stress on flowering and inhibitory effect on growth and plant height. Water stress induces directly or indirectly, the products of both adverse and stimulatory effect on plants (Ashraf and Harris, 2006).

In the mean of two years under field experiment, maximum dry flower yield (18.48 g/plant) was obtained with water stress at W_{80} level. Minimum dry flower yield was recorded in W_{60} (17.26 g/plant). Dry flower yield was significantly affected by mulching types, as observed in the high dry flower yield (17.93 g/plant) obtained with lemon grass mulch (M_1) treatment. Results of the interaction between water stress levels and mulching types showed that $W_{80}M_1$ recorded significantly high dry flower yield (18.75 g/plant) compared to other treatments. Least fresh flower yield (16.63 g/plant) was recorded in $W_{60}M_2$.

Better moisture availability and edaphic environment under organic mulching (lemon grass mulch, M_1) appears to have enhanced flower yield and ultimately oil yield. Due to lack of adequate soil moisture in the plots receiving irrigation at 60% F.C. and plastic mulch condition, plant productivity was suppressed, leading to lower flower and oil yields. Because in plastic mulch, water deficit resulted in slow development in comparison under the treatment without mulch. Hence after irrigation, mulch plots have taken longer time in reaching to optimum F.C. The increase of herbage yield because of organic mulch has been reported in *Pelargonium graveolens* (Muni Ram *et al.*, 2003), *Pogostemon cablin* (Blanco) Benth. (Singh *et al.*, 2002).

In Table 17, the dry flower yield (g/plant) as a mean of two years is given. In the without mulch (M_0) treatment the dry flower yield increase from 17.46 to 18.56 g/plant at 100% to 80% F.C., respectively. In severe stress treatment (W_{60}) the dry flower yield in the without mulch treatment ($W_{60}M_0$) decrease to 17.56 g/plant. With regard to the lemon grass mulch (M_1) the dry flower yield was

almost similar at all moisture regimes. For example in $W_{100}M_1$, $W_{80}M_1$, and $W_{60}M_1$ the dry flower yield was 17.45, 18.75 and 17.58 g/plant, respectively again showing that the dry flower yield was similar to the without mulch (M_0) treatment all the moisture regimes. **However, it must be noted that in mildly stress condition (W_{80}) with lemon grass mulch treatment ($W_{80}M_1$), the dry flower yield of 18.75 g/plant was obtained with only 20 irrigation as compared to 25 irrigation in without mulch treatment ($W_{80}M_0$). In other words, because moisture was conserved in the lemon grass mulch treatment ($W_{80}M_1$), it required much less irrigations to give the same amount of dry flower yield as that without mulch ($W_{80}M_0$).**

A similar trend was observed for $W_{60}M_0$ treatment. In the $W_{60}M_1$ treatment the dry flower yield was nearly similar to $W_{60}M_0$ treatment (17.58 and 17.56 g/plant, respectively). **However, the significant point to note is that, in the severe stress condition, lemon grass mulch ($W_{60}M_1$) required only 12 irrigation to give a dry flower yield of 17.58 g/plant as compared to 17 irrigations in the without mulch treatment ($W_{60}M_0$).** Exactly similar trend was observed with plastic mulch also.

Therefore the highlight of the study was that a major beneficial effect of the two kinds of mulches used (lemon grass mulch and plastic mulch) was revealed. The beneficial effects accrued from the lesser number of irrigation require both W_{80} and W_{60} treatments because of the significant moisture conservation.

The above results are in harmony with results of Seliskar (1987) who reported production of *Grindelia integrifolia* was larger under the overall field water capacity conditions, than either in dry or saturated soils. Also, Mahmoud (2002) reported that extending or shortening the irrigation period to more or less

than 4 days intervals reduced the plant growth as well as the flower production in *Grindelia camporum*.

There was the no compensation effect between yield of water stress treatments at 60% F.C. under mulching types compared with other treatments in the pot and the field experiments. Because, during the pot experiment, water content of soil was kept at constant levels as per the water stress treatments (W_{100} , W_{80} , W_{60}). It was measured by daily weighing and watering for replacement of water loss. However in the field experiment, water content was not constant and watering of the plots occurred when soil moisture had reached water stress levels of treatments (W_{100} , W_{80} , W_{60}). In the field experiment after irrigation, first, 100 F.C. was achieved. Later, it was reduced to water stress levels of treatment, so that in the field experiment after each irrigation, crops had recovery of growth by extra moisture of irrigation. When plants are recovering from stress there may be a brief period during which growth exceeds that of non-stressed plants (Simpson, 1981).

On the other hand in water stress at 80% F.C. of field experiment reduction in growth rate caused by water deficits was made up by rapid “Compensatory” growth when leaves regained turgor. In some experiments when water becomes available after a short period of stress, growth is very rapid for a short time, so that no net reduction is caused by the stress. It is sometimes termed stored or compensatory growth, because it is suggested that metabolites accumulated during the period when cell enlargement is inhibited by lack of turgor are available for cell wall synthesis and other processes associated with growth after turgor is restored (Kramer, 1983). Rewatering stressed plants restored these parameters at values higher to those of plants permanently irrigated with 100% F.C. Moreover these results are in conformity with *Matricaria chamomilla* L. (Afzali *et al.*, 2007), *Matricaria chamomilla* L. (Pirzad *et al.*, 2006), *Silybum marianum* (Belitz and Sams, 2007) and *S. khasianum* (Yaniv *et al.*, 1983).

5.3 ESSENTIAL OIL QUANTITY

The results on water stress levels showed significant influence on essential oil percentage and yield in both the experiments (pot and field experiments). Also essential oil yield was significantly affected by mulching types in the field experiment. Moreover results of the interaction between water stress levels and mulching types showed significant influence on essential oil yield in both the experiments.

5.3.1 Essential Oil Percentage (% v/w dry weight)

In the pot experiment, maximum essential oil percentage (0.783% v/w DW) was recorded with water stress at W_{80} level. However, the mulching types and interaction between water stress levels and mulching types did not have significant effect on essential oil content.

In the mean of two years under field experiment, maximum essential oil percentage (0.757% v/w DW) was obtained with water stress at W_{60} level. However, the mulching types and interaction between water stress levels and mulching types did not have significant effect on essential oil percentage.

In Table 19, the essential oil percentage as a mean of two years is given. In the without mulch (M_0) treatment the essential oil percentage increase from 0.70 to 0.75% at 100% to 80% F.C., respectively. In severe stress treatment (W_{60}), the essential oil percentage in the without mulch treatment ($W_{60}M_0$) increase to 0.76%. With regard to the lemon grass mulch (M_1), the essential oil percentage was similar at all moisture regimes. For example in $W_{100}M_1$, $W_{80}M_1$, and $W_{60}M_1$ the essential oil percentage was 0.70, 0.75 and 0.76%, respectively again showing that the essential oil percentage was similar to the without mulch (M_0) treatment all the moisture regimes. **However, it must be noted that in mildly stress condition (W_{80}) with lemon grass mulch treatment ($W_{80}M_1$), the essential oil**

percentage of 0.75% was obtained with only 20 irrigation as compared to 25 irrigation in without mulch treatment ($W_{80}M_0$). In other words, because moisture was conserved in the lemon grass mulch treatment ($W_{80}M_1$), it required much less irrigations to give the same amount of essential oil percentage as that without mulch ($W_{80}M_0$).

A similar trend was observed for $W_{60}M_0$ treatment. In the $W_{60}M_1$ treatment the essential oil percentage was similar to $W_{60}M_0$ treatment (0.76% v/w dry weight). However, the significant point to note is that, in the severe stress condition, lemon grass mulch ($W_{60}M_1$) required only 12 irrigation to give a essential oil percentage of 0.76% as compared to 17 irrigations in the without mulch treatment ($W_{60}M_0$). Exactly similar trend was observed with plastic mulch also.

Therefore the highlight of the study was that a major beneficial effect of the two kinds of mulches used (lemon grass mulch and plastic mulch) was revealed. The beneficial effects accrued from the lesser number of irrigation require both W_{80} and W_{60} treatments because of the significant moisture conservation.

In addition to physiological factors, environmental factors, such as water, play an important role in the accumulation and synthesis of secondary metabolites (Yaniv and Palevitch, 1982).

Increase in essential oil percentage of W_{80} and W_{60} is due to role of stem length, because the stem has an important role in translocation of mineral nutrients, water and assimilates within the plant. Reduction in stem height reduces the distances water moves from soil to leaf to the atmosphere without reducing the resistance to water flow (Simpson, 1981). Water stress is not always injurious.

Although it reduces vegetative growth it sometimes improves the quality of plant products (Wolf, 1962).

Oil content had significantly reduced at W₁₀₀ which may be due to dilution effect. The decrease of essential oil percentage in W₁₀₀ because of mulch has been reported in *Pogostemon cablin* (Blanco) Benth. (Singh *et al.*, 2002).

The increase of essential oil percentage because of water shortage has been reported in *Matricaria chamomilla* L. (Pirzad *et al.*, 2006), *Calendula officinalis* L. (Rahmani *et al.*, 2008), *Melissa officinalis* L. (Ardekani *et al.*, 2007), *Satureja hortensis* L. (Baher *et al.*, 2002), *Melissa officinalis* L. (Abbaszadeh *et al.*, 2008), *Deracocephalum moldavica* L. (Safikhani *et al.*, 2007), *Ocimum basilicum* (Omidbaigi *et al.*, 2003), *Cymbopogon martini* and *C. winterianus* (Fatima *et al.*, 2006), Balm (Aliabadi *et al.*, 2009), *Ocimum basilicum* L. and *O. americanum* L. (Khalid, 2006), chicory (Taheri *et al.*, 2008), coriander (Aliabadi *et al.*, 2008), *Cymbopogon nardus* and *C. pendulus* (Singh-Sangwan *et al.*, 1994) and *Cymbopogon martini*, *C. winterianus* (Farooqi *et al.*, 2005).

5.3.2 Essential Oil Yield (kg/ha)

In the pot experiment, maximum essential oil yield (16.19 kg/ha) was obtained with water stress at W₈₀ level and minimum essential oil yield was recorded in W₁₀₀ (8.99 kg/ha). However, the mulching types did not have significant effect on essential oil yield. Results of the interaction between water stress levels and mulching types showed that W₈₀M₁ gave significantly high essential oil yield (16.39 kg/ha) compared to other treatments. Least essential oil yield was recorded in W₁₀₀M₂ (7.68 kg/ha).

In the mean of two years under field experiment, maximum essential oil yield (13.88 kg/ha) was obtained with water stress at W₈₀ level and minimum essential oil yield was recorded in W₁₀₀ (12.09 kg/h). Essential oil yield was

significantly affected by mulching types, as observed in the high essential oil yield (13.23 kg/ha) obtained with lemon grass mulch (M_1) treatment. Results of the interaction between water stress levels and mulching types showed that $W_{80}M_1$ gave significantly high essential oil yield (14.14 kg/ha) compared to other treatments. Least essential oil yield (11.86 kg/ha) was recorded in $W_{100}M_2$.

In Table 20 the essential oil yield as a mean of two years is given. In the without mulch (M_0) treatment the essential oil yield increase from 12.20 to 13.91 kg/ha at 100% to 80% F.C., respectively. In severe stress treatment (W_{60}) the essential oil yield in the without mulch treatment ($W_{60}M_0$) decrease to 13.33 kg/ha. With regard to the lemon grass mulch (M_1) the essential oil yield was similar at all moisture regimes. For example in $W_{100}M_1$, $W_{80}M_1$, and $W_{60}M_1$ the essential oil yield was 12.20, 14.14 and 13.33 kg/ha, respectively again showing that the essential oil yield was similar to the without mulch (M_0) treatment all the moisture regimes. **However, it must be noted that in mildly stress condition (W_{80}) with lemon grass mulch treatment ($W_{80}M_1$), the essential oil yield of 14.14 kg/ha was obtained with only 20 irrigation as compared to 25 irrigation in without mulch treatment ($W_{80}M_0$). In other words, because moisture was conserved in the lemon grass mulch treatment ($W_{80}M_1$), it required much less irrigations to give the same amount of essential oil yield as that without mulch ($W_{80}M_0$).**

A similar trend was observed for $W_{60}M_0$ treatment. In the $W_{60}M_1$ treatment the essential oil yield was similar to $W_{60}M_0$ treatment (13.33 kg/ha). **However, the significant point to note is that, in the severe stress condition, lemon grass mulch ($W_{60}M_1$) required only 12 irrigation to give a essential oil yield of 13.33 kg/ha as compared to 17 irrigations in the without mulch treatment ($W_{60}M_0$).** Exactly similar trend was observed with plastic mulch also.

Therefore the highlight of the study was that a major beneficial effect of the two kinds of mulches used (lemon grass mulch and plastic mulch) was revealed. The beneficial effects accrued from the lesser number of irrigation require both W_{80} and W_{60} treatments because of the significant moisture conservation.

The stimulation of essential oil production under water stress condition (W_{80}) compared with control (W_{100}) could be due to the fact that plants produce high terpene concentrations under environmental stress conditions because of a low allocation of carbon to the growth, suggesting a trade-off between growth and defense (Turtola *et al.*, 2003).

Besides, least yield of essential oil at 100% field capacity could be attributed to excess water. The low amount obtained at 60% field capacity is perhaps due to water deficit. Damage resulting from drought stress is related to the detrimental effects of desiccation on protoplasm and to an increase in solute concentration as the protoplast volume shrinks, which may itself have serious structural and metabolic consequences. The integrity of membranes and proteins is also affected by desiccation, which in turn leads to metabolic dysfunctions. In addition to membrane damage, numerous studies have shown that cytosolic and organellar proteins may undergo substantial loss of activity or complete denaturation when dehydrated. Photosynthesis can be affected by water stress in two ways, closure of the stomata and effects on the structural integrity of the photosynthetic machinery (Hopkins, 1995). Both electron transport and photophosphorylation were reduced in the chloroplasts isolated from sunflower leaves with leaf water potential below about -1.0 Mpa. These effects reflect damage to the thylakoid membranes and ATP synthetase protein (Rao *et al.*, 1987). The consequence of all these events is a general disruption of metabolism in the cell and reduction of yield and yield components (Hopkins, 1995).

Bettaieb *et al.* (2009) reported that variation in essential oil yield and composition could be due to its effect on enzyme activity and metabolism improvements.

A preliminary biochemical investigation has resulted in the isolation of a protein-P33 of 33K molecular weight. The protein has been found to be associated with the oil bodies in the cultured chamomile shoot primordial. The oil bodies are normally found in the mature seeds. The protein shows carboxypeptidase activity and in an assay, it acts by liberating the carboxyl terminal amino acid residues of angiotensin I (Hirata *et al.*, 1996; Iyer, 1994). The protein showed maximum activity at 6.5 pH. It was inactive below 5 pH or above 8.5 pH. The activity was inhibited by specific inhibitors iodoacetamide, p-chloromercuribenzoic acid (PCMB) and L-3 transcarboxyxiran-2-carbonyl L-leucyl agmatine (E-64). It appears that the P33 protein has a cell-protective function.

The increase of essential oil yield because of water shortage has been reported in *Melissa officinalis* L. (Ardekani *et al.*, 2007), *Salvia officinalis* (Bettaieb *et al.*, 2009), *Cymbopogon flexuosus* (Munnu Singh, 2000) and *Lippia berlandieri* (Dunford and Vazquez, 2005).

The increase of essential oil yield because of organic mulch has been reported in *Pelargonium graveolens* (Muni Ram *et al.*, 2003), *Pogostemon cablin* (Blanco) Benth. (Singh *et al.*, 2002).

5.4 ESSENTIAL OIL QUALITY

Essential oil composition and yield of the main components of essential oil (kg/ha) were affected by interaction between water stress levels and mulching types in the field experiment. The main components of the essential oil of *Matricaria chamomilla* L. were α -Bisabolol oxide B, α -Bisabolone oxide A, α -Bisabolol, Chamazulene, α -Bisabolol oxide A and (Z)-En-yn-dicycloether. Other

components were included in low magnitudes (Sashidhara *et al.*, 2006; Syamasundar *et al.*, 2002; Moumita Das *et al.*, 1998; Honcariv and Repack, 1979).

5.4.1 Essential Oil Composition

In the first year under field experiment, results of the interaction between water stress levels and mulching types showed that the maximum percentage of α -Bisabolol oxide B, α -Bisabolone oxide A, α -Bisabolol, Chamazulene, α -Bisabolol oxide A and (Z)-En-yn-dicycloether obtained from W₆₀M₂ (5.9%), W₈₀M₁ (3.91%), W₁₀₀M₀ (21.06%), W₈₀M₂ (4.04%), W₆₀M₂ (64.32%) and W₆₀M₁ (10.49%), respectively when compared to other treatments and minimum percentage were recorded in W₁₀₀M₀ (3.09%), W₆₀M₀ (0.23%), W₆₀M₂ (5.21%), W₈₀M₀ (1.82%), W₁₀₀M₀ (49.32%) and W₈₀M₁ (7.16%), respectively .

In the second year under field experiment, results of the interaction between water stress levels and mulching types showed that the maximum percentage of α -Bisabolol oxide B, α -Bisabolone oxide A, α -Bisabolol, Chamazulene, α -Bisabolol oxide A and (Z)-En-yn-dicycloether obtained from W₆₀M₁ (6.57%), W₈₀M₂ (5.2%), W₁₀₀M₁ (24.55%), W₆₀M₁ (4.66%), W₆₀M₀ (65.94%) and W₆₀M₂ (11.66%), respectively when compared to other treatments and minimum percentage was recorded in W₁₀₀M₂ (2.96 %), W₆₀M₀ (0.79%), W₆₀M₂ (3.22%), W₆₀M₀ (2.29%), W₁₀₀M₁ (47.94%) and W₈₀M₀ (6.1%), respectively.

The change of essential oil composition because of mulching types has been reported in *Rosmarinus officinalis* L. (De Falco *et al.*, 2006). Also the quality of essential oil of *Pogostemon cablin* (Blanco) Benth. (Singh *et al.*, 2002) and *Pelargonium graveolens* (Muni Ram *et al.*, 2003) in terms of its major constituents, were found to be of a standard acceptable in international trade.

5.4.2 Yield of Essential Oil Main Components (kg/ha)

Based on mean yield of essential oil and per cent of its constituents, calculated yield of oil components is discussed. Under field experiment, the results on different treatments showed different influence on yield of main components of essential oil in the mean of two years. Maximum yield of the main components such as α -Bisabolol oxide B, α -Bisabolone oxide A, α -Bisabolol, Chamazulene, α -Bisabolol oxide A and (Z)-En-yn-dicycloether obtained from W₆₀M₀ (0.747 kg/ha), W₈₀M₂ (0.505 kg/ha), W₁₀₀M₀ (2.582 kg/ha), W₈₀M₂ (0.510 kg/ha), W₈₀M₁ (8.636 kg/ha) and W₆₀M₁ (1.295 kg/ha), respectively and minimum percentage was recorded in W₁₀₀M₂ (0.359 kg/ha), W₆₀M₂ (0.047 kg/ha), W₆₀M₂ (0.533 kg/ha), W₈₀M₀ (0.292 kg/ha), W₁₀₀M₀ (6.115 kg/ha) and W₁₀₀M₁ (0.940 kg/ha), respectively.

The data show that the yield of the chamomile essential oil composition varies depending on soil moisture regime and mulching types. The environmental factors control content and yield of secondary metabolites (Ross and Sombrero, 1991). The α -Bisabolol and Chamazulene contents of the essential oil and oil productivity of chamomile are affected by the environment of cultivation (Moumita Das *et al.*, 1998).

Salamon (2006) found that various growing conditions induced some alterations in the chamomile essential oil quality. Peneva *et al.* (1987) reported that however the flavonoid components in the flowers did not change under different ecological conditions, while variation in chamazulene determining blue vs. yellow essential oil color depended more on ecological than on genetical factors. It is critical to know the effect of the environment on individual phytochemicals.

It has been found that individual Mendelian genes control the presence or absence of chamazulene and bisabolol. The most desirable genotype with high

amount of chamazulene and bisabolol is a double recessive genotype (Franz, 1982; Horn *et al.*, 1988).

Terpenes also deter herbivores and attract pollinators, may stabilize and protect plant membranes against high temperatures (Loreto *et al.*, 1998) or act as antioxidants in leaves (Youdim *et al.*, 2002). The capacity of production of terpenes is influenced by temperature (Tingey *et al.*, 1980), irradiance (Loreto *et al.*, 1996), seasonality (Peñuelas and Llusà, 1997) and water availability (Bertin and Staudt, 1996). All the terpenoid compounds present in chamomile oil are formed from mevalonic acid via pyruvate pathway. Geranyl pyrophosphate which is the precursor for sesquiterpens, condenses with isopentenyl pyrophosphate to form farnesyl pyrophosphate which is converted to (E)- β -farnesene. Farnesene is the precursor of both chamazulene and bisabolol. Once (E)- β -farnesene is formed, it undergoes a series of reactions like cyclisation, oxidation, esterification, lactonisation *etc.* to form matricine. Matricine is converted to chamazulene via chamazulene carboxylic acid. Cyclization of farnesene in a different mode forms α -Bisabolene which undergoes oxidation to form α -Bisabolol. Subsequent oxidation of bisabolol forms bisabolol epoxide which further get converted into α -Bisabolol oxide A or α -Bisabolol oxide B. Oxidation of bisabolol oxide A leads to the formation of α -Bisabolone oxide. All these transformations takes place in the plant by influence of enzymes such as oxidase, epoxidase *etc.*

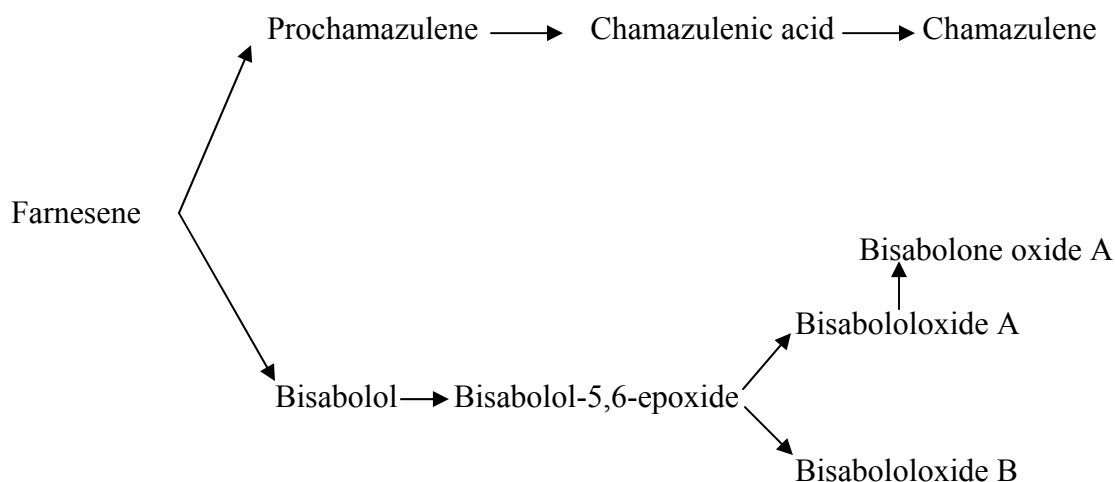


Fig. 19. Biosynthetic pathway of chamazulene and bisabolol and its oxides in chamomile (Moumita Das *et al.*, 1998).

However, severe drought may cause oxidative stress due to the formation of reactive oxygen species and photoinhibitory damage (Asada, 1996 and Osmond *et al.*, 1997). In the chloroplasts, protection against oxidative damage is provided by both enzymatic and non-enzymatic antioxidant (Asada, 1999). Antioxidant contents may therefore increase in water stressed plants (Eskling *et al.*, 1997 and Depka *et al.*, 1998) and this may be the case for increase in the secondary metabolite concentrations and terpenes with antioxidant properties (Zobayed *et al.*, 2007, Gershenzon *et al.*, 1978 and Llusia and Peñuelas, 1998). Other studies have shown that antioxidants (tocopherols, carotenoids and abietane diterpenes) increase in rosemary leaves subjected to severe drought (Munné-Bosch *et al.*, 1999, Munné-Bosch and Alegre, 2000 and Munné-Bosch and Alegre, 2003) and that peppermint monoterpenes may be influenced by osmotic stress and irrigation regimes (Gershenzon *et al.*, 2000, Charles *et al.*, 1990 and Mitchell and Yang, 1998).

The data of this research and review of studies indicated that change in chamomile essential oil composition may be due to effect of water stress and

mulching types on change of enzymes activity in process of essential oil production. It goes through a series of reactions like cyclisation, oxidation, esterification, lactonisation *etc.* Oxidation reactions can be one of the good reasons for increasing the production of the oxygenated sesquiterpene compounds *viz.* α -Bisabolol oxide A, α -Bisabolol oxide B and α -Bisabolone oxide A during the water stress condition.

Moreover proline as a important Osmoprotectant compound may be has a corporation effect on increasing the essential oil component because during the water stress regimes, its concentration was showed increase.

The increase in essential oil component because of water shortage has been reported in *Matricaria chamomilla* L. (Pirzad *et al.*, 2006), *Ocimum basilicum* (Omidbaigi *et al.*, 2003), *Salvia officinalis* (Bettaieb *et al.*, 2009), *Satureja hortensis* L. (Baher *et al.*, 2002), chicory (Taheri *et al.*, 2008), *Cymbopogon nardus* and *C. pendulus* (Singh-Sangwan *et al.*, 1994), *Mentha spicata* L. and *Rosmarinus officinalis* L. (Delfine *et al.*, 2005), *Artemisia* (Charles *et al.*, 1993) and *Cymbopogon martinii* and *C. winterianus* (Fatima *et al.*, 2002).

5.5 PROLINE PRODUCTION

The results on water stress levels showed significant influence on proline production in both the experiments (pot and field experiments). Also proline production was significantly affected by mulching types and interaction between water stress levels and mulching types in the field experiment.

In the pot experiment, maximum proline production (234.5 $\mu\text{g/g}$ fresh weight) was obtained with water stress at W₆₀ level. However, the mulching types and interaction between water stress levels and mulching types did not have significant effect on proline production.

In the mean of two years under field experiment, maximum proline production (201.3 $\mu\text{g/g}$ fresh weight) was obtained with water stress at W_{60} level. Proline production was significantly affected by mulching types, as observed in the high proline production (146.0 $\mu\text{g/g}$ fresh weight) obtained with plastic mulch (M_2), **because in mulch treatments especially in plastic mulch, water deficit resulted in slow development in comparison under the treatment without mulch. Hence after irrigation, mulch plots have taken longer time in reaching to optimum F.C.**

Results of the interaction between water stress levels and mulching types showed that $W_{60}M_2$ recorded significantly high proline production (207 $\mu\text{g/g}$ fresh weight) compared to other treatments. Least proline production (92 $\mu\text{g/g}$ fresh weight) was recorded in $W_{100}M_0$.

Proline accumulation in plants can increase the drought tolerance of plants. When the plants are affected by drought and other parameters that decrease the water potential in cytosol, the concentration of osmolites (proline) has to be increased so that the absorption of water continued under stress conditions. An effective mechanism to reduce damage from water stress is brought about by the accumulation of high intercellular levels of osmoprotectant compounds, such as proline (Cseke *et al.*, 2006). Proline catabolism takes place in rewatering stressed plants. Osmoprotectant biosynthesis pathways, as a potential way to improve stress tolerance, was reported by Rontein *et al.* (2002). Therefore, it is suggested that levels of proline are regulated at the level of transcription of the genes of P5CS (pyrulline 5 carboxylase synthase) and PDH (proline dehydrogenase) enzymes during dehydration and rehydration, respectively.

The increase in density of proline because of water shortage has been reported in *Ocimum basilicum* (Moeini Alishah *et al.*, 2006), *Tribulus terrestris* and *T. pentandrus* (El-Sayed *et al.*, 2008), *Cymbopogon winterianus* (Farooqi *et*

al., 1998), *Melissa officinalis* L. (Abbaszadeh *et al.*, 2008) *Ocimum basilicum* (Hasani *et al.*, 2004), *Deracocephalum moldavica* L. (Safikhani *et al.*, 2007), *Rosmarinus officinalis* L. and *Tanacetum parthenium* (Hamed *et al.*, 2004), *Cymbopogon* spp (Misra *et al.*, 1999), *Cymbopogon martinii* and *C. winterianus* (Fatima *et al.*, 2002) and *Satureja hortensis* (Nik *et al.*, 2004).

Plastic mulch plots (M_2) showed slow development of water deficit up to 80 or 60% F.C. compared to without mulch (M_0) and lemon grass mulch (M_1). Slow development of water deficit may induce osmotic adjustment in some plant species (Morgan, 1984) resulting in the maintenance of cell turgor at low water potential during drought by using of mulch (Kumar and Singh, 1998).

5.6 CORRELATION COEFFICIENT

Essential oil yield mostly depended on dry flower yield and essential oil percentage. As per results correlation coefficients between essential oil yield and dry flower yield were +0.99, +0.59 and +0.91 in the pot experiment, first and second years of the field experiments, respectively. Also correlation coefficients between essential oil yield and essential oil percentage were +0.84, +0.88 and +0.79 in the pot experiment, first and second years of the field experiments, respectively.

Moreover, essential oil yield showed positive correlation coefficients with drought tolerance sign *viz.* root/shoot ratio and proline production. Correlation coefficients between essential oil yield and root/shoot ratio were +0.42, +0.43 and +0.18 in the pot experiment, first and second years of the field experiments, respectively. Also correlation coefficients between essential oil yield and proline production were +0.50, +0.39 and +0.19 in the pot experiment, first and second years of the field experiments, respectively.

FUTURE LINE OF WORK:

- Study can be undertaken on the effect of water stress on chamomile essential oil quantity and quality at different growth stages viz. vegetative and reproductive stages.
- Besides water stress, the effect of other environmental stresses like light intensity, duration, temperature and season of sowing can be studied.
- Comparative studies on various other mulches can be tried since the organic lemon grass mulch has recorded significant results.

Summary

VI. SUMMARY

Relation between water availability and optimum production of secondary metabolites is rather complex. Differences exist in adaptation of specific plant species to environmental water stress and water management. Consideration of per-plant response vis-a-vis a whole field response is quite critical. In general, water stress to botanicals might not be productive; although, a stress with specific intensity might be beneficial.

The pot and field investigations were conducted at Sugandhavana, Medicinal and Aromatic section, Division of Horticulture, University of Agricultural Sciences, GKV, Bangalore (Zone- 5).

The pot experiment was conducted during 2008-2009 while the field experiments were taken up from 2008-2010 for a period of two years. These studies were made to investigate the effect of irrigation water (100, 80, 60% of F.C.), applied at different mulching types (1-No mulch or control 2- Plastic mulch 3- Dry lemon grass mulch) on growth, flower and essential oil yields of *Matricaria chamomilla* L. var. Vallary.

The purpose of this research was to find the stress management strategy that would minimize losses in flower yield and essential oil quantity and maximize essential oil quality. A compromise must be made between processors and growers to insure a profitable yield and a high quality product.

The summary is grouped under two headings as here under:

6.1 POT EXPERIMENT

Effect of water stress on morphological characters recorded highest shoot fresh weight (367.7 g/plant), shoot dry weight (68.01 g/plant), root fresh weight

(44.74 g/plant) and root dry weight (14.51 g/plant) obtained with W_{100} and highest root/shoot dry weight ratio (0.232) obtained with W_{60} . Also in the effect of mulching types, highest shoot fresh weight (348.7 g/plant) was obtained with M_2 treatment and highest root fresh weight (41.04 g/plant) and root/shoot dry weight ratio (0.225) were obtained with M_0 . The results of the interaction between water stress levels and mulching types showed that $W_{100}M_2$ gave significantly high shoot fresh weight (375 g/plant), shoot dry weight (68.80 g/plant) and root fresh weight (45.14 g/plant). Also maximum root dry weight (14.75 g/plant) and root/shoot dry weight ratio (0.252) were obtained with $W_{100}M_0$ and $W_{60}M_1$, respectively when compared to other treatments.

Biomass yield and yield component due to the effect of water stress, showed that highest fresh flower yield (95.87 g/plant), dry flower yield (20.67 g/plant) and weight of 100 dry flowers (1.97 g) was obtained with W_{80} . While, high fresh weight of 100 flowers (9.44 g) and number of flowers per plant (1173.5) was obtained with W_{100} and W_{60} treatments, respectively. Also in the effect of mulching types, maximum fresh flower yield (83.67 g/plant) was obtained with M_1 . Further, the results of the interaction between water stress levels and mulching types showed that $W_{80}M_1$ gave significantly high fresh flower yield (96.8 g/plant) and dry flower yield (21.0 g/plant) per plant when compared to other treatments.

The results on essential oil quantity due to effect of water stress, showed highest essential oil percentage and yield (0.783% and 16.19 kg/ha, respectively) were obtained with W_{80} treatment. Moreover for essential oil yield, the results of the interaction between water stress levels and mulching types showed that $W_{80}M_1$ gave significantly the maximum essential oil yield (16.39 kg/ha) when compared to other treatments.

With regard to the proline production due to effect of water stress, highest proline production (234.5 µg/g fresh weight) was obtained with W₆₀.

6.2 FIELD EXPERIMENTS (mean of two years)

The growth parameters as affected by water stress, recorded highest plant height (78.8 cm) with W₈₀. While, highest shoot fresh weight (386 g/plant), shoot dry weight (67.17 g/plant), root fresh weight (44.93 g/plant) and root dry weight (14.38 g/plant) were obtained with W₁₀₀ treatment and highest root/shoot dry weight ratio (0.2260) obtained with W₆₀ treatment. Further, mulching types, recorded highest shoot dry weight (64.37 g/plant), root fresh weight (41.39 g/plant), root dry weight (14.31 g/plant) and root/shoot dry weight ratio (0.2209) with M₁ and highest plant height (72.8 cm) and shoot fresh weight (364 g/plant) obtained with M₀. Moreover for morphological characters, the results of the interaction between water stress levels and mulching types showed that W₁₀₀M₁ gave significantly high shoot fresh weight (389 g/plant), shoot dry weight (68.05 g/plant) and root dry weight (14.65 g/plant) which it was equal with W₁₀₀M₀ on shoot fresh weight. Maximum root fresh weight (45.59 g/plant) and root/shoot dry weight ratio (0.2282) were obtained with W₁₀₀M₀ and W₆₀M₁ treatments, respectively.

With respect to biomass yield and yield components considered by effect of water stress, highest fresh flower yield (95.86 g/plant), dry flower yield (18.84 g/plant) and weight of 100 dry flowers (1.92 g) was with W₈₀. While also highest number of flowers per plant (960.1) though small was obtained with W₆₀ treatment. Also, in the effect of mulching types, high fresh flower yield (94.35 g/plant), dry flower yield (17.93 g/plant) was obtained with M₁. While, maximum number of flowers per plant (946.5) was obtained with M₀. For biomass yield and yield component, the results of the interaction between water stress levels and mulching types showed that W₈₀M₁ gave significantly maximum fresh flower

yield (96.48 g/plant) and dry flower yield (18.75 g/plant) per plant when compared to other treatments.

The main focus of this investigation being on essential oil quantity due to the effect of water stress, highest essential oil percentage and yield (0.757% and 13.88 kg/ha, respectively) were obtained with W_{60} and W_{80} treatments, respectively. Also in the effect of mulching types, highest essential oil yield obtained (13.23 kg/ha) with M_1 . The results of the interaction between water stress levels and mulching types showed that $W_{80}M_1$ gave significantly high essential oil yield (14.14 kg/ha) compared to other treatments.

With regard to the proline production due to effect of water stress, highest proline production (201.3 $\mu\text{g/g}$ fresh weight) was obtained with W_{60} . Also in the effect of mulching types, highest proline production (146.0 $\mu\text{g/g}$ fresh weight) was obtained with M_2 . The results of the interaction between water stress levels and mulching types showed that $W_{60}M_2$ gave significantly high proline production (207 $\mu\text{g/g}$ fresh weight) compared to other treatments.

Results of the interaction between water stress levels and mulching types showed that the maximum percentage of α -Bisabolol oxide B, α -Bisabolone oxide A, α -Bisabolol, Chamazulene, α -Bisabolol oxide A and (Z)-En-yn-dicycloether obtained from $W_{60}M_2$ (5.9%), $W_{80}M_1$ (3.91%), $W_{100}M_0$ (21.06%), $W_{80}M_2$ (4.04%), $W_{60}M_2$ (64.32%) and $W_{60}M_1$ (10.49%), respectively in the first year and $W_{60}M_1$ (6.57%), $W_{80}M_2$ (5.2%), $W_{100}M_1$ (24.55%), $W_{60}M_1$ (4.66%), $W_{60}M_0$ (65.94%) and $W_{60}M_2$ (11.66%), respectively in the second year when compared to other treatments.

A variation of main component yield of essential oil in the mean of two years was observed under the interaction with water stress and mulch types. Maximum yield of the main components such as α -Bisabolol oxide B, α -

Bisabolone oxide A, α -Bisabolol, Chamazulene, α -Bisabolol oxide A and (Z)-En-yn-dicycloether obtained from W₆₀M₀ (0.747 kg/ha), W₈₀M₂ (0.505 kg/ha), W₁₀₀M₀ (2.582 kg/ha), W₈₀M₂ (0.510 kg/ha), W₈₀M₁ (8.636 kg/ha) and W₆₀M₁ (1.295 kg/ha), respectively and minimum percentage was recorded in W₁₀₀M₂ (0.359 kg/ha), W₆₀M₂ (0.047 kg/ha), W₆₀M₂ (0.533 kg/ha), W₈₀M₀ (0.292 kg/ha), W₁₀₀M₀ (6.115 kg/ha) and W₁₀₀M₁ (0.940 kg/ha), respectively.

This investigation perhaps shall act as a guideline for irrigation management which will produce the most economical and best quality product. The present experiments deal with agrotechnology under water stressed conditions of one important essential oil yielding species of commerce growing in India viz. chamomile (*Matricaria chamomilla* L.).

In conclusion, it seems that the water management options are to employ cultural practices to increase the availability of stored soil moisture, to improve water-use efficiency, or to exploit other methods by which plants can yield reasonably well under water deficit conditions. Water deficits affect every aspect of plant growth, including the morphology, physiology and biochemistry. Economic effects of drought vary with species. In crops this may or may not be significant, depending upon whether the economic part of the crop is the vegetative or the reproductive portion.

Results of the experiments have shown showed that in *Matricaria chamomilla* L. var. Vallary showed drought resistance through viz. proline production and root/shoot ratio increased during the water stress conditions. Moreover, chamomile produced highest flower yield resulting in high essential oil yield and quality under water stress conditions. The study suggests that chamomile could be a crop of high aromatic values that could considered for commercial cultivation under dry land situation.

Matricaria chamomilla L. var. Vallary has low water needs. The data underline the fact that excessive watering decreases plant productivity, similarly water stress. Irrigation at 80% field capacity with lemon grass mulch is a suitable irrigation regime and mulching for *Matricaria chamomilla* L. var. Vallary in Bangalore condition; but when water supply is limited, irrigation at 60% field capacity may be practiced to produce components such as α -bisabolol oxide B and (Z)-En-yn-dicycloether.

The highlight of the study was that a major beneficial effect of the two kinds of mulches used (lemon grass mulch and plastic mulch) was revealed. The beneficial effects accrued from the lesser number of irrigation require both W₈₀ and W₆₀ treatments because of the significant moisture conservation. Also lemon grass mulch gave best results in chamomile cultivation on water stress condition.

The content of compounds with potential medicinal activity in plants can be affected dissimilarly by environmental factors. If a medicinal plant is grown in a controlled environmental system for improved phytochemical production, it will inherently involve a decision of which metabolite to target, knowing that such a decision will potentially result in a trade off, e.g., decreased levels of other key phytochemicals.

The oxygenated sesquiterpene compounds viz. α -Bisabolol oxide B, α -Bisabolol oxide A and α -Bisabolone oxide A of the essential oil increased with high levels of water stress (W₆₀ and W₈₀). However, a reduction of plant biomass (dry flower yield) would reduce the total yield of essential oils per hectare in W₆₀ compare to W₈₀. We suggest an approach to irrigation management where the processes of foliage development and terpenes accumulation are well balanced to achieve maximum oil yield and aromatic components.

These natural ingredients of high quality are likely to play an increase role in tomorrow's perfumery and flavour industries.

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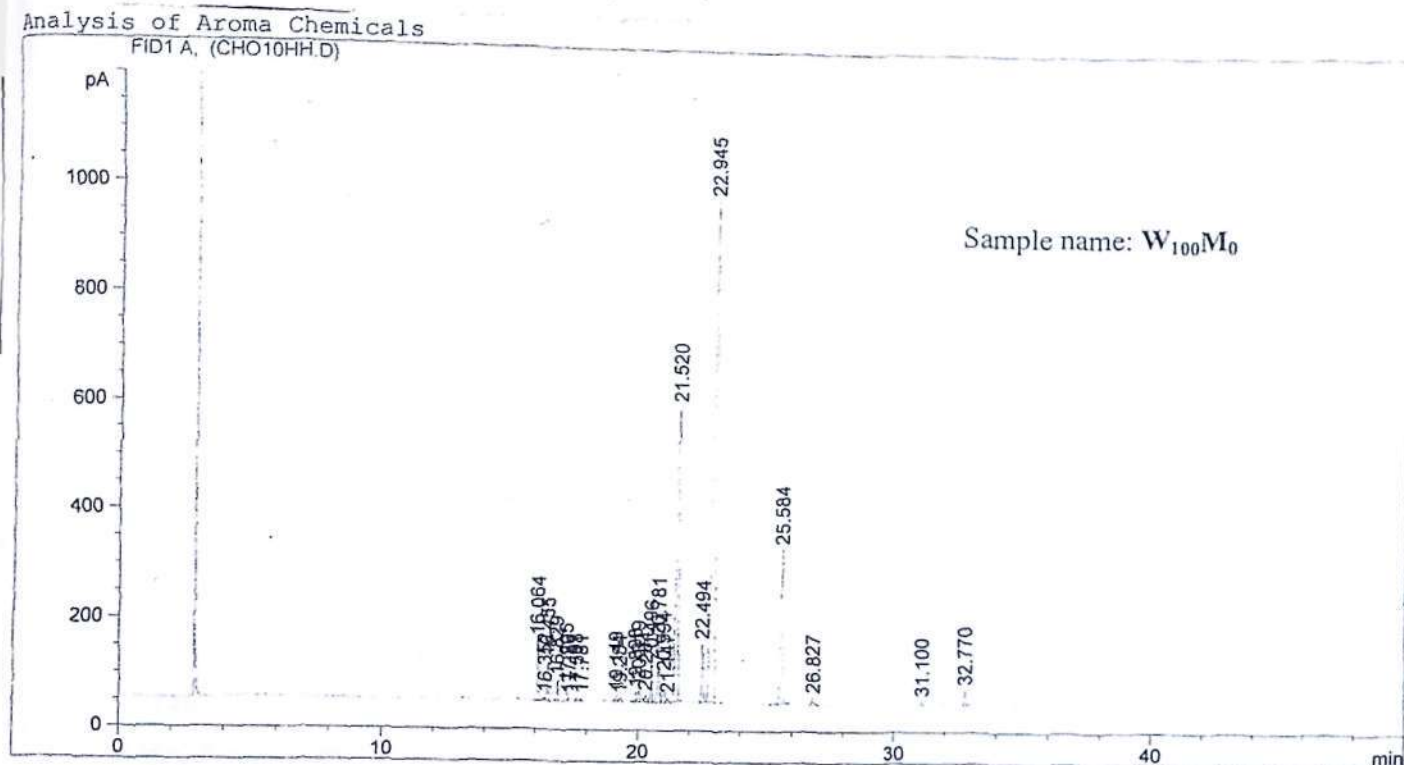
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Appendices

Appendix 1

GC results of chamomile essential oil (second year)



Area Percent Report

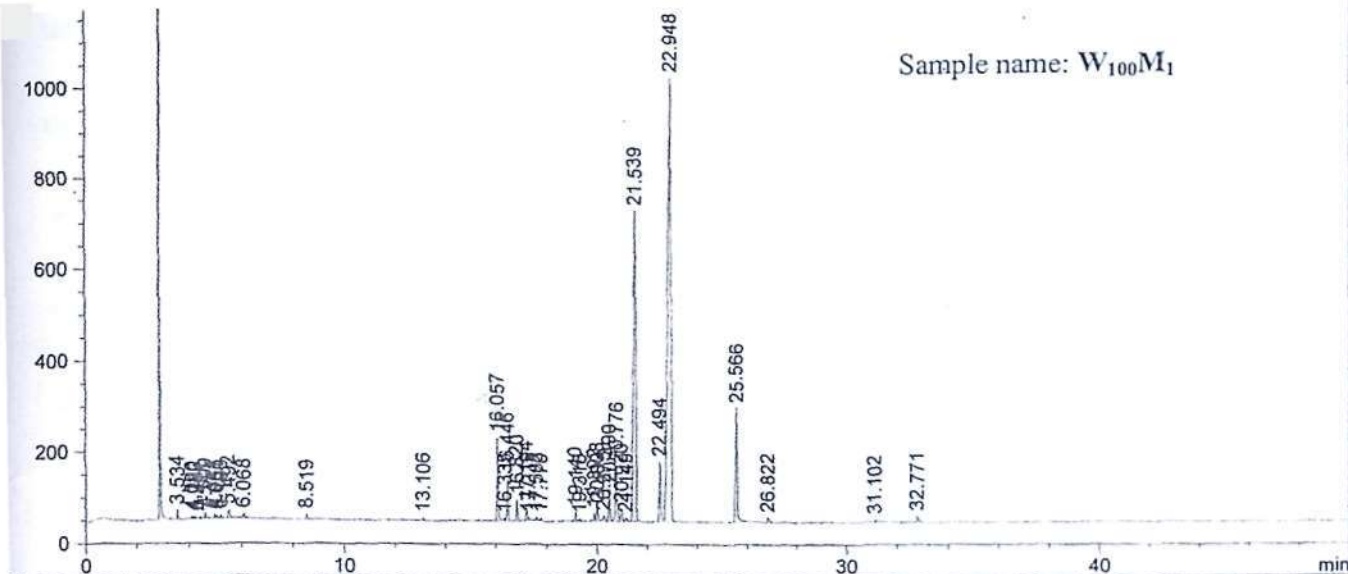
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Multiplier : 1.0000
Dilution : 1.0000
Use Multiplier & Dilution Factor with ISTDs

Signal 1: FID1 A,

Peak #	RetTime [min]	Type	Width [min]	Area [pA*s]	Height [pA]	Area %
1	16.064	BV	0.0560	408.46921	110.68842	2.62695
2	16.352	VV	0.0588	19.89782	5.01235	0.12797
3	16.455	VV	0.0511	237.14444	72.44408	1.52513
4	16.829	VV	0.0513	122.63293	37.77695	0.78868
5	17.205	BV	0.0527	84.14336	24.81943	0.54114
6	17.286	VV	0.0467	17.22611	5.66300	0.11078
7	17.593	VV	0.0560	23.87244	6.57775	0.15353
8	17.781	VB	0.0547	18.33102	5.13356	0.11789
9	19.149	VV	0.0526	37.52589	11.23147	0.24134
10	19.284	VV	0.0904	33.85582	5.40901	0.21773
11	19.898	VV	0.0578	64.89337	17.35729	0.41734
12	20.019	VV	0.0670	137.25656	31.42187	0.88273
13	20.284	VV	0.0770	65.79961	11.62237	0.42317
14	20.496	VV	0.0583	264.74640	70.95985	1.70264
15	20.781	VV	0.0661	517.21375	114.38406	3.32631
16	20.994	VV	0.0708	220.64368	49.22026	1.41901
17	21.147	VV	0.0728	40.86877	8.33104	0.26284
18	21.520	PV	0.0880	3308.61719	546.81989	21.27842
19	22.494	BV	0.0584	415.61856	107.99297	2.67293
20	22.945	VV	0.1170	7928.88965	930.31104	50.99238
21	25.584	BV	0.0689	1431.76880	286.09485	9.20801
22	26.827	BB	0.0728	57.48668	11.51036	0.36971
23	31.100	BB	0.0323	12.08307	5.78806	0.07771
24	32.770	BB	0.0448	80.17921	27.04086	0.51565

Totals : 1.55492e4 2503.61079

Sample name: W₁₀₀M₁



Area Percent Report

Sorted By : Signal
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Dilution : 1.0000
Use Multiplier & Dilution Factor with ISTDs

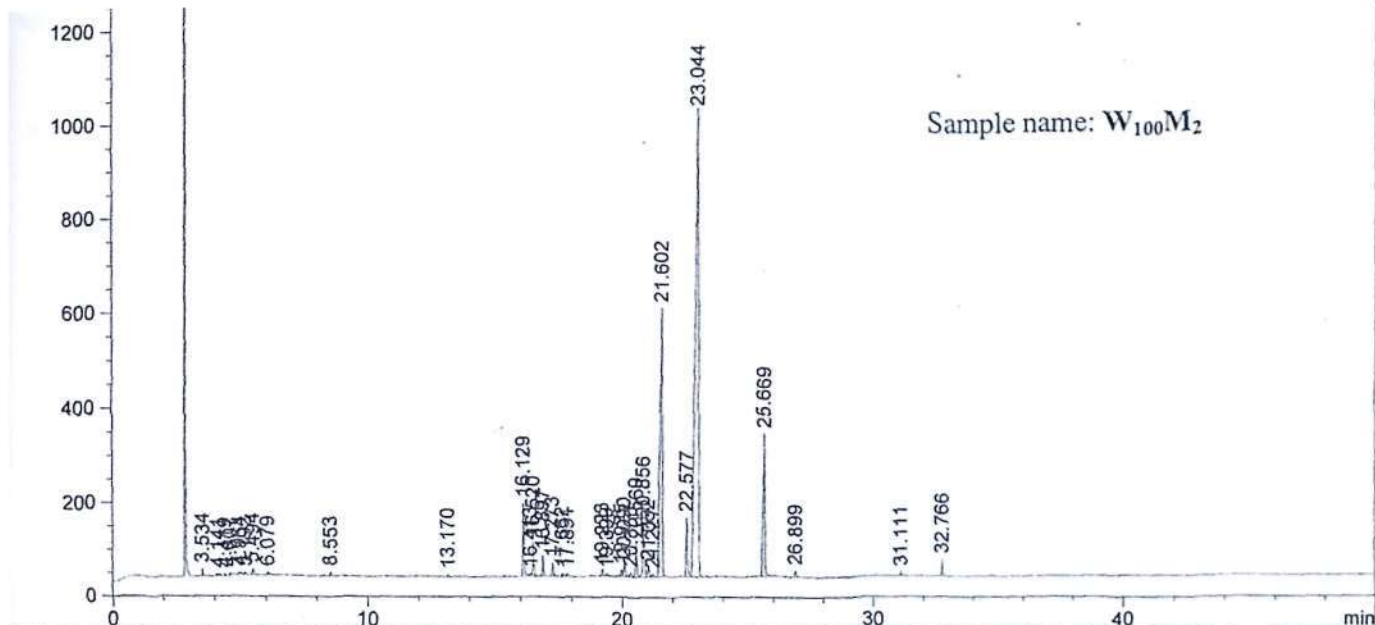
Signal 1: FID1 A,

Peak #	RetTime [min]	Type	Width [min]	Area [pA*s]	Height [pA]	Area %
1	3.534	BB	0.0890	51.75110	19.68214	0.28577
2	4.090	BV	0.0350	9.03020	5.23153	0.04987
3	4.140	VV	0.0467	16.05055	5.73305	0.08863
4	4.229	VV	0.0338	10.92729	5.38432	0.06034
5	4.421	PV	0.0523	13.35059	4.50833	0.07372
6	4.599	PV	0.0398	30.46807	11.34464	0.16825
7	4.963	BV	0.0491	26.71893	8.02300	0.14754
8	5.051	VV	0.0465	18.32368	5.56536	0.10118
9	5.190	VB	0.0584	31.82501	7.84864	0.17574
10	5.492	BB	0.0687	78.30549	16.97385	0.43241
11	6.068	BB	0.0645	40.07621	9.39124	0.22130
12	8.519	BB	0.0600	40.35762	10.37787	0.22286
13	13.106	BB	0.0550	19.59213	5.55177	0.10819
14	16.057	BV	0.0548	647.99786	183.85500	3.57830
15	16.335	VV	0.0577	25.23178	6.54766	0.13933
16	16.446	VV	0.0515	318.67621	97.19706	1.75976
17	16.820	VV	0.0515	154.78265	47.34353	0.85472
18	17.194	BV	0.0530	111.09007	32.56669	0.61345
19	17.275	VV	0.0514	21.67299	7.03152	0.11968
20	17.582	VV	0.0679	39.01198	8.30720	0.21543
21	17.770	VB	0.0565	25.60006	6.91308	0.14137
22	19.140	VV	0.0533	68.75639	20.56181	0.37968
23	19.316	PV	0.0692	26.60664	5.65779	0.14692
24	19.892	VV	0.0569	67.74933	18.33814	0.37412
25	20.008	VV	0.0642	137.53783	32.20575	0.75950
26	20.275	VV	0.0736	63.78798	12.20667	0.35224
27	20.490	VV	0.0604	281.69928	72.64183	1.55557
28	20.776	VV	0.0669	545.19226	122.25121	3.01060
29	20.970	VV	0.0682	134.07671	29.24787	0.74038
30	21.149	VV	0.0791	42.15493	7.95753	0.23278
31	21.539	PV	0.0854	4445.13184	690.44373	24.54641
32	22.494	BV	0.0605	521.49585	133.11337	2.87975
33	22.948	VV	0.1134	8682.11621	992.25800	47.94341
34	25.566	BB	0.0716	1240.59070	254.67422	6.85065
35	26.822	BB	0.0750	55.81316	10.67389	0.30821
36	31.102	BB	0.0729	13.85693	5.32227	0.07652
37	32.771	BB	0.0539	51.68518	13.90686	0.28541

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1.81091e4 2926.83841

Sample name: W₁₀₀M₂



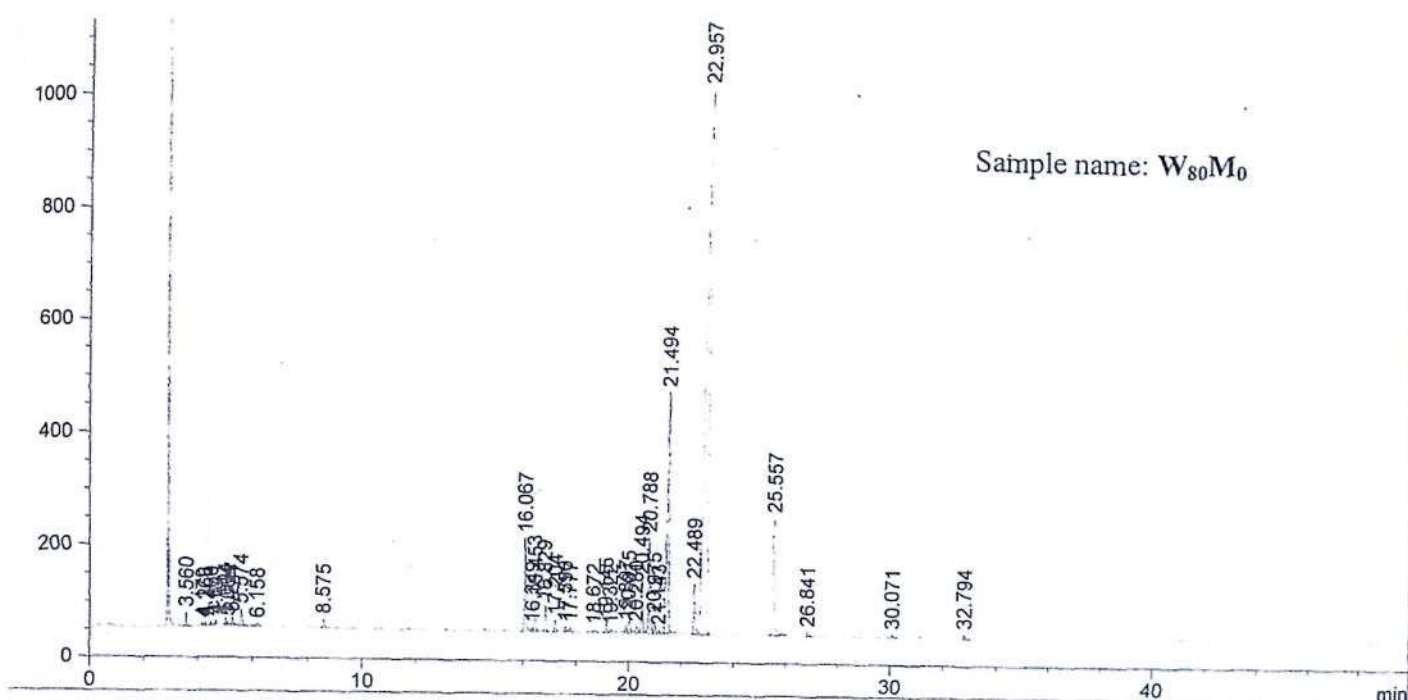
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Dilution : 1.0000
Use Multiplier & Dilution Factor with ISTDs

Signal 1: FID1 A,

Peak #	RetTime [min]	Type	Width [min]	Area [pA*s]	Height [pA]	Area %
1	3.534	BB	0.0907	40.83871	14.83538	0.22959
2	4.141	PV	0.0384	8.65871	3.75911	0.04868
3	4.419	BV	0.0363	10.91805	4.52176	0.06138
4	4.607	PV	0.0547	15.39218	4.69079	0.08653
5	4.964	BV	0.0482	19.49327	5.88907	0.10959
6	5.192	VB	0.0578	22.95165	5.76579	0.12903
7	5.494	BB	0.0698	62.71415	13.46053	0.35258
8	6.079	BB	0.0664	28.91741	6.55745	0.16257
9	8.553	BB	0.0593	33.31112	8.66244	0.18727
10	13.170	BB	0.0547	17.44674	5.01205	0.09808
11	16.129	BV	0.0551	574.48596	160.38190	3.22973
12	16.413	VV	0.0574	24.15382	6.33221	0.13579
13	16.520	VV	0.0523	244.69496	73.27171	1.37566
14	16.897	VV	0.0518	150.04930	45.73258	0.84357
15	17.273	BV	0.0523	98.09140	28.89593	0.55146
16	17.662	VV	0.0666	36.87347	8.10607	0.20730
17	17.851	VB	0.0599	24.63028	6.25144	0.13847
18	19.223	VV	0.0536	52.84545	15.60396	0.29709
19	19.399	PV	0.0675	24.88296	5.56610	0.13989
20	19.975	VV	0.0577	54.44965	14.58632	0.30611
21	20.090	VV	0.0691	129.13835	28.56532	0.72601
22	20.356	VV	0.0727	53.91002	10.35923	0.30308
23	20.569	VV	0.0592	271.72461	71.70584	1.52762
24	20.856	VV	0.0671	525.60004	118.03447	2.95489
25	21.052	VV	0.0655	106.84110	24.73391	0.60065
26	21.227	VV	0.0754	35.39008	6.98475	0.19896
27	21.602	PV	0.0874	3580.73071	578.13092	20.13066
28	22.577	BV	0.0598	501.75006	128.12990	2.82081
29	23.044	VV	0.1211	9287.40039	999.92853	52.21324
30	25.669	PV	0.0734	1571.69189	308.99689	8.83596
31	26.899	BB	0.0672	65.86475	14.50332	0.37029
32	31.111	BB	0.0503	16.24035	8.87699	0.09130
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Area Percent Report

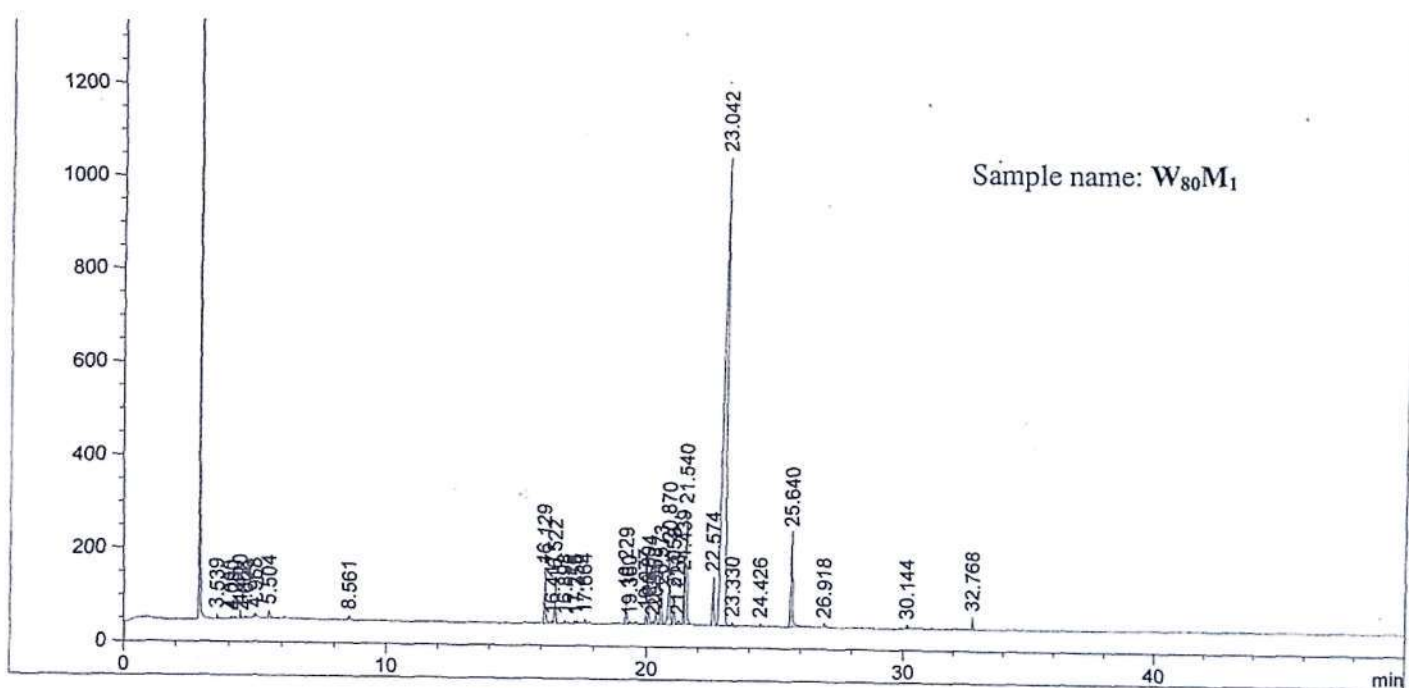
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1	3.560	BB	0.0659	54.48693	24.54816	0.34594
2	4.179	VV	0.0482	11.93815	4.12638	0.07580
3	4.266	VV	0.0291	10.98769	5.83624	0.06976
4	4.460	VV	0.0322	14.17310	6.74962	0.08999
5	4.641	PV	0.0575	24.80469	8.57245	0.15749
6	5.004	BV	0.0509	34.62270	11.34426	0.21982
7	5.084	VV	0.0519	16.13631	5.18177	0.10245
8	5.247	VV	0.0597	52.59918	12.77170	0.33396
9	5.574	PB	0.0631	123.11110	29.25793	0.78165
10	6.158	BB	0.0633	19.62849	4.71913	0.12462
11	8.575	BB	0.0580	57.46448	15.15793	0.36485
12	16.067	BV	0.0548	603.98828	168.15193	3.83479
13	16.349	VV	0.0586	26.01567	6.62269	0.16518
14	16.453	VV	0.0511	178.60648	54.36531	1.13399
15	16.829	VV	0.0504	147.56598	46.09835	0.93691
16	17.204	BV	0.0534	73.27720	21.41416	0.46524
17	17.590	VV	0.0552	33.50814	9.29619	0.21275
18	17.777	VB	0.0563	28.16471	7.64495	0.17882
19	18.672	BB	0.0926	27.59908	4.43103	0.17523
20	19.145	VV	0.0521	55.12137	16.70545	0.34997
21	19.322	PV	0.0715	21.95105	4.59111	0.13937
22	19.897	VV	0.0587	48.46635	12.60805	0.30772
23	20.015	VV	0.0685	132.54280	29.47708	0.84153
24	20.280	VV	0.0851	62.21624	10.92554	0.39502
25	20.494	VV	0.0577	352.97922	95.64664	2.24110
26	20.788	VV	0.0647	740.25378	174.07703	4.69995
27	20.975	VV	0.0595	110.51837	28.28629	0.70169
28	21.143	VV	0.0707	27.11786	5.59004	0.17217
29	21.494	PV	0.0736	2285.78271	434.05566	14.51268
30	22.489	BV	0.0623	374.19553	90.81418	2.37581
31	22.957	VV	0.1184	8928.83789	980.68805	56.69017
32	25.557	BB	0.0655	960.69989	212.95129	6.09959
33	26.841	BB	0.0812	44.86117	7.97952	0.28483
34	30.071	BB	0.0775	27.79248	5.38325	0.17646
35	32.794	BB	0.0645	38.22621	8.36064	0.24270

Tals :

1.57502e4 2564.43001



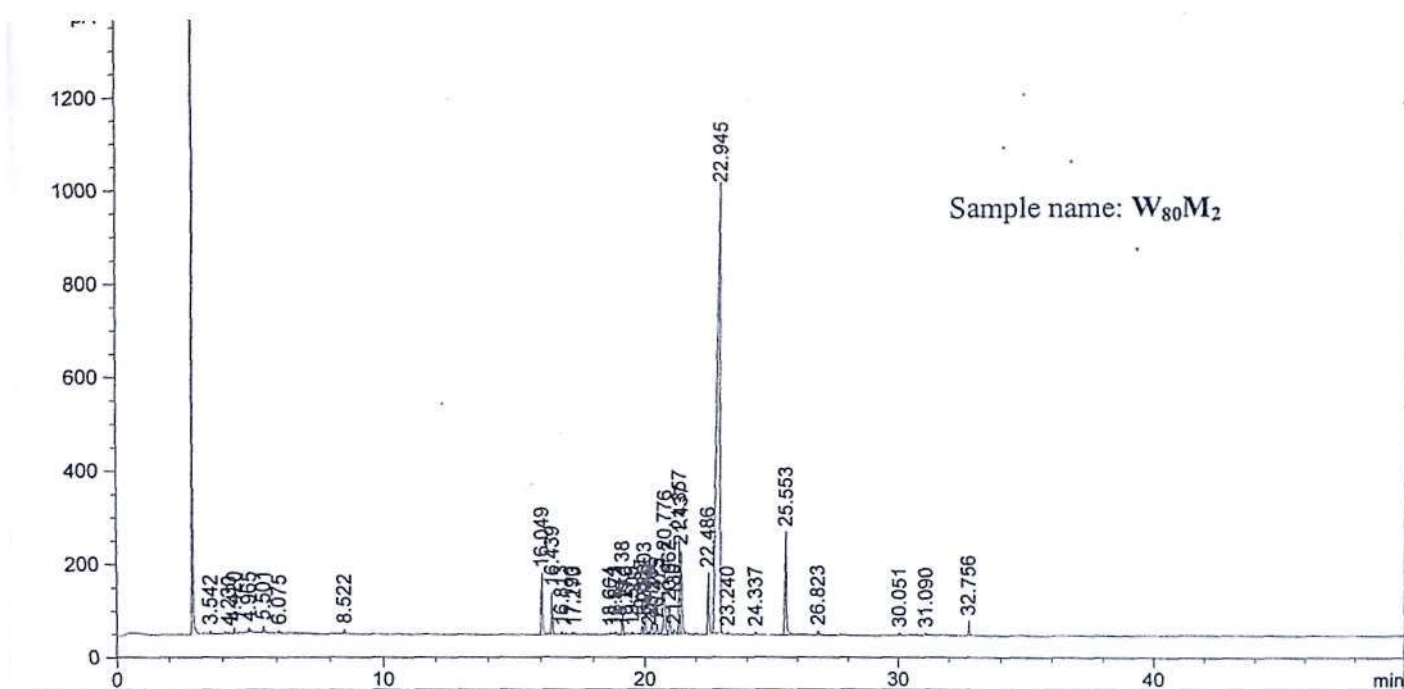
Area Percent Report

Sorted By : Signal
Multiplier : 1.0000
Dilution : 1.0000
Use Multiplier & Dilution Factor with ISTDs

Signal 1: FID1 A,

Peak #	RetTime [min]	Type	Width [min]	Area [pA*s]	Height [pA]	Area %
1	3.539	BB	0.0412	28.38013	9.90665	0.19168
2	4.090	VV	0.0381	8.50224	5.26955	0.05742
3	4.230	VB	0.0460	9.83549	5.02752	0.06643
4	4.420	BV	0.0434	35.80688	17.44872	0.24184
5	4.606	PB	0.0403	12.34794	4.42963	0.08340
6	4.968	BV	0.0515	21.30565	7.01530	0.14390
7	5.504	BB	0.0655	68.77710	15.69893	0.46452
8	8.561	BB	0.0604	37.41230	9.51882	0.25268
9	16.129	BV	0.0551	416.30115	115.45708	2.81167
10	16.417	VV	0.0572	24.87946	6.52160	0.16803
11	16.522	VV	0.0522	278.27625	83.56840	1.87946
12	16.898	VV	0.0525	22.54607	6.77015	0.15227
13	17.276	BV	0.0550	22.43962	6.26212	0.15156
14	17.358	VV	0.0508	18.53556	5.67273	0.12519
15	17.664	BV	0.0525	27.03242	8.15642	0.18258
16	19.229	BV	0.0514	218.03203	66.45731	1.47257
17	19.360	VV	0.0674	23.48978	5.18998	0.15865
18	19.977	VV	0.0562	70.94471	19.64029	0.47916
19	20.094	VV	0.0536	174.38736	50.58811	1.17780
20	20.257	VV	0.0640	27.50748	6.55030	0.18578
21	20.358	VV	0.0623	96.00330	22.97722	0.64840
22	20.573	VV	0.0582	273.36319	73.14495	1.84628
23	20.870	VV	0.0636	711.77509	168.26257	4.80728
24	21.058	VV	0.0594	251.25380	66.44395	1.69695
25	21.223	VV	0.0758	49.72228	9.12293	0.33582
26	21.439	PV	0.0499	344.23264	105.77448	2.32492
27	21.540	VV	0.0606	998.23218	251.19090	6.74199
28	22.574	BV	0.0630	433.49237	104.67629	2.92778
29	23.042	VV	0.1106	8940.06445	1020.94659	60.38060
30	23.330	VB	0.0748	35.51507	7.01285	0.23987
31	24.426	BB	0.0545	23.24354	6.43603	0.15699
32	25.640	BB	0.0698	943.69598	206.80766	6.37366
33	26.918	BB	0.0783	45.89865	8.35671	0.31000
34	30.144	BB	0.0644	31.30969	7.63240	0.21146
35	32.768	BB	0.0432	81.64594	28.35252	0.55143

Totals : 1.48062e4 2542.28766

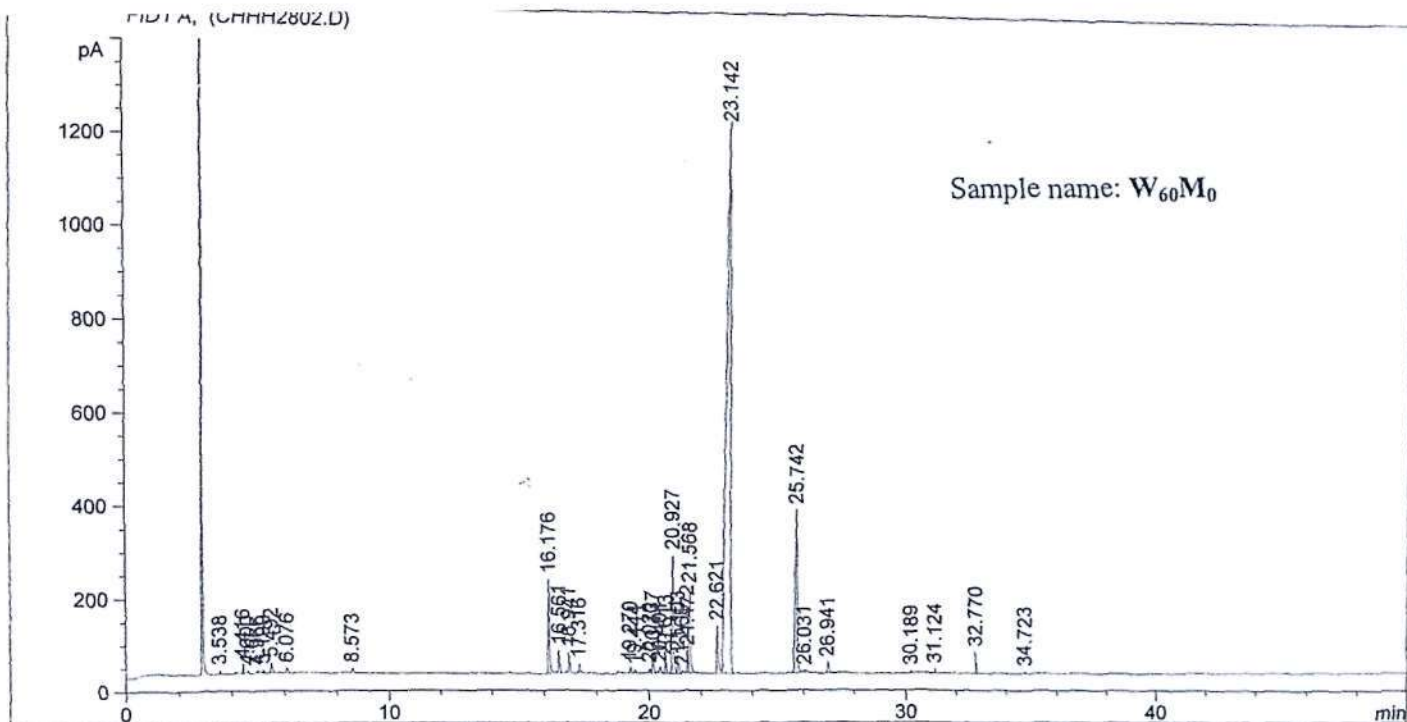


Area Percent Report

Sorted By : Signal
Multiplier : 1.0000
Dilution : 1.0000
Use Multiplier & Dilution Factor with ISTDs

Signal 1: FID1 A,

Peak #	RetTime [min]	Type	Width [min]	Area [pA*s]	Height [pA]	Area %
1	3.542	BB	0.0610	17.17352	6.03553	0.11732
2	4.230	VB	0.0508	10.68989	4.14943	0.07303
3	4.420	BV	0.0324	27.83944	13.30064	0.19018
4	4.965	BV	0.0445	25.13783	9.41772	0.17173
5	5.501	BV	0.0654	59.83916	13.54000	0.40878
6	6.075	BB	0.0684	24.94834	5.47538	0.17043
7	8.522	BB	0.0643	37.61730	8.81689	0.25698
8	16.049	BV	0.0558	482.70450	133.98222	3.29754
9	16.439	VV	0.0508	300.82193	92.19647	2.05503
10	16.813	PV	0.0512	21.06916	6.45069	0.14393
11	17.190	BV	0.0525	19.27446	5.65973	0.13167
12	17.273	VV	0.0507	18.79871	5.74655	0.12842
13	18.664	VV	0.0735	22.11389	4.57589	0.15107
14	18.872	VV	0.0828	37.48870	6.45804	0.25610
15	19.138	VV	0.0526	205.26515	61.02709	1.40224
16	19.270	VV	0.0795	28.75558	5.11221	0.19644
17	19.505	VV	0.0620	22.21667	5.36028	0.15177
18	19.887	VV	0.0560	69.84232	19.35678	0.47712
19	20.003	VV	0.0543	201.28261	57.83570	1.37504
20	20.166	VV	0.0595	27.43723	6.78277	0.18743
21	20.265	VV	0.0618	106.39683	25.74183	0.72684
22	20.475	VV	0.0643	98.91546	23.02532	0.67573
23	20.776	VV	0.0610	699.60101	170.89705	4.77924
24	20.962	VV	0.0609	233.68831	59.60376	1.59641
25	21.130	VV	0.0722	48.24680	9.40563	0.32959
26	21.357	PV	0.0539	761.47308	214.01442	5.20191
27	21.437	VV	0.0551	658.29968	181.31749	4.49709
28	22.486	BV	0.0579	502.33478	133.46399	3.43164
29	22.945	VV	0.1185	8602.54590	966.86145	58.76725
30	23.240	BB	0.0681	21.63538	5.07932	0.14780
31	24.337	BB	0.0571	23.19086	6.10219	0.15843
32	25.553	BB	0.0728	1043.80371	224.36555	7.13062
33	26.823	BB	0.0731	46.69597	9.30919	0.31900
34	30.051	BV	0.0787	29.94126	5.89031	0.20454
35	31.090	BB	0.0547	9.01740	4.48178	0.06160
36	32.756	BB	0.0431	92.23053	32.30785	0.63006



Area Percent Report

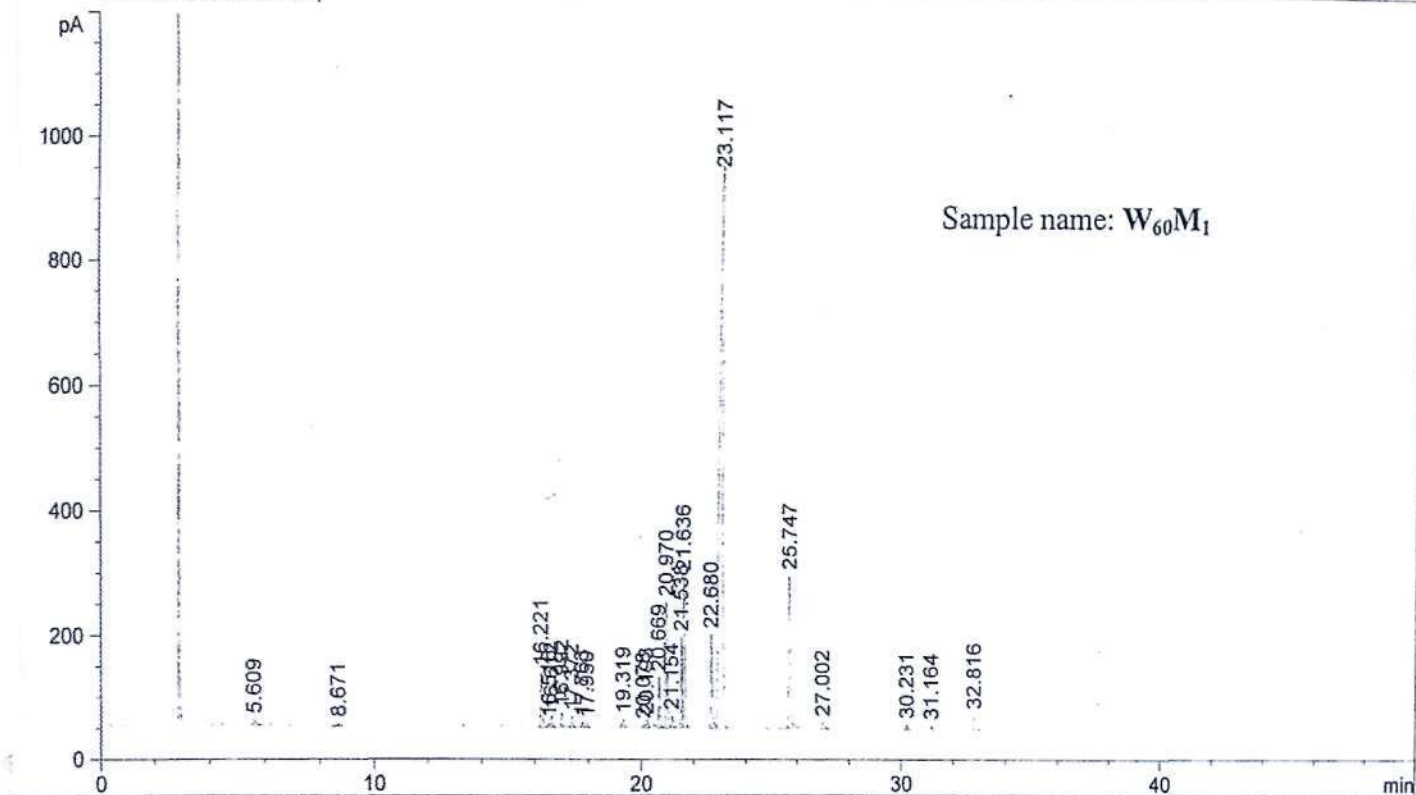
Sorted By : Signal
Multiplier : 1.0000
Dilution : 1.0000
Use Multiplier & Dilution Factor with ISTDs

Signal 1: FID1 A,

Peak #	RetTime [min]	Type	Width [min]	Area [pA*s]	Height [pA]	Area %
1	3.538	BB	0.0415	22.46186	7.84275	0.11356
2	4.416	BV	0.0439	39.83186	20.11448	0.20138
3	4.600	PV	0.0439	17.11149	5.55367	0.08651
4	4.966	BV	0.0483	15.45513	4.57294	0.07814
5	5.190	VB	0.0584	24.17690	6.00271	0.12223
6	5.492	BB	0.0646	88.68530	20.72238	0.44837
7	6.076	BB	0.0648	42.79510	10.03779	0.21636
8	8.573	VB	0.0644	39.36325	9.16902	0.19901
9	16.176	BV	0.0545	728.25330	206.62036	3.68184
10	16.561	VB	0.0518	165.65402	50.13735	0.83750
11	16.941	VV	0.0517	144.66661	44.13893	0.73139
12	17.316	BV	0.0472	55.18644	19.12897	0.27901
13	19.270	VV	0.0530	46.96691	13.89443	0.23745
14	19.444	PV	0.0637	29.60289	6.98962	0.14966
15	20.020	BV	0.0527	33.29916	9.99182	0.16835
16	20.137	VV	0.0598	138.98447	35.60235	0.70267
17	20.401	VV	0.0649	62.13378	13.92321	0.31413
18	20.613	VV	0.0587	108.49169	28.84842	0.54850
19	20.927	VV	0.0618	1072.32300	259.13739	5.42136
20	21.103	VV	0.0620	151.61935	38.36452	0.76654
21	21.265	VV	0.0669	26.12079	5.65080	0.13206
22	21.472	PV	0.0490	155.72491	48.87760	0.78730
23	21.568	VV	0.0577	705.95856	184.95520	3.56912
24	22.621	BV	0.0662	453.72437	104.99520	2.29390
25	23.142	VV	0.1457	1.30433e4	1189.30115	65.94320
26	25.742	BV	0.0862	2052.78174	356.88321	10.37828
27	26.031	VV	0.1246	43.83503	4.82295	0.22162
28	26.941	BB	0.0622	100.38181	23.90298	0.50750
29	30.189	BB	0.0561	18.73437	5.18678	0.09472
30	31.124	BB	0.0481	16.64563	9.34961	0.08416
31	32.770	BB	0.0377	116.43640	48.45852	0.58867
32	34.723	BB	0.0552	18.89386	5.18677	0.09552

Totals :

1.97796e4 2798.36390



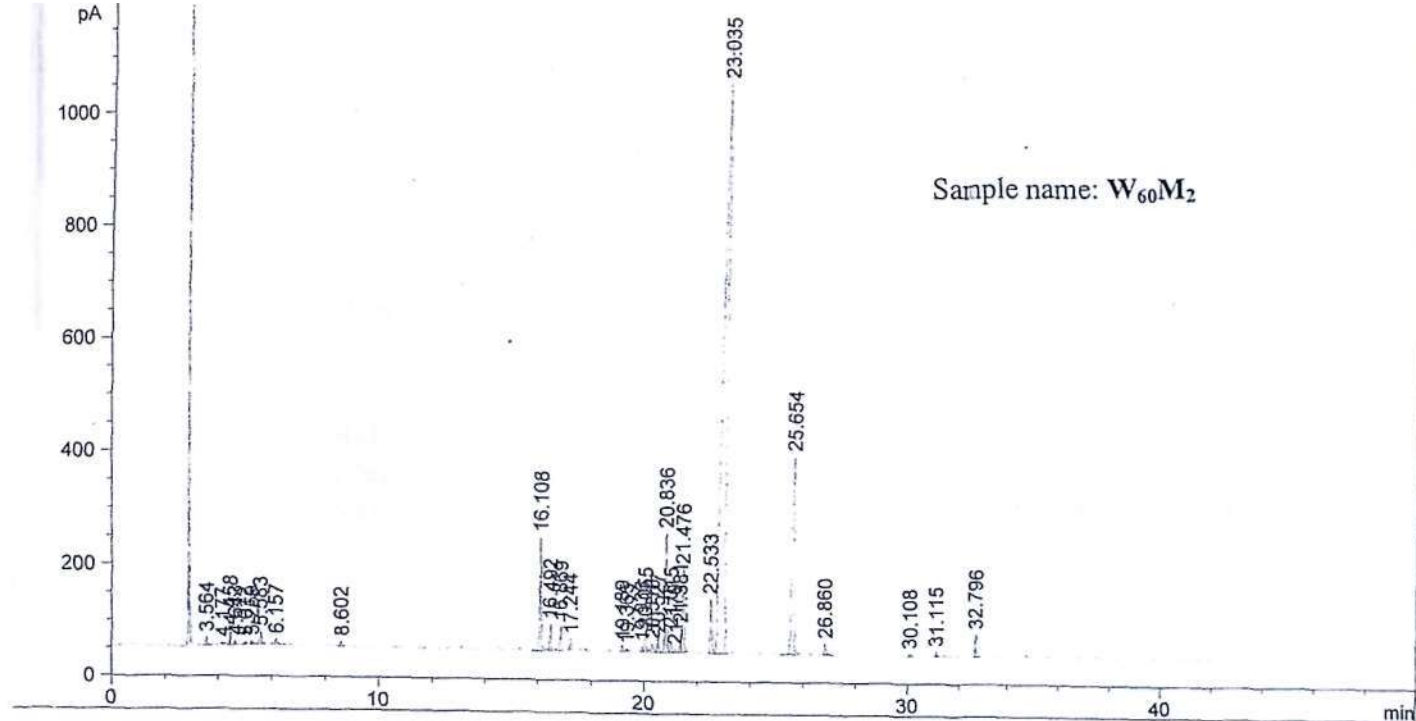
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 Area Percent Report
 =====

Sorted By : Signal
 Multiplier : 1.0000
 Dilution : 1.0000
 Use Multiplier & Dilution Factor with ISTDs

Signal 1: FID1 A,

Peak #	RetTime [min]	Type	Width [min]	Area [pA*s]	Height [pA]	Area %
1	5.609	BB	0.0754	41.61633	7.99653	0.31711
2	8.671	BB	0.0677	20.16234	4.42597	0.15364
3	16.221	BV	0.0598	359.92426	90.82645	2.74259
4	16.516	VV	0.0593	25.09789	6.29190	0.19124
5	16.612	VB	0.0540	68.65344	19.40086	0.52313
6	16.992	VV	0.0528	79.75792	23.75360	0.60775
7	17.372	BV	0.0575	66.67382	17.58411	0.50805
8	17.763	VV	0.0616	33.53973	8.12223	0.25557
9	17.950	VB	0.0555	23.26721	6.45973	0.17729
10	19.319	VV	0.0741	69.39149	13.37676	0.52876
11	20.078	VV	0.0656	23.26737	5.37038	0.17730
12	20.193	VV	0.0791	64.90675	12.33331	0.49458
13	20.669	VV	0.0551	292.20343	83.22973	2.22657
14	20.970	VV	0.0643	862.11737	205.54439	6.56927
15	21.154	VV	0.0615	77.45663	19.42923	0.59021
16	21.538	PV	0.0507	494.59897	148.45392	3.76881
17	21.636	VV	0.0613	948.95715	246.81396	7.23098
18	22.680	BV	0.0609	611.72803	154.34306	4.66132
19	23.117	VV	0.1067	7622.33398	907.69183	58.08159
20	25.747	BV	0.0648	1160.99158	251.64201	8.84667
21	27.002	BB	0.0738	57.16822	11.25150	0.43562
22	30.231	BB	0.0557	29.09675	8.00121	0.22171
23	31.164	BB	0.0342	12.20205	5.46934	0.09298
24	32.816	BB	0.0486	78.38098	23.65083	0.59726

Totals : 1.31235e4 2281.46284



Area Percent Report

Sorted By : Signal
Multiplier : 1.0000
Dilution : 1.0000
Use Multiplier & Dilution Factor with ISTDs

Signal 1: FID1 A,

Peak #	RetTime [min]	Type	Width [min]	Area [pA*s]	Height [pA]	Area %
1	3.564	BB	0.0585	39.32572	14.32175	0.22193
2	4.177	PV	0.0369	8.57045	3.86589	0.04837
3	4.458	BV	0.0414	46.55848	25.71107	0.26274
4	4.643	PV	0.0455	22.83268	8.35977	0.12885
5	5.012	BV	0.0456	13.18801	4.31982	0.07442
6	5.259	PB	0.0634	27.08194	6.20309	0.15283
7	5.583	BB	0.0618	91.16292	22.10276	0.51446
8	6.157	BB	0.0625	36.61827	8.92132	0.20665
9	8.602	BB	0.0610	32.84673	8.16424	0.18536
10	16.108	BV	0.0545	731.44904	205.42955	4.12776
11	16.492	VV	0.0521	160.17421	47.98172	0.90391
12	16.869	VV	0.0512	143.72357	44.29532	0.81107
13	17.244	BV	0.0480	57.91768	19.36855	0.32684
14	19.189	VV	0.0514	36.54084	11.17398	0.20621
15	19.365	PV	0.0656	23.60790	5.36183	0.13323
16	19.936	BV	0.0518	32.09155	9.78381	0.18110
17	20.055	VV	0.0613	138.89851	34.78753	0.78384
18	20.318	VV	0.0699	71.30219	14.46198	0.40238
19	20.527	VV	0.0576	95.48386	25.69152	0.53884
20	20.836	VV	0.0637	870.67371	216.59755	4.91344
21	21.015	VV	0.0610	141.24544	36.37369	0.79709
22	21.179	VV	0.0651	25.21215	5.64199	0.14228
23	21.381	PV	0.0544	143.02467	43.81378	0.80713
24	21.476	VV	0.0572	570.21680	150.83820	3.21788
25	22.533	BV	0.0639	415.87973	98.59871	2.34692
26	23.035	VV	0.1295	1.14415e4	1144.70776	64.56721
27	25.654	BV	0.0840	2065.68799	358.81592	11.65722
28	26.860	BB	0.0672	93.11739	20.32952	0.52549
29	30.108	BV	0.0709	20.94924	4.46925	0.11822
30	31.115	BB	0.0564	15.02924	7.65201	0.08481
31	32.796	BB	0.0719	108.36710	40.91735	0.61154

Totals : 1.77202e4 2649.06125

APPENDIX - II

Meteorological characteristics during the first year cultivation (2008-2009).

	Total rain fall (mm)	Rainy days (No)	PET (mm)	Temperature		SSH (hrs)	WS (km/hr)	Rel. hum. (%)		Evp. (mm)
				Max	Min			I hr	II hr	
Nov	20.6	5	3.1	26.8	15.8	6.6	6.1	92	53	4.6
Dec	1.8	0	3.1	26.8	14.7	8.2	5.2	94	49	4.5
Jan	0	0	3.2	27.6	12.2	9.0	4.9	92	38	4.3
Feb	0	0	4.1	30.8	14.2	9.9	5.3	88	32	4.9
March	10.2	1	4.6	32.7	17.4	8.2	5.0	89	31	5.2

Meteorological characteristics during the second year cultivation (2009-2010).

	Total rain fall (mm)	Rainy days (No)	PET (mm)	Temperature		SSH (hrs)	WS (km/hr)	Rel. hum. (%)		Evp. (mm)
				Max	Min			I hr	II hr	
Nov	49.4	5	3.3	27.0	17.7	6.7	6.2	94	55	3.9
Dec	11.0	1	3.1	26.8	16.3	5.7	7.8	92	54	4.2
Jan	0	0	3.4	27.5	15.0	8.3	7.4	92	48	4.5
Feb	0	0	4.3	31.1	15.7	9.8	6.6	90	38	5.4
March	34.2	1	5.0	34.2	18.7	8.3	6.5	85	34	7.9

Appendices

APPENDIX - II

Meteorological characteristics during the first year cultivation (2008-2009).

	Total rain fall (mm)	Rainy days (No)	PET (mm)	Temperature		SSH (hrs)	WS (km/hr)	Rel. hum. (%)		Evp. (mm)
				Max	Min			I hr	II hr	
Nov	20.6	5	3.1	26.8	15.8	6.6	6.1	92	53	4.6
Dec	1.8	0	3.1	26.8	14.7	8.2	5.2	94	49	4.5
Jan	0	0	3.2	27.6	12.2	9.0	4.9	92	38	4.3
Feb	0	0	4.1	30.8	14.2	9.9	5.3	88	32	4.9
March	10.2	1	4.6	32.7	17.4	8.2	5.0	89	31	5.2

Meteorological characteristics during the second year cultivation (2009-2010).

	Total rain fall (mm)	Rainy days (No)	PET (mm)	Temperature		SSH (hrs)	WS (km/hr)	Rel. hum. (%)		Evp. (mm)
				Max	Min			I hr	II hr	
Nov	49.4	5	3.3	27.0	17.7	6.7	6.2	94	55	3.9
Dec	11.0	1	3.1	26.8	16.3	5.7	7.8	92	54	4.2
Jan	0	0	3.4	27.5	15.0	8.3	7.4	92	48	4.5
Feb	0	0	4.3	31.1	15.7	9.8	6.6	90	38	5.4
March	34.2	1	5.0	34.2	18.7	8.3	6.5	85	34	7.9