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Review

Medicinal and aromatic plants farming under drought conditions

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Drought stress is especially important in countries where crop agriculture is essentially rain-fed. Drought stress causes an increase in solute concentration in the environment, leading to an osmotic flow of water out of plant cells. This in turn causes the solute concentration inside plant cells to increase, thus lowering water potential and disrupting membranes along with essential processes like photosynthesis. These drought-stressed plants consequently exhibit poor growth and yield. In worst case scenarios, the plants completely die. Certain plants have devised mechanisms to survive under low water conditions. These mechanisms have been classified as tolerance, avoidance or escape. Also, medicinal and aromatic plants have been an integral part of our daily life for thousands of years. There are cave paintings in which medicinal and aromatic herbs are depicted. To this day, modern research continues to discover health benefits of plants while illustrating the importance of preserving our ecosystem. This review may give applicable advice to commercial farmers and medicinal and aromatic plants researches for management and proper use of water in medicinal and aromatic plants farming under drought conditions and increases quantity and quality characteristics of medicinal and aromatic plants in arid and semi-arid areas.

Key words: Drought conditions, tillage system, essential oil content, water use efficiency, nitrate reductase activity, proline accumulation, medicinal and aromatic plants farming.

INTRODUCTION

Drought stress is one of the most important environmental stresses affecting agricultural productivity around the world and may result in considerable yield reductions (Boyer, 1982; Ludlow and Muchow, 1990). Drought resistance refers to a plant's ability to grow and reproduce satisfactorily under drought conditions, and drought acclimation refers to a plant's ability to slowly modify its structure and function so that it can better tolerate drought (Turner, 1986). Apart from the effect of drying soil on the transport of nutrients to plant roots, the morphological and physiological mechanisms involved in cellular and whole plant responses to water stress are of considerable interest and are frequently examined (Hsiao, 1973; Levitt, 1980; Blum, 1988; Davies and Zhang, 1991; Smith and Griffiths, 1993; Close and Bray, 1993; Kramer and Boyer, 1995; Neumann, 1995). A strategy for improving medicinal and aromatic plants yields is to identify the production compounds practices that are relatively drought resistant and that will result in superior yields under dryland conditions (Popp et al., 2002). Therefore, the objective of this review was to identify the water deficit stress damages in medicinal and aromatic plants farming under drought conditions.

Till-system in medicinal and aromatic plants farming under drought conditions

Tillage systems can impact soil moisture status because tillage influences infiltration, runoff, evaporation and soil water storage. With conventional tillage, weeds that compete with medicinal and aromatic plants for moisture and

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other growth resources are mechanically removed. On the other hand, conventional tillage can promote drought stress through low residue cover, increased runoff, and reduced water infiltration (Dao,1993; Unger and Cassel, 1991; Unger and Fulton,1989).Tillage systems management influence soil chemical properties that can impact the long-term sustainability of dryland production systems. No-till (NT) and minimum-till (MT) systems are effective steps in efficiently saving more precipitation for medicinal and aromatic plants production (Tarkalson et al., 2006).Peterson et al. (1996) and McGee et al. (1997) pointed out that MT and NT fallow systems have a high soil water percentage in the profile recharged by the first spring following harvest. Annual increases in residue production within a cropping system and/or decreased tillage frequencies maintain soil organic carbon levels or even increase them with time, depending on the quantity and types of residue input to the soil (Larson et al., 1972; Rasmussen et al., 1980; Rasmussen and Rohde, 1988; Havlin et al., 1990; Peterson et al., 1998). Lal et al. (1998) have pointed out that general adoption of best management practices by farmers on cropland may help reverse the atmospheric enrichment of CO_2 resulting by sequestering carbon (C) in soil. Furthermore, converting to a no-till system and cropping more intensively can contribute to an improved environment by decreasing wind erosion and decreasing the atmospheric dust load (Fryrear, 1985; Papendick and Saxton, 1997). Tillage treatments in study of Kucharski and Mordaiski (2008) were conventional till (CT), MT, and NT. Their results showed that highest production of *Coriandrum sativum* L. was achieved under MT. Also, in an experiment that was carried out in Iran, with the cultivation of *Thymus vulgaris*, for CT and NT systems. The cultivation systems increase the soil bulk density and reduce total porosity, microporosity, water retention and availability, the CT reduces aggregate stability, whereas NT, after two years, increases it. The bulk density, macroporosity, organic carbon content and aggregate stability are good indicators of the changes observed in the soil management systems (Lebaschi, 2009). Reducing tillage with herbicidal weed control and intensifying the cropping system also has the potential to increase soil organic carbon (Campbell and Zentner, 1997; Halvorson et al., 2002; Havlin et al., 1990; Havlin and Kissel, 1997; Rasmussen and Smiley, 1997; Peterson et al., 1998). Consequently, farmer sand researchers most use a capable till-system for contribute to protect soil water in medicinal and aromatic plants farming under drought conditions.

Medicinal and aromatic plants growth under drought conditions

The effect of drought stress on medicinal and aromatic plants growth and development has been studied lowly. The results were indicated that water deficit during the vegetative period (before flowering stage) can result in shorter plants and smaller leaf areas of mint (Abbaszadeh et al., 2008), yarrow (Sharifi Ashoorabadi et al., 2005) and chicory (Taheri et al., 2008), reduced water use due to the reduction in plant size of calendula (Rahmani et al., 2008), decreased vegetative dry matter of balm (Aliabadi et al., 2009). Drought stress reduces yield of medicinal and aromatic plants by three main mechanisms: First, whole canopy absorption of incident photosynthetically active radiation may be reduced, either by drought-induced limitation of leaf area expansion, by temporary leaf wilting or rolling during periods of severe stress, or by early leaf senescence. Second, drought stress decreased the efficiency with which absorbed photosynthetically active radiation is used by the crop to produce new dry matter (the radiation use efficiency). This can be detected as a decrease in the amount of crop dry matter accumulated per unit of photosynthetically active radiation absorbed over a given period of time, or as a reduction in the instantaneous whole-canopy net CO_2 exchange rate per unit absorbed photosynthetically active radiation. Third, drought stress may limit grain yield of medicinal and aromatic plants by reducing the harvest index (HI). This can occur even in the absence of a strong reduction in total medicinal and aromatic plants dry matter accumulation, if a brief period of stress coincides with the critical developmental stage around flowering (Earl and Davis, 2003). Water deficit during the reproductive period can decrease the interval from seed formation to pollen shed and shorten the grain filling period. There also is a large amount of literature on the effect of water deficit on different medicinal and aromatic plants yields components (Barnabas et al., 2007). The numerous studies were indicated that grain yield can be drastically reduced as a result of water deficit during the reproductive period of coriander (Aliabadi et al., 2008), Mexican marigold (Mohamed et al., 2002) and grapevine (Scalabrelli et al., 2007). This grain yield reduction has been attributed to reduced grain number, grain weight, or both. Sinclair et al. (1990) attributed the greater sensitivity of grain yield to water deficit at anthesis to this stage also being the period of maximum biomass accumulation and water use. Consequently, drought stress reduced vegetative growth period and plant move to flowering stage. Therefore, quantity characteristics of medicinal and aromatic plants decreased under drought conditions sorely.

Essential oil content of medicinal and aromatic plants under drought conditions

An essential oil is a concentrated, hydrophobic liquid containing volatile aroma compounds from some plants. Essential oils do not as a group needs to have any specific chemical properties in common, beyond conveying characteristic fragrances. They are not to be confused with essential fatty acids. Essential oils are generally extracted by distillation. Other processes include expression or solvent extraction. They are used in perfumes, cosmetics and bath products, for flavoring food and drink, and for scenting incense and household cleaning products (Sellar, 2001). Drought stress increases the essential oil percentage of more medicinal and aromatic plants, because in case of stress, more metabolites are produce in the plants and substances prevent from oxidization in the cells, but essential oil content reduce under drought stress, because the interaction between the amount of the essential oil percentage and shoot yield is consider important as two components of the essential oil content and by exerting stress, increases the essential oil percentage but shoot yield decreases by the drought stress, therefore essential oil content reduces (Aliabadi et al., 2009). The effect of water stress on essential oil was studied in excised leafs of palmarosa (*Cymbopogon martinii* var. motia) and citronella java (*C. winterianus*). Essential oil percentage was increased under water stress and essential oil content 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 al., 2009). Also, Khalid (2006) evaluated the influence of water stress on essential oil of two species of an herb plant that is *Ocimum basilicum* L. (sweet basil) and *Ocimum americanum* L. (American basil). For both species under water stress, essential oil percentage and the main constituents of essential oil increased. Seventy five percent of field water capacity resulted in the highest yield of herb and essential oil for both species. Also, three parsley cultivars (plain-leafed, curly-leafed and turnip-rooted) were grown under conditions of 35 - 40 and 45 - 60% water deficit in order to evaluate the effect of this form of stress on essential oil yield and composition. Water stress increased the yield of essential oil (on a fresh weight basis) from leafs of plain-leafed and curly-leafed, but not turnip-rooted, parsley. However, on an m^2 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 yield 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 m^2. 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 oil percentage of calendula. Their results showed that highest oil yield was achieved under non-drought condition and highest oil percentage was achieved under drought condition. Also, Bettaieb et al. (2008) 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 (DBI) degree. This later was provoked mainly by a strong reduction of linolenic acid proportion and the disappearance of palmitoleic acid. Besides, moderate deficit increased the essential oil yield (expressed as g/100 g 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 on essential oil content of Iranian *Satureja hortensis* L. The volatile constituents of the aerial parts of cultivated *S. hortensis* L. were isolated by steam distillation and analyzed by GC/MS. 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). Singh-Sangwan et al. (2006) indicated that the level of essential oils was maintained or enhanced under drought condition. The major oil constituents, geraniol and citral increased substantially in two lemon grasses (*Cymbopogon nardus* and *Cymbopogon pendulus*). Activity of geraniol dehydrogenase was also modulated under moisture stress. In the study of chicory water supply was determined with irrigation according by water evaporation from evaporation pan (50, 100 and 150 mm water evaporation). They noticed 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 of flowering shoot and essential oil percentage of flowering shoot of coriander and highest upon characteristics were achieved under without stress conditions and highest oil percentage of flowering shoot was achieved under water stress conditions (Aliabadi et al., 2008). Consequently, drought stress reduces essential oil content of more medicinal and aromatic plants and increases essential oil percentage under drought conditions.

Water use efficiency of medicinal and aromatic plants under drought conditions

Limited soil water availability reduces medicinal and aromatic plants growth more than all other environmental factors combined. In arid and semi-arid regions where water resources for irrigation are being depleted, methods for more efficient irrigation scheduling are needed for commercial growers. The best option for medicinal and aromatic plants production, yield improvement, and yield stability under soil moisture deficient conditions is to develop drought tolerant medicinal and aromatic plants varieties. A physiological approach would be the most attractive way to develop new varieties rapidly, but breeding for specific, suboptimal environments involves a deeper understanding of the yield-determining process. Leaf water potential is considered to be a reliable parameter for quantifying plant water stress response. Sinclair and Ludlow (1985) proposed that leaf relative water content (LRWC) was a better indicator of water status than was water potential. Canopy temperature is also related to water stress. Aliabadi Farahani et al. (2008) reported that the canopy temperature provided a good indication of the plant water potential of coriander when comparing environments with varying degrees of water stress and suggested simple method for determination of water use efficiency (WUE) by following formula.

$$\text{WUE} = \frac{\text{Biological or Grain yield (kg)}}{\text{Water used by evapotranspiration (m}^3\text{)}}$$

The potential soil moisture deficit produces two meaningful numbers: a critical deficit beyond which yield is reduced, and a reduction in yield per unit of potential deficit when the critical deficit is exceeded (Martin et al., 2001).Water use efficiency for the whole plant (WUE[t]) and single leaves (WUE[i]) were studied in a greenhouse as a function of soil moisture during four phenological stages of *Opuntia ficus-indica* and *O. robusta* growths. WUE[t] increased significantly with soil moisture stress and attained its maximum value before the flowering stage. WUE[t] and WUE[i] were linearly related, and WUE[i] was correlated with the transpiration rate, stomatals conductance and photosynthetic rate. Carbon isotope discrimination decreased as soil moisture decreased and was negatively correlated with both WUE[t] and WUE[i] (Snyman, 2005). Egilla et al. (2005) evaluated the influence of drought stress upon whole-plant water use efficiency of *Hibiscus rosa-sinensis* cv. Leprechaun (*Hibiscus*) plants. Their results indicated WUE increased under drought stress. Cheruth et al. (2008) investigated differential responses in water use efficiency in two varieties of *Catharanthus roseus* under drought stress. Two varieties, rosea and alba, of *C. roseus* (L.) G. Don. were screened for their water use efficiency under two watering regimes, viz. 60 and 100% filed capacity in the present study. Drought stress was imposed at 60% filed capacity from 30 - 70 days after sowing, while the control pots were maintained at 100% filed capacity throughout the entire growth period. Water use efficiency significantly increased in both varieties under water stress. Consequently, drought stress reduces biological yield of medicinal and aromatic plants sorely, but increased the water use efficiency because, plants use available water in soil optimally. Also, plants decrease evapotranspiration by blocked or half-blocked of stomatals and reductions in leaf areas, plant height and lateral stem number. Therefore, water use efficiency of medicinal and aromatic plants increases under drought conditions.

Examples for activity of nitrate reductase in medicinal and aromatic plants under drought conditions

NR activity is coordinated with the rate of photosynthesis and the availability of C skeletons by both transcriptional and posttranslational controls. Transcription of the NR gene nia is induced by NO_3 and repressed by Gln. It is also induced by sugars. Moreover, a circadian rhythm in NR gene expression has been observed. In situations of water deprivation, maximal foliar extractable NR activity has been found to decrease in some cases. Posttranslational regulation of NR activity is superimposed on the regulation of NR transcript accumulation (Melzer and O'Leary, 1987). A study set out to determine the effect of drought stress on nitrate reductase (NR, EC 1.6.6.1.) activity and to see if the maintenance of this enzymatic activity under stress conditions is a factor involved in the drought tolerance. *Lactuca saliva* L. was grown under controlled conditions at constant soil water potential (close to -0.04 MPa) or at -0.17 MPa during the last six weeks of plant growth. Results obtained: showed that higher NR activity (NRA) was appeared under water stress conditions. Control plants had 57% less NRA under well watered conditions, with a reduction in NRA of 79% when the plants were subjected to drought stress. It was concluded that drought stress decreased NRA, this effect may be a factor in the drought tolerance of lettuce (Ruiz-Lozano and Azcon, 1996). Also, Singh et al. (2001) investigated the effect of benzyladenine (BA) and ascorbic acid (AA) on nitrate reductase (NR) activity under sufficient water supply and moisture stress was studied in senna (*Cassia angustifolia* Vahl.) at seedling, vegetative, flowering and pod formation stages. The NR activity had negative effect on water stress. Therefore, the NR activation state and maximal extractable NR activity declined rapidly in response to drought.

Proline accumulation rate in medicinal and aromatic plants under drought conditions

Drought stress results in an increase of proline biosynthesis rate. Proline accumulation may in part involve induction and/or activation of enzymes of proline biosynthesis, possibly coupled with a relaxation of proline feedback inhibition control of the pathway, decreased proline oxidation to glutamate mediated at least in part by down-regulation of proline dehydrogenase, decreased utilization of proline in protein synthesis and enhanced protein turnover. Water deficits induce dramatic increases in the proline concentration of phloem sap in medicinal and aromatic plants, suggesting that increased deposition of proline at the root apex in water stressed plants could in part occur via phloem transport of proline. A proline transporter gene, ProT2, is strongly induced by water and salt stress in *Arabidopsis thaliana* (Rentsch et al., 1996), Ketchum et al. (1991) suggest that translation but not transcription is necessary for production of proline in stressed cells. Stress-hypersensitive mutants of higher medicinal and aromatic plants which exhibit disturbed proline metabolism can contribute significantly to the elucidation of the signals to which proline accumulation may respond. Petunias (*Petunia hybrida* cv. 'Mitchell') accumulate free proline (Pro) under drought-stress conditions (Yamanda et al., 2005). Comparison of the kinetic properties ornithine aminotransferase OAT showed that the enzyme from water-stressed leafs is more stable to heat inactivation compared to that of control. These results showed that during water stress there are alterations in the metabolism of proline in cassava, and the extent of alteration varies between drought-susceptible and tolerant cultivars (Sundaresan and Sudhakaran, 2006). A study was conducted to examine the response of date palm (*Phoenix dactylifera* L., cvs. Barhee and Hillali) calli to water stress. After 2 weeks, proline accumulation was assessed. Increasing PEG concentration was also associated with a progressive reduction in water content and increased content of endogenous free proline (Al-Khayri and Al-Bahrany, 2004). *Rehmannia glutinosa* seedlings were pretreated with choline chloride (CC) in concentrations of 0, 0.7, 2.1 and 3.5 mM, and then subjected to drought and dewatering treatment to study the effect of CC on the proline accumulation. CC pretreatment accelerated accumulation of proline during drought stress and retarded the drop in proline concentration after dewatering. Consequently, 2.1 mM of CC is suitable for promoting proline accumulation of *R. glutinosa* seedlings under drought stress (Zhao et al., 2007). Seedlings of two *C. arabica* genotypes (Catuai and BA10C1110-10) with different drought tolerance levels were subject to controlled water stress. Proline content of secondary, tertiary and quarternary leaf pairs, from the apex, were evaluated. In both genotypes, the secondary leaf pair had higher proline content. Although proline levels increased with increased water deficit, it was not possible to distinguish between the two coffee seedlings using this parameter. Proline accumulation seemed to be related to injury imposed by water stress (Mazzafera and Teixeira, 2006). Aliabadi et al. (2008) investigated the effects of arbuscular mycorrhizal fungi, different levels of phosphorus and drought stress on proline accumulation rate of coriander (*Coriandrum sativum* L.). Their results showed that drought stress had significant effect on proline accumulation rate and highest proline accumulation rate was achieved under stress conditions. Also, Baher et al. (2002) indicated proline accumulation of *S. hortensis* L. was increased under drought stress. Therefore, proline accumulation rate increases under drought conditions in medicinal and aromatic plants sorely.

Conclusion

The paper reviewed the importance of drought stress in reducing the growth of medicinal and aromatic plants. Therefore, water management can persist less damaging of drought stress in medicinal and aromatic plants farming. In addition, this may also be considerable situation in the agricultural activities in dry regions to enhancing the medicinal and aromatic plants drought resistance.

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