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Review article

Understanding crop-ecology and agronomy of *Rosa damascena* Mill. for higher productivity

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Abstract

Crop-ecology and agronomic factors are the major determinants of crop growth and development. Medicinal and aromatic plants synthesize and store a variety of biochemical compounds. The secondary metabolites of *Rosa damascena* are used in the pharmaceutical, flavours, and fragrance industries. The rising demand of essential oil is causing an accelerated replacement of natural fragrance by synthetic fragrance. Out of 200 species of the genus *Rosa*, the *R. damascena* is the important essential oil bearing plant. The content and relative composition of major components of rose oil predominantly depend on temperature, light, soil, pruning, nutrient supply, harvesting time and other management factors. Natural rose oil is most expensive in the world market as compared to its synthetic substitute, and the global demand of high grade rose oil is likely to increase in near future. In order to meet the rising demand, reconciliation of crop-ecological and agronomical approaches is required. Thus, there is pressing need to understand how these two factors and their interaction would provide noble strategies to stabilize yield of *R. damascena* in fluctuating environment. We do not attempt comprehensive review on *R. damascena*, rather we focus on crop ecology and agronomy, which determine the yield of flower and secondary metabolites.

Keywords: Agronomic factors, crop-ecology, essential oil, fluctuating environment, *Rosa damascena*, secondary metabolite.
Abbreviations: @- at the rate of; BA- benzyl adenine; GA_3- gibberellic acid; IAA- indole acetic acid; IBA- indole butyric acid; LER- land equivalent ratio; NAA- naphthalene acetic acid; NUE- nutrient use efficiency; PAR- photosynthetically active radiation; TDZ- thidiazuron; WUE- water use efficiency

Introduction

Crop-ecology and agronomy are inter-related and central issue in ensuring ecosystem security and sustainable productivity in various environmental conditions. Plant is one kind of biological factory that processes light, CO_2, water and nutrient into harvestable part. The harvestable part of *R. damascena* is flower, which is used for essential oil production. Cultivation and processing of essential oil bearing plant and medicinal plants have over the years created a central area in the global agri-business with an estimated annual growth rate of 7-10 % (Thomas et al., 2000). Out of 200 species of the genus *Rosa*, only a few have been registered as essential oil bearing crops. Among them *R. damascena* is recognized superior for high value essential oil, which is used in the pharmaceutical, flavouring and fragrance industries (Lawrence, 1991; Rusanov et al., 2009). These days use of rose oil in pharmaceutical industries is steadily increasing. The content and relative compositions of major components are the key parameters to determine the quality of rose oil (Nikolav et al., 1977), which is chiefly governed by the genotype, ecological and agronomical factors. Nevertheless, *R. damascena* is adapted to a wide range of environmental conditions. In order to meet the rising demand of the rose oil, there is pressing need to understand how ecological and agronomical factors directly influence on productivity of *R. damascena*. Fundamental research on *R. damascena* is still pressingly needed to understand and translate major unresolved questions in cell biology, physiology, crop-ecology, and agronomy. Now the main module of agriculture is the stabilization of yield in various environmental conditions. Proper knowledge of crop-ecology and agronomic practices will, thus, unlock new strategies to create sustainable production techniques of *R. damascena* for stabilizing the yield in changing biotic and abiotic conditions. Consequently, it will be helpful to improve the existing crop production packages available to the farmers. We do not attempt a comprehensive review on *R. damascena*, rather we focus on major areas of recent researches, which determine the yield of flower and secondary metabolites. Concurrently, we are looking for to set a common framework to understand the crop-ecology and agronomy of *R. damascena* and to define new perspectives.

Atmospheric temperature and physiological processes

Temperature is the force factor of heat energy. Most of the physiological processes are affected by atmospheric temperature, which determines the length of growing season. Atmospheric temperature also decides the momentum of respiration and dark reaction. Active growth in most of the plants occurs at the temperature ranging from 5 - 40° C. Within this range, the cardinal temperature and the optimum temperature range vary from species to species, and within optimum temperature range, growth increases with increment in the temperature. Temperature is the decisive factor for production of roses. Generally, roses are cultivated over a range of 20– 30° C day temperature and 18– 20° C night temperature (Beeson, 1990; Kool et al., 1996; Bredmose, 1998; Gonzalez-Real and Baille, 2000; Kim and Lieth, 2003). In major Damask rose growing regions (Kazanlik) of Bulgaria, an average spring temperature of 5 – 15° C is considered as optimum (Oyen and Dung, 1999). If low night temperature of 10- 12° C prevails during flowering stage, the oil synthesis reduces considerably. Nevertheless, low temperature for a fortnight prior to blooming enhances the quality and quantity of *R. damascena* flowers. The ideal temperature for growing of most of the roses is 19 – 27° C. Weiss (1997) stated that a lengthy period in spring with mean temperature of 5 – 15° C ensures large number of flowers per plant with high oil content. He also stated that low night temperature of 10 – 12°C inhibits flowering, but up to 20° C increases oil synthesis. Flower production of roses is determined by the ability of sprouting of axillary buds and their conversion into flowering buds. Temperature has a pronounced effect on shoot growth of rose, and it may be a major factor affecting growth potentiality of axillary buds. Temperature during axillary buds formation has also distinct effect on subsequent shoot growth (Moe, 1971; Zamski et al., 1985; Patrick, 1988; Marcelis –van Acker, 1995). Length and weight of the flowering shoot decrease when temperature exceeds 24° C (De Vries et al., 1982). Sensitivity to temperature depends on the developmental phases of rose (Berninger, 1994). At low temperature, carbohydrate content usually increases because growth is more limited than the rate of photosynthesis (Farrar, 1988). Although a decrease in temperature may reduce the rate of cell division (Francis and Barlow, 1988), the number of pith cells in cross section decreases slightly with higher temperature during axillary bud formation (Marcelis–van Acker, 1995). Ushio et al. (2008) observed that photosynthetic capacity of assimilated shoot and rubisco / nitrogen content in leaf increases at 20° C and 15° C of day and night temperature, respectively. Finally, they concluded that the photosynthetic capacity of rose strongly depends on the growth temperature even if the nutritional conditions are the same. In contrast, Kim and Lieth (2003) reported that the photosynthetic rate in rose does not differ between 20 and 30° C. Photosynthesis in rose plant is moderately sensitive to temperatures in the range 20– 30° C (Bozarth et al., 1982). In general, internodes length and plant height are affected by the diurnal temperature pattern (Myster and Moe, 1995). Higher night temperature than day temperature was found to have only a negative effect on stem length in roses (Mortensen and Moe, 1992). In these plants, low temperature increases the activities of several photosynthetic enzymes, such as rubisco, stromal fructose-1, 6-bisphosphatase, and sucrose-phosphate synthase (Ushio et al., 2008). It has been reported that Net Assimilation Rate (NAR) increases during growth at low temperature caused by increase in rubisco (Ushio et al., 2008). Similarly, anthocyanin content in flower increases at low temperature (Harborne, 1967). Other growth attributes like leaf area, stem length and stem diameter generally increase along with temperature effects (Shin et al., 2001).

Sunlight and day-length act as controller of yield attributes

Day length depends on latitude and position of the sun. The relative length of day and night influences the life process of many plants (Waldren, 2003). Though flowering of rose is not determined by photoperiod, many yield attributes, such as number of lateral bud, rate of flower bud abortion, formation of new shoots, growth rate of flowering shoot etc. are influenced by light. Very few reports are found regarding the effects of light and day length on Damask rose compared to ornamental or greenhouse grown roses. That is why we try to set up a common outline for understanding the role of light and day-length. Roses are generally day neutral plant, and flowering is recurrent throughout the year in suitable conditions. In contrast, Mor and Halevy (1984) reported that light intensity and day length play important role in flowering and sprouting of shoots in rose. Reduction of 10, 35, 60 and 70 % in light transmitted into the greenhouse by shading of plants during winter reduces the number of flowers per plant (Zieslin and Halevy, 1969). Carpenter et al. (1972) reported that extension of day length from 9-16 h with mixed wide spectrum Gro-Lux and incandescent light of relatively low level of irradiance of 12 µmol s^{-1} m^{-2} PAR increased the number of flower per plant of four rose cultivars. The stomatal diffusive resistance of cut roses (in vases) is much lower, and the transpiration rate is much higher when rose is grown at a photoperiod of 20 h compared to those at the natural photoperiod of about 10 h (Slootweg and Van Meeteren, 1991). The stomata of cut roses grown under a long photoperiod remain open for more than 40 h in darkness, while those grown at a short photoperiod close almost immediately (Slootweg and Van Meeteren, 1991). However, Mortensen and Fjeld (1998) did not find any positive effect of increasing the light period on fresh weight of rose shoots. On the other hand, blind shoot of roses increased with low light intensity (Kamp, 1948; Zieslin et al., 1973; Cockshull, 1975; Zieslin and Halevy, 1975). Light accelerates the development of a rose bud to harvestable shoot (Zieslin and Mor, 1990) and leads to longer shoots with higher weight (De Vries et al., 1986). Leaf photosynthesis in rose plant increases when radiation becomes double from 150-µmol m^{-2} s^{-1} at 20^0 C (Dieleman and Meinen, 2007). This report has conformity with the findings of Bozarth et al. (1982) and Jiao and Grodzinski (1998). Sometimes light and temperature act in an integrated way. Low light intensity with low temperature and 88 % relative humidity can increase the *R. damascena* flower yield and its quantity and quality of essential monoterpenes oil (Misra et al., 2002). The high light and low temperature increase the starch content of the leaves (Dieleman and Meinen, 2007), which may lead to feedback inhibition of the photosynthesis (Guinn and Mauney, 1980). Goldschmidt and Huber (1992) found a distinct relationship between leaf starch content and the inhibition percentage of the maximal photosynthesis rate in a number of crops. However, they concluded that starch itself could not be directly accountable for the decrease in photosynthesis. Low light intensity also reduces the pigmentation of yellow roses containing carotenoids as the major pigment, but pink roses (cultivar 'Carol') are not affected (Lahav and Halevy, 1969). Quality of light also plays an important role in shoot length of roses. High red and far-red ratio promotes shoot bud sprouting, while a low ratio inhibits it (Zieslin and Mor, 1990). Mortensen and Fjeld (1998) show that fluorescent light gives shorter rose shoots than HPS light, which validates the fact that the increase in the ratio of blue to red light reduces stem elongation

(Warrington and Mitchell, 1976; Thomas, 1981; Mortensen and Stromme, 1987).

Atmospheric humidity determines the longevity of flower and transpiration rate

Atmospheric humidity exerts indirect effect on crop growth through its influence on the availability of net energy, precipitation phenomena, outbreak of pest and disease epidemics, and it makes easy entry of foliar sprays (Venkataraman and Krishna, 1992). By and large, most of the crops are successfully grown in the humidity range of 50 – 90 %. There are minor effect of air humidity on growth of roses (Mortensen, 1986) and other plant species (Grange and Hand, 1987). Nevertheless, high air humidity during the growth of the rose shoots can significantly reduce the vase life of roses (Mortensen and Fjeld, 1995). During spring and early summer, 70 % humidity is optimum for good harvest of Damask rose. Aerial humidity needs to be considered as a factor in crop-weather relationship studies (Arkley, 1963). During anthesis, the air humidity should be above 60 % (Weiss, 1997). Increased relative humidity reduces transpiration (Ehret and Ho, 1986; Gislerod et al., 1987), and it is well documented that tissues which have a low rate of transpiration will inherently have a low rate of xylem volume flow and hence a low translocation of Ca (Marschner, 1995). The roses grown at high relative humidity wilted earlier after harvest, probably because of the water stress caused by reduced stomata function (Mortensen and Fjeld, 1995, 1998; Torre and Fjeld, 2001).

Soil environment and plant growth

Soil is the storehouse of plant nutrition and water, but availability of nutrient and retention capacity of water depends on physico-chemical properties of soil. A deep and fertile loam soil is the most suitable for commercial rose growing. Nevertheless, it can be successfully grown on a wide range of soils with the help of good agronomic practices. Roses do well in slightly acidic to slightly alkaline soil reaction having pH range from 6.0 to 7.5. The acidic soil inhibits the plant growth and reduces flower yield probably due to imbalance of micronutrients. Brichet (2003) reported that rose plant is sensitive to saline and alkaline soil. The electrical conductivity should be < 2.0 m mhos cm^{-1}. However, alkali – saline soil with pH range 8-9 is somewhat suitable in Indian conditions (Singh and Sharma, 1969; Singh, 1970; Sharma, 1982). Calcareous soils are not suitable for rose cultivation especially where irrigation water is alkaline (Weiss 1997). Though *R. damascena* dislikes water logging, but porous soils are generally unsuitable in low rainfall area. Poorly drained soil may lead to root diseases and nutritional deficiencies (Karlik et al., 2003).

Generation of quality planting material

Rose plants can be propagated either by sexual method or vegetative method. Seed is generally used for propagation of the species, new cultivars and for production of rootstocks (Horn, 1992). The perfumery and cosmetics industries are considerate to procure consistent quality of rose oil. Vegetative propagation, therefore, is the most vital and sole method to produce true to type planting material. That is why *R. damascena* is mostly vegetatively propagated to produce consistent quality of essential oil. Generally, the Damask rose is propagated by stem cutting, budding and grafting (Horn, 1992; Hudson et al., 2002). Nevertheless, stem cutting is the easy method for rose multiplication (Anderson and Woods, 1999). The establishment and growth rate of the cutting depend upon many factors like season of cutting, age and portion of the branch, growth media, moisture and nutrient status (Khan et al., 2006). About 20-25 cm long and 0.75-1.25 cm thick stem cuttings are prepared from one-year-old stems, which begin to lignify. In India, the ideal time of deriving the cutting is November – December. Root initiation starts after 3 months of planting of cutting, and the sprouted cuttings get ready for transplant in the main field in about 9-12 months.

In case of *R. Damascena*, the effects of crop-ecological conditions during cutting on flower production efficiency are not properly reported in scientific literature. However, the prevailing environmental conditions like light, temperature and relative humidity play vital role for rooting and subsequent growth and development of cutting. By and large, the ideal temperature for proper rooting and growth of cutting is 19- 27 º C. Bradmose et al. (2004) reported that a temperature of 24.6 º C is optimal to enhance the root growth of cutting. Bright sunlight with more than 60 % relative humidity is ideal for establishment of cutting. Synthetic root promoting chemicals that have been found most reliable in stimulating adventitious root production of cuttings are the auxins i.e. indole acetic acid (IAA), naphthalene acetic acid (NAA) and indole butyric acid (IBA) (Arteca 1996). Sharma (1982) reported that treatment of cutting with IBA 200 ppm induces profuse rooting. Keisling and Kester (1979) reported that poor rooting of the cutting could be due to marginal condition of growing media. Leaf mould is the most effective media to promote growth of rose cuttings (Khan et al., 2006). Greenhouse rose cultivars are propagated through budding or grafting on root-stock and seldom grown on their own roots. This may be mainly due to the observation that plant performance and flower production in grafted plant are higher than in non-grafted plants, particularly when planted in soils or soil-based growing media (Zieslin et al., 1973; Hanna and Grueber, 1987). Besides, it is probably due to production of favourable root system in the root-stock than the cutting of the scion.

Judicial nutrient management systems enhance productivity

To increase the fertilizer use efficiency in agricultural systems a great understanding of the factors that influence the nutrient absorption by plant roots is required. In accordance with Liebig's Law of the minimum, the biomass production will be limited by the deficiency in nutrient availability. Nutrient absorption rate by roots varies according to cultivar (Nielsen and Barber, 1978; Barber and Mackay, 1986; Teo et al., 1992; Kelly et al., 2000; Sharifi and Zebarth, 2006), growing conditions (Steingrobe and Schenk, 1994; Wheeler et al., 1998), plant age (Jungk and Barber, 1975; Malagoli et al., 2004) and the nutritional history of the plant (Jungk, 1977; Lindgren et al., 1977; Jungk et al., 1990; Wheeler et al., 1998; Walker et al., 2001; Subasinghe, 2006). All 16 essential elements have been established to play important role in proper growth and development of rose. The growth and quality of roses are greatly influenced by nutrient management (Savvas, 2002). Flower development is dependent on nutrient supply, which affects phytohormone balance and source-sink relationship through the transport of photoassimilate (Bernier et al., 1988). Damask rose is an exhaustive crop and wants ample supply of plant nutrients. In Bulgaria, it was estimated that 64 kg nitrogen (N), 8.7 kg phosphorus (P) and 36 kg potassium (K) get harvested annually per hectare of rose field and flower contained approximately 3 % N, 0.34 % P and 1 % K (Koseva et al., 1978). Flower yield and oil yield of rose are correlated with NPK levels in leaf at bud development stage (Orlova, 1984). The concentration of N, P and K reduced 35 %, 67 % and 25 % respectively, between bud development and main flowering stage (Weiss, 1997). Suitable concentrations of NO_3-N, NH_4-N, phosphorus and potassium in soil for rose growing are 35 - 180, 0 -20, 5- 50, and 50- 300 ppm respectively (Karlik et al., 2003). Nitrogen uptake by rose plants is related to shoot development, but periods of maximum nitrogen uptake is not correlated to higher rate of shoot elongation (Cabrera et al., 1995_a). A good crop requires 200 kg nitrogen ha^{-1}, which is applied in two equal doses particularly in saline alkaline soil (Srivastava, 1975). Generally nitrogen is applied in two equal doses, half at the time of pruning and remaining half 15 days later. However, the dynamics of nitrogen within the rose plant have not been reported lucidly. The current demand of nitrogen for rapidly elongating shoots may be met by redistribution within the plant rather than by current uptake of nitrogen from the soil. So more extensive research becomes imperative for optimization of nitrogen application schedule. Cabrera et al. (1995_b) observed that during the period of rapid growth of flower- shoot, the nitrogen was redistributed from old stem, old leaves and root to support the demand of the flower-shoot. Calcium ammonium nitrate is the best source of nitrogen for rose cultivation. Phosphorus and potassium both are the less mobile in soil than nitrogen.

The potassium should be applied in a judicious manner. Excessive amount of potassium can induce deficiency of other essential nutrients. The amount of phosphorus and potassium needed for rose crops is 50 – 90 kg ha^{-1} and 20 – 50 kg ha^{-1}, respectively in each year, although some growers prefer higher dose of potassium. In Kashmir valley, in India, application of 200 kg N, 100 kg P_2O_5 and 50 kg K_2O ha^{-1} y^{-1} has been found to provide high flower production in Damask rose (Jhon et al., 1992). They also found maximum shoot length with 200 kg N ha^{-1} over 100 N ha^{-1}. Increase in the length of shoots due to higher dose of nitrogen and phosphorus application has also been reported in *R. damascena* var. trigentipetala (Tajuddin et al., 1986). Besides macronutrients, plants need micronutrients in minute quantities, which are involved in enzymatic activities. Concentrations of micronutrients influence crop growth as well as quality attributes viz., length and thickness of stem, colour, and longevity of flowers (Marschner, 1995; Khoshgoftarmanesh et al., 2008).

The suggested micro nutrient concentrations in the soil for the roses are as follows: boron 0.05- 0.5, iron 0.3- 3.0, manganese 0.2- 3.0, and zinc 0.03- 3.0, copper 0.001- 0.5, and molybdenum 0.01- 0.1 ppm (Karlik et al., 2003). Khoshgoftarmanesh et al. (2008) reported that micronutrient treatments reduced mildew infection in of rose plant. Various effects of micronutrients on diseases and pests have also been reported (Marschner, 1995). Zinc plays an important role in enhancing tolerance of rose cultivars to biotic stress of mildew infection (Khoshgoftarmanesh et al., 2008). Misra et al., (2005) observed a correlation between CO_2 exchange rate and Zn concentration in tissue of *R. damascena* plant. Iron deficiency symptom occurs in mature rose plants. This problem can be alleviated through foliar spray containing 0.1 – 2.0 % ferric chloride (Sharma, 1982). Nevertheless, there are no such reports on the effect of boron deficiency or toxicity on flower yield and oil content of rose.

Proper scheduling and method of irrigation increase water use efficiency (WUE)

Adequate water is essential throughout the vegetative and flowering periods of *R. damascena*. By and large, 90 % of water consumed by plant is utilized in biochemical process and as a loss thorough transpiration. The frequency and duration of irrigation depend on water holding capacity of soil, demand of crop, and seasonal weather condition. In all, 10-12 irrigation are required for *R. damascena* in a year. During rainy season, it may not be necessary to irrigate the plants. However, frequency of irrigation during summer may be once a week, and in winter it may be once a fortnight. Maintaining the soil moisture at 85 % field capacity during the growing period produced the higher flower yield in Russia (Korshunov and Umanets, 1984). Roses grow best when about 50 % of available water is depleted between two irrigations (Karlik et al., 2003), however, over watering may lead to root diseases and nutritional deficiencies. Irrigation just after pruning is essential. Dip irrigation is most effective. Sprinkler irrigation is also efficient in terms of WUE, but it encourages the infection of leaf diseases (Porter et al., 1987). Developments of agronomical and physiological contemplation have already increased the WUE in many crops (Angus and Van Herwaarden 2001; Condon et al., 2002; Cifre et al., 2005). We believe that there is a substantial potentiality for further improvement of WUE in *R. damascena* through proper understanding water requirement and scheduling of irrigation.

Pruning for manipulating plant architecture

The pruning of rose is a horticultural art for manipulating plant architecture that depends on types of rose to be pruned and reason of pruning. It is also essential to force the plant into artificial rest or dormant period before flowering. The rose plant is essentially pruned to induce artificial dormancy. Pruning, de-shooting, de-budding and shoot bending are currently practiced for controlling whole plant development and promoting the quality of flower stems (Zieslin et al., 1975; Zieslin and Mor, 1981; Kool and Lenssen, 1997). Pruning seems to affect both morphological as well as yield parameters in *R. damascena* (Paul et al., 1995). Calatayud et al. (2007, 2008) observed some physiological effects of pruning under greenhouse condition. The main effect of pruning has been studied on carbohydrate movement to storage tissues in lower parts of the plant (Zieslin et al., 1975; Bore et al., 2003; Li, 2003). It was also reported that pruned plant have higher capacity to promote the photosynthetic light reaction, a large number of metabolic sinks and a higher turgor pressure than non-pruned plants (Calatayud et al., 2007). As holds true for ornamental plant, pruning has been found to be fruitful even in case of the aromatic rose (Blacker, 1995). Annual pruning is essential to attain proper shape of bushes and promoting branches. Time, level and intensity of pruning are the important yield determinants. However, extent of pruning depends on agronomic management, climate and cultivars. Rose plant is pruned at 45- 60 cm from the ground level. In Bulgaria, light to moderate pruning increased the flower yield and flower oil content, whereas heavy pruning reduced both (Astadzhov et al., 1986). In India, pruning at 15 cm from ground level provided higher flower yield than moderate or light pruning (Singh and Ram, 1987).

Nevertheless, Hassanein (2010) reported that light and medium pruning were better than the heavy pruning in terms of petals weight and oil content, respectively. Though pruning time is mainly governed by the climate of the place, pruning of *R. damascena* is usually done from October to January in different regions of India. The pruned plants take 70- 90 days to flower after pruning. Time of flowering can be adjusted through date of pruning. However, Saffari et al. (2004) reported that the time of pruning did not affect the petal oil content. Pruning at the beginning of autumn improved flower quality and essential oil content (Hassanein, 2010). Damask roses are generally pruned annually. Astadzhov et al. (1986) reported that pruning once every 3 years is acceptable in terms of cost and flower yield. This cultural practice is useful in removing photosynthetic old parts and regenerates new healthy photosynthetic parts, subsequently increases flower production.

Dynamics of crop-weed competition and weed management

Weeds compete for all the growth factors with their associated crops. *Rosa damascena* is a deciduous shrub bearing less number of leaves and branches during initial 2-3 years. Thus, it faces severe weed infestation throughout the year. *Rosa damascena* is more vulnerable to competition by weeds during the initial period of establishment of rooted stem cutting in field. Weeds like *Oxalis corniculata, Solanum nigrum, Bidens pilosa, Ageratum conyzoides, Polygonum hydropiper, Gnaphalium peregrinum, Erigeron canadensis, Coronopus didymus, Drymaria cordata, Galinsoga parviflora, Plantago lanceolata, Eupatorium odoratum, Cynodon dactylon, Paspalum dilatatum, Setaria glauca, Cyperus* spp. are found in *R. damascena* field at IHBT, Palampur, India. The magnitude of crop-weed competition is high during rainy season. *Apluda mutica* is a tall grass weed which emerges late in the rainy season, and it causes maximum damage among the rainy season weeds. Uncontrolled weed growth causes about 39 % reduction in rose flower production (Singh and Singh, 2004). Notwithstanding, report on weed management of Damask rose is lacking in literature. Mechanical and physical methods of weed control are the most effective and eco-friendly approach but are laborious, time consuming and expensive measures. Generally, 3 weedings are required in a year. The organic mulches reduce the population of weed in rose field and make hand-weeding easy. Though there is a great deal of interest in organic cultivation of rose, the role of herbicides cannot be overlooked. The selection of herbicides depends on weed spectrum associated with the crop. Roses are sensitive to herbicides which are used to control broad-leaf weeds, such as 2, 4-dichlorophenoxyaceticacid, triclorpyr and dicamba (Karlik and Tjosvold, 2003). However, annual weed can be controlled by application of herbicides like simazine or atrazine @ 3 kg a.i. ha^{-1} in light soils and 5 kg a.i. ha^{-1} in medium and heavy soils. Singh (2004) reported that atrazine, pendimethalin, and metribuzin are less effective than rice-straw-mulch. There is no such published evidence regarding harmful effect of herbicides on Damask rose.

Intercropping is the source for creating plant diversity

Roses are seldom under-planted and intercropped with other crops. Damask rose is generally propagated through stem cutting, and the growth rate of transplanted cutting is slow during initial two years. Moreover, it remains in dormancy during winter. Thus, there is little scope for intercropping during the early stage of development and dormant period. The yield advantages through intercropping are well documented. In Damask rose-based intercropping system, the crop species that possess short life cycle and fast growth habit without much branching would be suitable as a component crop. In an interesting variation, sequential intercropping of *R. damascena* with potato-maize, geranium - maize, and cowpea-maize greatly increases the land equivalent ratio (LER) and provides large economical gain (Yaseen et al., 2001). Tajuddin et al. (1993) reported that few crops are compatible with commercial rose oil production. They also observed that the quality of rose oil was not affected by intercrops. Similarly, positive effect on soil fertility improvement and proper utilization of nutrient from different layers of soil has been observed. Moreover, rose is a sunshine loving plant that prefers plenty of light. Intercropping suitable crops will improve utilization of natural resources as well as support suppression of weeds. Intercropping not only enhances productivity in a cropping system but also supports biodiversity and promotes agro-ecosystem health.

Use of plant growth regulator to promote growth and development

Plant growth regulators also play pivotal role in influencing different plant processes comprising mostly of growth, differentiation and development e.g. rooting of cutting, root growth, flowering, aging, prevention or promotion of stem elongation, colour enhancement of fruit etc (Hobbie, 1998; George, 1993; Foskett, 1994). Growth regulators are also called as phytohormones that are biologically effective in very low concentration and influence several metabolic processes of plant growth and development. It has been found that auxins (NAA, IBA, IAA) are the most effective systemic chemicals for adventitious root production in stem cutting (Arteca, 1996). Khan et al. (2006) reported that NAA had more beneficial effect than IAA in terms of root growth and development. They also concluded that the effective levels of NAA were 50 and 75 mg L^{-1}. Application of GA_3 reduces the flowering period (Ma et al., 1985) and oil content in petals of *R. damascena* (Farooqi et al., 1993; 1994; Saffari et al., 2004). Bernier et al. (1988) confirmed that gibberellin affects vegetative-shoot-growth. In India, during the initial period of growth, ethephon increased flowering and flower oil content (Farooqi and Sharma, 1990). Application of kinetin also increased flower production of Damask rose (Farooqi et al., 1993). Besides these, growth regulators have wide uses in micropropagation to be discussed in next section.

Micropropagation for rapid multiplication of superior quality planting material

The common way of propagation of Damask rose is stem cutting. This method is very slow and time-consuming, and usually associated with various problems, such as limitation of stock plant and prolonged nursery stage (Skirvin et al., 1990). In this context, tissue culture is employed for achieving faster rates of multiplication (Khosh-Khui and Sink, 1982; Ishioka and Tanimoto, 1990; Kornova and Michailova, 1994; Kumar et al., 2001; Pati et al., 2001; Kapchina-Toteva et al., 2002). The tissue culture techniques for rapid multiplication have often resulted in superior quality planting material (Paek et al., 1998; Billir, 1999). Different features of tissue culture propagation systems for *R. damascena* have been described by several researchers (Kumar et al., 2001; Pati et al., 2004; Jabbarzadeh and Khosh-Khui, 2005; Nikbakht et al., 2005). Supplementing the media with GA_3 can improve multiplication of Damask rose explants (Kumar et al., 2000). They also reported the senescence symptoms in proliferated shoots and tried to manage the problem by modifying the media. Khosh-Khui and Sink (1982) concluded that the most effective hormonal compounds for *in vitro* propagation of Damask rose are BA @ 2 mg l^{-1} and NAA @ 0.1mg l^{-1}. Jabbarzadeh and Khosh-Khui (2005) observed that BA @ 2.5 - 3.0 mg l^{-1} in combination with low rate of IBA was the most effective treatment for *in vitro* multiplication of *R. damascena*. Nevertheless, *in vitro* rooting of Damask rose is much more difficult than modern roses. Pati et al. (2001) also found that 2 mg l^{-1} BA is the most appropriate concentration *in vitro* propagation of Damask rose. In contrast, Kumar et al. (2000) reported that the best BA concentration for micro-propagation of Damask rose was 1.25 mg L^{-1}. High concentration of BA induces malformation and abnormal shoots (Carelli and Echeverrigary, 2002). Some rose species are relatively more resistant to higher BA concentration (up to 5.8 mg l^{-1}) in media (Damiano et al., 1987). However, the desirable concentration mostly ranges between 1-2 mg l^{-1} (Rout et al., 1999). Cai and Qian (1984) observed no significant result with NAA, but Khosh-Khui and Sink (1982) reported that NAA (0.1 mg l^{-1}) and BA (1 mg l^{-1}) were necessary for Damask rose micropropagation. Some researchers have also used different anti-ethylene compounds in culture media to overcome senescence problem (Rout et al., 1999; Kumar et al., 2000). The cuttings derived from *in vitro* raised plants of *R. damascena* showed a significantly better response in terms of rooting percentage, root number, root length and bottom buds (Pati et al., 2004). Khosh-Khui and Jabbarzadeh (2007) also reported that application of 2.5 mg 2,4-D l^{-1} for the Damask rose explants, transferred in MS medium, was the best treatment for rooting. *In vitro* propagated cut roses were found to be more compact (Onesto et al., 1985) than those propagated by conventional methods using stem cutting. Regeneration of shoot was achieved from petiole explants of *R. damascena* (Pati et al., 2004). They observed that TDZ was effective in inducing shoot morphogenesis, and $AgNO_3$ hastened the regeneration at least by 1 week. However, micro-propagation is not commercially practiced for propagation of Damask rose.

Biotic stress

Rosa species are susceptible to a number of diseases and insects. Some varieties of roses are naturally more resistant or immune than others to certain pests and diseases. The most common diseases that severely affect the scented rose are black spot (*Diplocarpon rosae* Wolf), rust (*Phragmidium mucronatum* Pers.), mildew (*Sphaerotheca pannosa* Wallr.) and botrytis blight (*Botrytis cinerea* Pers.: Fr.) (Margina and Zheljazkov, 1995; Joy et al., 2001; Rusanov et al., 2009). Severe infestation of rust disease almost defoliates plant; subsequently plant becomes more susceptible to frost. A preventive measure of fungicides spray programme is best approach to control fungal diseases in the rose rather than trying to cure an infected plant. The important bacterial disease on rose is bacterial crown gall, caused by *Agrobacterium tumefaciens* (Karlik et al., 2003). The main fungal diseases can be controlled by regular application of 1 % Bordeaux mixture or 0.2 % mancozeb. The fungicides *viz.*, Baikor, Folicurphus saprol, and Impact are reported to be most effective against rust and black spot diseases (Margina and Zheljazkov, 1995). Oil bearing roses are also attacked by a number of insects, some of the most important are Curculionidae (*Rhynchites hungaricus Herbst*), aphids (*Macrosiphum rosae* L.), cane borer (*Agrilus cuprescens* Men.), rose curculio (*Homalorynchites hungaricus* Fussly.), rose scale insect (*Rodoccocus bulgariensis* Wunn.), rose chafer (*Epicometis hirta* Poda.), and red spider mite (*Tetranychus telarius*) (Joy et al., 2001; Mann, 2002 Rusanov et al., 2009). Insects that particularly attack the flowers are chafer beetles, thrips, midges, earwigs and sawflies (Weiss, 1997). The major plant parasitic nematodes associated with roses are *Meloidogyne hapla, Pratylenchus vulnus, Pratylenchus penetrans, Xiphinema index, Longidorus macrosoma and Criconematidae* Species (Esmenjaud, 2003).

Harvesting time and stage are the key factors for higher yield and quality

Flower is the economical part of *R. damascena*. The harvesting period is short and depends upon the prevailing weather conditions. In a cool and cloudy spring, it may continue for about 1 month, while in hot seasons it may last only for 16- 20 days (Perry, 1925; Orozoff, 1906). Flowering period is directly governed by climatic conditions, but normally completed by 20 – 25 days. In India, the main season of flowering in the north Indian plains is during March and April, while in hills it is slightly late- during April and May. The ideal stage of harvesting is blossoming stage. Lawrence (1991) reported that the higher oil content in flower was found when petals start to swell and 2 or 3 petals begun to open. Harvesting at cup shape stage is also profitable in terms of quality and quantity of essential oil. The flower harvesting should be started before dawn and should be stopped when the sun dries the dew on the flower. The oil is significantly lower if the flowers are picked after 9.00 AM (Igolen, 1966). High temperature during harvest reduces oil content of flower (Baydar and Baydar, 2005) due to removal of essential oil from the trichomes of the petals (Weiss, 1997). The rose petals generally contain very little essential oil in comparison with other essential oil crops. One kg of rose oil can be obtained from about 3000 kg of rose petals (Baser, 1992), so oil content is only about 0.03%. At the beginning stage of harvest, 4000 kg flower is required to obtain 1 kg oil (Garnero and Buil, 1976). Oil composition varies to a large extent over the flowering stages owing to variations in rate of photosynthesis of various parts of the plants (Weiss, 1997). Mihailova et al. (1997) have also reported that the oil compositions vary with the flowering stages, flower parts, and the harvesting period (Mihailova et al., 1997). The petal oil constituents have been examined in detail by Velioglu and Mazza (1991). The stage at which flowers are picked is a major factor not only for oil yield but also for quality of oil. Results of some studies (Misra et al., 2002; Baydar and Baydar, 2005) showed environmental effects on the quantity and quality of flower and essential oil. The variation in yield and quality of essential oil can be due to different harvesting and distilling techniques (Bayrak and Akgul, 1994). It was also reported that the effect of storage temperature between 0° C to 3° C on oil content was not significant, whereas the effect of storage duration was significant (Kazaz *at al*. 2009). They reported that the highest essential oil content (0.043%) was obtained from the petals distilled immediately after the harvest, while the lowest oil content (0.022%) was obtained from the petals stored for 28 days. Although flower yield depends on genetic and climatic factors, agronomic management is the key factor to determine the flower yield. There is a direct correlation between the level of crop management and crop yield. A high level of agronomic management produces higher flower and oil yield. The productivity of rose plant depends on variation in different component of yield, such as number of lateral buds released from inhibition, the rate of flower bud abortion, formation of new shoots, and the growth rate of the flower stems (Zieslin et al., 1973). All these yield attributes may be manipulated through agronomic practices. The average annual flower yield in Bulgaria, Iran and India is 2000- 3000 kg ha^{-1}; in Turkey, 2000- 2500 kg ha^{-1}; and in Russia, 1500-2000 kg ha^{-1}.Yield may not be directly comparable because different cultivars are involved. The improved cultivars of Damask rose developed at IHBT, Palampur provide 4000-5000 kg ha^{-1} flower yield (Kaul et al., 1999). Generally, flower yield follows a linear pattern up to 5 or 7 years from date of transplantation, although the economic life of a plantation *R. damascena* is 10- 12 years.

Research needs

An integrated multidisciplinary research is needed to sustain the productivity of *R. damascena* and to meet the present demand of rose oil. There is pressing need to set up models regarding relationship among crop-ecology, agronomic factors, and yield. It is also necessary to develop proper integration of organic and inorganic sources of plant nutrition for enhancing the nutrient use efficiency (NUE) and restoration of ecosystem. Moreover, the dynamic of plant nutrition in the rose crop is to be investigated lucidly. Agronomical research programs are needed to increase the land use efficiency (LUE) and for creating plant diversity. Beside this, research should be conducted on water management to increase crop water productivity.

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