academicJournals

Vol. 7(34), pp. 2489-2493, 10 September, 2013
DOI: 10.5897/JMPR2013.4466
ISSN 1996-0875 ©2013 Academic Journals
http://www.academicjournals.org/JMPR

Journal of Medicinal Plants Research

Review

Effect of cultural practices and environmental conditions on yield and quality of herbal plants: Prospects leading to research on influence of nitrogen fertilization, planting density and eco-physiological parameters on yield and quality of field-grown bush tea (*Athrixia phylicoides* DC.)

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Accepted 23 August, 2013

Herbal plants are grown in diverse regions of varying climates with growth and productivity being influenced by both biotic and abiotic factors. Cultural practices have a significant influence on growth and productivity of these plants. In order to maximize yield and quality of tea as an herbal plant, cultural practices such as fertilization and planting density should be optimized. Fertilization improves growth, total polyphenols, tannins and total antioxidant content of herbal tea. In particular, nitrogen fertilization increases the production of new shoots and the content of nitrogenous compounds, such as free amino acids, which are the major quality indicators of herbal tea. Plant population density also plays role in tea productivity. In addition dense planting may increase the initial yield and revenue. This review discusses the effects of nitrogen fertilization, timing of nitrogen fertilization, planting density and climatic conditions on growth and productivity of herbal teas and other medicinal plants.

Key words: Fertilization, light intensity, planting density, tea quality, temperature.

INTRODUCTION

Athrixia phylicoides DC (Bush tea) is a native plant of South Africa and is reported to be growing naturally in different climatic conditions of South Africa (van Wyk and Gericke, 2000; Mavundza et al., 2010; Nchabeleng et al., 2012). It is used as a herbal tea and traditional medicine (Rampedi and Olivier, 2005; Nchabeleng et al., 2012), for treatment of various ailments such as boils, acne, infected wounds, cuts, headaches, colds, loss of voice, throat infection as a gargle (Roberts, 1990; Mabogo, 1990; Joubert *et al*., 2008), hypertension, heart disease and diabetes (Rampedi and Olivier, 2005). The Vhavenda people are reported to use extracts from soaked roots and leaves as antihelminthic (Mbambezeli, 2005). It is also used for cleansing or purifying blood (Roberts, 1990; Joubert *et al*., 2008). Various studies have been conducted to determine medicinal properties of bush tea and its benefits (Mudau et al., 2006; Mavundza et al., 2010).

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Botanically, *A. phylicoides* belongs to the family Asteraceae (van Wyk and Gericke, 2000). It is commonly known as bushman's tea (English), Boesmans tee (Afrikaans), Mutshatshaila (Venda), Mohlahlaishi (Pedi), Icholocholo, Itshelo and Umthsanelo in Zulu (Nchabeleng et al., 2012).

Bush tea has been described as an aromatic (Mavundza et al., 2010), perennial evergreen, small pretty shrub, branched with a woolly stem, small dark green pointed leaves, with white woolly barks and small pink daisy flowers with bright yellow centre (Roberts, 1990). The plant flowers appear throughout the year depending on the climatic conditions and edaphic factors, with the best flowering time from March to May (Mbambezeli, 2005). The color of the flowers differs depending on soil types and geographic location (van Wyk and Gericke, 2000).

The active chemical compounds present in herbal tea influence the quality of herbal tea and serve as the main indicators of the medicinal potential due to their antioxidant activities (Mudau et al., 2006). Leaves of bush tea contain 5-hydroxy-6,7,8,3',4',5'-hexamethoxy flavon-3-ol (Mashimbye et al., 2006), 3-0-demethyldigicitrin, 5,6,7,8,3',4'-hexamethoxyflavone and quecertin (Mavundza et al., 2010), antioxidants (Mogotlane et al., 2007), polyphenols (Mudau et al., 2006, 2007a), tannins (Mudau et al., 2007a) and has cytotoxic activities (McGraw et al., 2007). Furthermore, it has been reported that bush tea do not contain caffeine and pyrrolizidine alkaloids (McGraw et al., 2007) making it a desirable feature of a healthy beverage.

The quality of herbal tea is a critical factor (Ravichandran and Parthiban, 1998), influenced by chemical compounds (Owuor et al., 2000). The concentration of chemical compounds such as total flavonoids and phenolics is influenced by biotic and abiotic factors (Fine et al., 2006). Cultural practices such as mineral nutrition (Mudau et al., 2006) and planting density (Kigalu, 2007a) have been shown to have significant influence on tea growth and productivity (Owuor, 1998).

The objective of this paper is to review the effects of nitrogen fertilization, planting density and climatic conditions on growth and productivity of herbal teas and other medicinal plants. The review is meant to provide better insight on effect of nitrogen fertilization, timing of nitrogen fertilization, planting density, eco-physiological parameters and the interaction between plant density and nitrogen fertilization on various chemical compositions on the field grown bush tea.

QUALITY OF HERBAL TEA

Antioxidant activities associated with the compounds such as polyphenols, flavonols and tannins are regarded as indicators of the medicinal potential of herbal tea (Hirasawa et al., 2002). Free amino acids are also regarded as important quality indicators of tea (Cheng et al., 2009). The agronomic quality of tea plants is evaluated by bud length, 100-bud weight, and density of buds indices (Fan et al., 2005). The sensory quality attributes of tea are astringent taste, bitterness, sweetness, and aroma (Hu et al., 2001).

The quality of herbal tea is a critical factor, which determines the price of tea (Ravichandran and Parthiban, 1998), commercialization and export sales (Mudau et al., 2007a). The quality of herbal tea is influenced by chemical compounds (Owuor et al., 1998; Owuor et al., 2000). The chemical composition of tea is complex; and includes polyphenols, alkaloids (caffeine, theophylline and theobromine), amino acids, carbohydrates, proteins, chlorophyll, volatile compounds, minerals, trace elements (Karori et al., 2007), antioxidant and tannins (Maudu et al., 2012). Polyphenolic compounds in the leaves of tea are functional components that are beneficial to human health (Chen et al., 2010).

EFFECT OF CLIMATE ON GROWTH AND PRODUCTIVITY OF HERBAL TEA

Tea is mainly cultivated in tropical and subtropical climates, but commercial cultivation could also be found in temperate areas (den Braber et al., 2011). In order to increase the profitability of the enterprise, tea is grown in diverse regions of varying climates (Owuor et al., 2010). However, the concentrations of total flavonoids and phenolics compounds are influenced by biotic and abiotic factors (Fine et al., 2006). In addition, ecological influence has also been reported on the same cultivars planted in different ecological types synthesising different quantities of flavonoids (Cheng et al., 2009; Ghasemzadeh and Ghasemzadeh, 2011a). Nchabeleng et al. (2012) found that bush tea harvested from different areas and altitude had different chemical compositions, with bush tea grown in high altitudes contained highest polyphenol content compared to bush tea grown in low altitudes of South Africa. In addition, Nchabeleng et al. (2012) also observed a positive correlation between altitude and total polyphenol content as compared to the other climatic and soil factors. On the other hand, the authors found no significant tannin and total antioxidant content in bush tea, regardless of different altitude, rainfall, temperature, soil macro elements and soil pH.

EFFECT OF LIGHT INTENSITY ON GROWTH AND PRODUCTIVITY OF HERBAL TEA

Light is the most imperative factor among all the ecological factors (Ghasemzadeh and Ghasemzadeh, 2011b). It is a source of energy for plant life known to affect plant photosynthesis rate and assimilate accumulation; playing regulatory role, which controls plant growth and development (Sysoeva et al., 2010). Biosynthesis of phenolics and flavonoids requires light, while the formation of flavonoid is absolutely light-dependent (Graham, 1998). There is no work done on bush tea in this regard, but according to den Braber et al. (2011), it is difficult to give details on the optimum range of shade required by the tea plant, however about 50% diffused sunlight is generally required for optimal physiological activity of *Camellia sinensis* tea types. In addition, it has been reported that *Camellia* tea requires long hours of sunshine with an ideal day length of 11¼ h for good vegetative growth (den Braber et al., 2011). The study conducted by Ghasemzadeh et al. (2010) on ginger (*Zingiber officinale*) demonstrated that different light intensities affect the synthesis of phenolics and flavonoids components differently with low light intensity enhancing the synthesis of flavonoids such as quercetin, catechin, epicatechin and naringenin. Ghasemzadeh and Ghasemzadeh (2011b) also demonstrated that shade/low irradiance is able to enhance synthesis of flavonoid compounds and other bioactive compounds such as apigenin. On the other hand, Ghasemzadeh et al. (2011) reported that decreasing light intensity from 790 to 310 µmol decreased the photosynthesis rate and consequently decreased soluble carbohydrate and plant biomass.

EFFECT OF TEMPERATURE ON GROWTH AND PRODUCTIVITY OF HERBAL TEA

Temperature is one of the environmental factors affecting plant growth and development (Lefsrud et al., 2005). It plays a vital role in physical and chemical processes, which in turn controls biological reactions in plants. Significant role in crop physiological cycles such as diffusion rate, liquid changes, solubility of substances, the equilibrium and stability of various systems, compounds and enzymes are functions of temperature (Hasan et al., 1999). Gera et al. (2007) found that carbon accumulation in *Panax quinquefolius* was strongly affected by a 5°C increase in growth temperature. Leaf senescence was accelerated, and photosynthesis and stomata conductance were reduced during the season as the temperature increased. It was concluded that a 5°C increase in temperature is highly detrimental to enhance the productivity of *P. quinquefolius*. The ideal temperature for tea growth is 18 to 30°C. Growth is limited by temperatures above 32 to 35°C and below 12 to 13°C (den Braber et al., 2011). Results obtained from the study conducted by Nchabeleng et al. (2012) showed that minimum and maximum temperatures have a negative correlation with the changes of total tannin content of bush tea grown in locations with different altitudes. In a study conducted to determine effect of fermentation temperature and time on chemical composition of bush tea, Hlahla et al. (2010) found that fermentation temperature has a significant effect on polyphenols. The authors further reported that bush tea fermented at temperatures between 30 and 38°C for 30 min was found to have significantly higher polyphenol content.

EFFECT OF FERTILIZATION ON GROWTH AND PRODUCTIVITY OF HERBAL TEA

In pot trials under 50% shade nets; separate fertilization with nitrogen, and phosphorus (300 kg/ha N and P) and potassium (200 kg/ha K) had been reported to improve growth and yield of bush tea (Mudau et al., 2005), total polyphenols (Mudau et al., 2006), tannins (Mudau et al., 2007a), and total antioxidant activity (Mogotlane et al., 2007). In shaded nursery environment Mudau et al (2007 b, c), found that nitrogen fertilization had significant linear relationships between leaf tissue N and total polyphenol content, regardless of season, which suggests a strong trade-off in nutrients channelled toward the production of phenolics. In contrast Owuor (1998), found that increasing nitrogenous levels in black tea decreased polyphenols.

Hamid et al. (2002) reported that the response of nitrogen at any level depends on the availability of other nutrients. Nitrogen remains one of the main nutrients required for plant growth and yield (Ibrahim et al., 2011a). Tea is grown as perennial monoculture, which requires application of appropriate nitrogen management strategies to avoid decline of its productivity and profitability (Kamau et al., 2008). Fertilizer recommendations vary widely for different tea growing regions depending on the age of the bushes, pruning cycle, yield, and soil fertility. Generally, tea plants need 40 to 200 kg/ha/year of nitrogen during the first 5 to 6 years of growth (den Braber et al., 2011). The production of new shoots and content of nitrogenous compounds, such as free amino acids, which are major quality indicator of green tea, could be increased by application of nitrogen fertilizer (Oh et al., 2006). Quality indicators of green tea such as amino acid and protein content are influenced by soil fertility (Fan et al., 2005).

EFFECT OF PLANTING DENSITY ON GROWTH AND PRODUCTIVITY OF HERBAL TEA

Cultural practices such as planting density have effects on yield (Kigalu and Carr, 2006). Tea is normally planted in single or double rows separated by 1.2 to 1.8 m between the rows to allow access to the bushes for plucking and maintenance (den Braber et al., 2011). Dense planting can improve the early yield and revenue, encouraging early establishment of plantlets and appropriate ground cover, reducing the cost of weeding and minimizing water losses by decrease of surface evaporation and run off (Kigalu, 2007a, 2007b). However, dense planting increases the initial capital costs, as more plants are required per hectare. Therefore, the most effective planting density should be determined from the interaction of various technical and financial factors (Kigalu, 2007a). General standard practice of 10,000 to 20,000 plants/ha are planted in tea growing regions of the world (den Braber et al., 2011).

ECO-PHYSIOLOGICAL PARAMETERS

The production of carbon-based secondary metabolites has been found on two hypotheses, namely the carbon/nutrient balance and the growth differentiation. The carbon/nutrient balance hypothesis states that when nitrogen availability in the soil is low, plant growth is limited than the rate of photosynthesis, which results in plant allocating the extra carbon that cannot be used for growth on the production of carbon based secondary metabolites. Contrary, the growth differentiation balance hypothesis states that nitrogen availability is not the only environmental factor that influences the secondary metabolites production, but the trade-off occurs between all growth and differentiation processes (Haukioja et al., 1998). According to Ibrahim and Jaafar (2011), an increase in carbon-base secondary metabolites frequently occurs when environmental conditions promote the accumulation of total non-structural carbohydrates in *Labisia pumila* Blume plants.The studies conducted by Mudau et al. (2007a, 2007b); demonstrated that there was a significant relationship between leaf tissue nitrogen and total polyphenol content, suggesting the strong trade-off in nutrients channelled towards the production of total polyphenols. In contrast, Ibrahim et al. (2011a) found that as more nitrogen is applied, the leaf tissue nitrogen of *L. pumila* seedlings increased with significant reduction on the production of total phenolics and flavonoids. The increase in production of secondary metabolites is related to the increase in Phenyl-Alanine-lyase (PAL) activities, which has been reported to increases as levels of nitrogen fertilization decreases and decreases as nitrogen fertilization increases (Ibrahim et al., 2011b). According to Ibrahim et al. (2011b) the increase of net photosynthesis is linked with the increase of chlorophyll content due to increase in nitrogen level. Ibrahim et al. (2011a, 2011b) discovered that the increased nitrogen application resulted in a simultaneously and steadily increased net photosynthesis rate, which demonstrated a significant negative relationship with the production of secondary metabolites.

CONCLUSIONS AND RECOMMENDATIONS

Various studies have been conducted to determine the effect of cultural practices such as minerals nutrition on the tea growth and productivity. However, relatively few studies have investigated the response of plant carbon based secondary metabolites (CBSM) on nitrogen fertilization, climatic conditions and plant density, especially on the medicinal and herbal tea. The CBSM topics have a lot of contradictions making it difficult to understand agronomic management of medicinal and herbal plants. This current review serves as a foundation towards a study to investigate the effects of nitrogen fertilization, timing of nitrogen fertilization, planting density and eco-physiological parameters on yield and quality of field grown bush tea. Knowledge and understanding of the importance of the cultural practices such as mineral nutrition (nitrogen fertilization) and planting density on the productivity and quality of bush tea is significant and could lead to viability of commercialization of bush tea industry in South Africa.

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