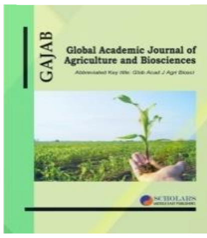
Global Academic Journal of Agriculture and Bio sciences

Available online at https://www.gajrc.com
DOI: 10.36348/gajab.2022.v04i03.002



ISSN:2706-8978 (P)
ISSN: 2707-2568 (O)

Original Research Article

Nitrogen and Tillage Management Impact on Spearmint (*Mentha spicata* L) Yield

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Article History
Received: 01.05.2022
Accepted: 04.06.2022
Published: 30.06.2022

Abstract: There is shortage of information on land preparation and nitrogen application rate for spearmint production in Ethiopia. Thus, a field experiment was conducted at the research site of Wondo Genet Agricultural Research Center (WGARC), Southern Ethiopia, in 2017/18 cropping season to assess the effect of tillage frequency and nitrogen fertilizer rates on growth, yield and essential oil content of spearmint and to evaluate the economic feasibility of treatments for spearmint production. The treatments were consisted of three tillage frequencies [once at the time of planting; twice (1st ten days before planting and 2nd at the time of planting and thrice (1st twenty days before planting, 2nd ten days before planting and 3rd at the time of planting] and five levels of nitrogen (0, 50, 100, 150 and 200 kg N ha^{-1}). Randomized complete block design in a factorial arrangement with three replications was used. Results showed that main effect of tillage frequency and nitrogen fertilizer rates significantly affected fresh stem weight per hectare (FSWPH) and dry herbage biomass per hectare (DHBPH). The highest (2972.58kg ha^{-1}) FSWPH and highest (2973.58kg ha^{-1}) DHBPH were obtained due to three-time tillage. The 200 kg N ha^{-1} gave the highest (3022.70 kg ha^{-1}) FSWPH and highest (3023.71kg ha^{-1}) DHBPH of spearmint. Days to flowering, plant height and dry leaf to stem ratio were significantly affected by interaction of tillage frequency and N rates. Three times tillage at 200 kg N ha^{-1} gave tallest plant (78.97 cm), highest essential oil yield per hectare (57.97 kg ha^{-1}) and delayed days to flowering (94 days) and gave highest (2.67) dry leaf to stem to ratio at 150 kg N ha$^{-1.}$ Fresh leaf to stem ratio and fresh herbage biomass per hectare were significantly affected by interaction of tillage frequency and N rates. The highest (4.40) fresh leaf to stem ratio and the highest (15808.50kg ha^{-1}) fresh herbage biomass per hectare were due to three times tillage at 200 kg N ha^{-1}. The highest (12852.50 kg ha^{-1}) fresh herbage yield per hectare and highest (3113.40 kg ha^{-1}) dry herbage yield per hectare) were obtained at three times tillage when 200kg N ha^{-1} was used. The highest net benefit (8911.79 Birr ha^{-1}) with marginal rate of return (432.01%) was obtained from three times tillage at N fertilizer rate of 100 kg ha^{-1}. Therefore, based on one season study at WGARC it is possible to say that under Wondo Genet and similar areas the highest and economically feasible herb could be produced using three times tillage and 100 kg N ha^{1}.

Keywords: Economic analysis, Essential Oil yield, Herbage yield.

1. INTRODUCTION

Mints comprise a group of species of the genus *Mentha* that belonging to the family *Lamiaceae*. Among mint species, spearmint (*Mentha spicata* L.) is considered industrial crop as it is a source of essential oils enriched in certain monoterpenes like carvol, dihydrocarveole, dihydrocarveylacetate, menthol, menthone, caryophyllene, terpineol and cubebene which is widely used in food (Edris *et al*., 2003), flavor (El-Wahab and Mohamed, 2009), cosmetic and pharmaceutical industries (Foda *et al*., 2010).

Spearmint is well adapted to climatic conditions in tropical and subtropical areas. It can be cultivated in wide range of soils and found in back gardens of homesteads. A climate with adequate and regular rainfall and good sunshine during its growing period ensures a good yield (Shormin *et al*., 2009).

Mint either as herb or its essential oil form is used for flavoring, perfume production and medicinal purposes (Dorman *et al.,* 2003). Mint is valued for its multipurpose uses in the field of pharmaceuticals, cosmetics as well as for flavoring foods beverages and tobacco (Ohloff, 1994). It is also used in oral products e.g. tooth paste and mouth fresheners due to its physiological cooling effect.

Spearmint essential oil has economic relevance due to its use in perfumery, confectionary, and pharmaceutical preparations. Besides its flavoring properties, spearmint is also widely used as an antimicrobial agent and as a preservative in food, mainly on account of the phenolic and terpenoid content (Kivilomplo *et al.,* 2007). The volatile (non-polar) profile of traditional cultivars of spearmint essential oils is mainly constituted by carvone (22%–73%) and limonene (8%–31%), with smaller quantities of 1,8-cineole (4%–7%), menthone (1%–5%), menthol, eucalyptol, and other minor compounds. The profile varies based on plant variety, growth, climate conditions, and harvest time (Telci 2010; Tyagi *et al*. 2011; Silva *et al*., 2013). The antimicrobial activity of these spearmint essential oil components has been widely described in the literature.

The global mint market exceeds billions of dollars. United States of America alone, imports mint leaf of 3000 ton and 798.2-ton essential oil. The farm-gate price of the commercialized mint reached 16 million U.S. Dollars in 2005, which is converted to in finished products (El-Wahab and Mohamed, 2009).

Tillage is one of the important activities in agriculture. It is defined as the mechanical manipulation of the soil for the purpose of crop production affecting significantly the soil characteristics such as soil water conservation, soil temperature, infiltration and evapotranspiration processes. It is carried out mainly to loosen the upper layer of soil, to mix the soil with fertilizer and organic residues, to control weeds, and to create a suitable seedbed for germination and plant growth (Rasmussen, 1999). Some other functions of tillage are to improve soil aeration, and subsequently promote organic N and P mineralization. Tillage and soil fertility influence both nutrient and soil moisture dynamics in the soil–plant system, which in turn affect nutrient use efficiency in a cropping system (Yoong *et al*., 2001; Dinnes *et al.,* 2002).

According to Srivastava *et al*. (2006), the objectives of tillage are to develop a desirable soil structure or suitable tilth for a seedbed. Tillage is crucial for crop establishment, growth and ultimately yield (Atkinson *et al*., 2007). A good soil management program protects the soil from water and wind erosion, provides a good weed-free seedbed for planting, destroys hardpans or compacted layers that may limit root development, and allows maintenance or even an increase of organic matter (Wright *et al*., 2008). Tillage practices influence soil physical, chemical and biological characteristics, which in turn may alter plant growth and yield (Ozpinar and Cay, 2006; Rashidi and Keshavarzpour, 2009).

There are two kinds of tillage based on the frequency or number of tillage. They are conventional and conservation tillage. Conventional tillage is the type of tillage practices in which primary cultivation, such as mould board ploughing is followed by a secondary cultivation to create a favorable seedbed. Conservation tillage is any method that leaves at least one-third of the soil covered with crop residue after planting. It consists of practices ranging from zero tillage (no-till) where new crop is planted in the residues of the previous crop without any prior soil tillage or seed bed preparation and it is possible when all the weeds are controlled by the use of herbicides, reduced (minimum) tillage, mulch tillage, ridge tillage, to contour tillage (Koller, 2003). Conservation agriculture has the purpose to prevent soil erosion and compaction, as well as to save labor and energy costs (Koepke, 2003). For its benefits, conservation agriculture is considered a part of the agricultural practices and agri-environmental measures (Bilalis *et al*., 2011; Garcia-Torres *et al*., 2002).

The tillage system can influence soil N availability due to its impact on soil organic C and N mineralization and subsequent plant N use or accumulation (Sanju and Singh, 2001; Dinnes *et al*., 2002; Al-Kaisi and Licht, 2004; Licht and Al-Kaisi, 2005). Compared with conservation tillage, conventional tillage (CT) system can significantly change the mineralizable C and N pools (Woods and Schuman, 1988). However, a long-term conservation tillage system has potentially greater mineralizable C and N pools compared with conventional tillage (Doran, 1980).

The relationship between yield and fertilization is not only of interest to understand plant growth, but also helps to comprehend the dynamics of nitrogen use efficiency (NUE). The global NUE, which is the share of the nitrogen fertilizer taken up by the crops (NUE = Y/F) is only about 50% (Bodirsky *et al.*, 2012), while the remainder pollutes the air and ecosystems, also harming human health substantially (Sutton *et al*., 2013). A dramatic escalation has occurred in global consumption of synthetic N, from 11.6 million tons in 1961 to 104 million tons in 2006 (Hoang and Alauddin, 2010: Mulvaney and khan*,* 2009). Over 40 years, the amount of mineral N fertilizers applied to agricultural crops increased by 7.4 fold, whereas the overall yield increase was only 2.4 fold (Lazutka *et al*., 2001;Tilman *et al*., 2002).

The plant N use can be altered by the different management practices and interactions between tillage systems, N rate, and N application timing. The interactive effects of different tillage systems, such as no tillage, conservation tillage or minimum tillage and N rate on grain N uptake was significant in increasing N removal with increasing N rate (Halvorson *et al.* 2001).

Working on the different species of *Mentha* Singh *et al.* (1989) reported that herbage and oil yields of *Mentha arvensis* (Japanese mint), *M. piperita* (Peppermint) and *M. spicata (*Spearmint) increased significantly with N fertilization. Plant height, leaf: stem ratio and leaf area index increased with N application. Previous studies have addressed the relationship between different N fertilizers and the growth characters, yield and yield components of spearmint. However, optimum N amount reported for maximum mint growth by different researches are substantially different. It has been reported that mint requires 150-280 kg N ha^{-1} (Brown, 2003).

There are diverse potential and ecological conditions in Ethiopia for cultivation of spearmint. Realizing this and its potential as an essential oil crop; Wondo Genet Agricultural Research Center (WGARC) of Ethiopian Institute of Agricultural Research (EIAR) has been given the national mandate for spearmint improvement practices in the country and the Center has identified and prioritized this crop to work on its improvement through research.

There is no production guideline for land preparation or no research was undertaken to solve the problem facing in crop establishment and there is difficulty in getting uniform stand even in research field. Similarly, no research has been conducted on nitrogen fertilizer in Ethiopia to determine rates for use. Blanket recommendation of 18kg ha^{-1} is being used at the Center (personal observation). This rate is not based on previous work of Brown (2003) and Singh *et al*. (1989).

Tillage and nitrogen rate are two of the several important yield limiting factors in Spearmint production. There is limited information about their effect on agronomic and economical parameters such as leaf and essential oil yield in Ethiopia. Thus, this study was undertaken with the following objectives:

a. to assess the effects of tillage frequencies and nitrogen fertilizer rates on growth, yield and essential oil content of spearmint; and
b. to evaluate the economic feasibility of treatments for spearmint production

MATERIALS AND METHODS

Description of the Study Area: The experiment was conducted during the main cropping season of 2017/18 at Wondo Genet Agricultural Research Center (WGARC). Wondo Genet is found in Sidama Zone of Southern Nations Nationality and Peoples Regional States. The study area is at 266 km South of Addis Ababa and 14 km from the nearest town Shashemene. Geographically Wondo Genet is located at 07° 04' 00.2'' N and 38° 31' 01.8'' and with an altitude of 1780 m.a.s.l. The site receives mean annual rain fall of 1128 mm with minimum and maximum temperature of 11 and 26°c, respectively. The soil textural class of the experimental area is sandy loam with pH of 6.4 (Abayneh *et al*., 2006).

Experimental Material: Spearmint variety WGSM-03 was used. This variety was released in Ethiopia in 2011 (MoA, 2011). The fertilizer materials used were urea and TSP. Medium to fertile deep soil is ideal for the cultivation of this variety.

Soil Sampling and Analysis: Representative soil samples were taken at 0-30 cm depth from different places of experimental field in a zigzag form before planting to make one composite sample and the collected soil sample was air dried in wooden tray, ground and sieved to pass through a 2 mm and 0.02 mm sieves.

The sample was analyzed for pH by using digital pH meter (Page, 1982), organic carbon content of the soil was determined based on oxidation of organic carbon with acid dichromate medium following the Walkley and Black method (Dewis and Freitas, 1970). Total nitrogen, CEC, available phosphorus, particle size (soil texture) was determined by micro-kjeldahl method (Dewis and Freitas, 1970); ammonium acetate method (Cottenie, 1980); Olsen method (Olsen and Dean, 1965); hydrometer method of Bouyoucos (Day, 1965) respectively.

Treatments and Experimental Design

The treatments consisted of three tillage frequencies [once at the time of planting; twice (1st ten days before planting and 2nd at the time of planting and thrice (1st twenty days before planting, 2nd ten days before planting and 3rd at the time of planting) and five levels of nitrogen (0, 50, 100, 150 and 200 kg N ha^{-1}). The experiment was arranged in a factorial randomized complete block design (RCBD) with three replications.

Experimental Procedure

The land was prepared for planting based on each tillage frequency manually using hand hoe. Spearmint was propagated by stolon. Stolon was properly uprooted from plants grown for this purpose at WGARC and prepared by dividing them into runners with roots and was cut in to 10 cm length to be used as a planting material. Properly arranged stolon was planted in rows of a plot by covering the whole stolon with light soil. The spearmint stolon was planted at inter-row spacing of 60 cm and 10 cm intra- row spacing. There were 6 rows per plot. The middle 4 rows were used for sampling purposes. The gross plot area was 3.6 m x 4.2 m =15.12 m^2.

Nitrogen was applied in two splits. One half was applied at the time of planting on July15, 2017 and the remaining one half was applied at the time of first cutting on November 18, 2018. In addition, 50 kg ha^{-1} of P was applied at planting time to each plot uniformly in the form of TSP (Guenther, 1961). Irrigation was used as needed. Weed controls was done by hand. Plants were harvested at maturity when older leaves changed their color to yellow almost three months from planting for first cut and one hand half months for second cut by cutting 10 cm above soil surface. The net plot area was 2.4 m x 4.2 m=10.08 m^2. The four middle rows were used as net plot area for sampling purpose. Samples were taken from net plot area by excluding the two boarder rows. The crop was harvested manually using a sickle at maturity.

DATA COLLECTION

Phenological and Growth Parameters

Days to flowering: Days to flowering was recorded by counting the number of days from planting up to when 50% of plants in the plot flowered nearest to maturity of crop three months from planting.

Tiller number: Tiller number was recorded by counting tiller numbers based on plants fall in 50cm length from an area of 0.5x0.6x5=1.5m2) from the middle 4 rows.

Plant height (cm): Five random plants from the net plot were measured from the soil surface to the tip of matured and longest stem in the plant at maturity.

Yield components and yield of spearmint

Fresh leaf weight/plot (g): Fresh leaf weight was determined by cutting plants from the middle 4 rows of 50cm length (from an area of 0.5x0.6x5=1.5m2). The leaves were separated from stem. The weights of the leaves from five samples were taken using sensitive balance and the average was recorded used for calculation of fresh leaf to stem ratio. Then obtained weight was converted to per hectare.

Dry leaf weight/plot (g): The same sample that was taken to determine the fresh weight was weighted and put separately in bags and dried in an oven at 105°C for 3 hours. The weight of the dry sample was recorded and used for calculation of dry leaf to stem ration. Then obtained weight was converted to per hectare.

Fresh stem weight/ha (kg); Fresh stem weight was determined by cutting plants from the middle 4 rows of 50cm length (from an area of 0.5x0.6x5=1.5m2). The leaves were separated from stem. The weight of stem was taken using sensitive balance and the average was recorded.

Dry stem weight/ha (kg): The same sample that was taken to determine the fresh stem weight was weighted and put separately in bags and dried in an oven at 105°C for 3 hours. Then weight of the dry sample was recorded.

Fresh leaf to stem ratio: obtained by dividing fresh leaf weight to fresh stem weight.

Dry leaf to stem ratio: obtained by dividing dry leaf weight to dry stem weight.

Fresh herbage biomass/ha (kg): It was recorded as the sum of above ground parts of plants fall in 50cm of the middle 5 rows (from an area of 0.5x0.6x5=1.5m2) which was taken randomly, weighted using sensitive balance and the average was recorded.

Dry herbage biomass/ha (kg): The same sample that was taken to determine the fresh herbage weight was weighted and put separately in bags and dried in an oven at 105°C for 3 hours. Then average weight of the dry sample was recorded.

Fresh herbage yield (kg/plot): this was recorded as the sum of above ground which will be cut from 5 randomly selected rows from 50cm length(0.5x0.6x5=1.5m2), which was weighted as soon as harvested using digital balance at maturity. Then obtained weight was converted to per hectare. This was determined by cutting plants from the middle 4 rows of 50cm length (from an area of 0.5x0.6x5=1.5m2). The leaves were separated from stem. The weights of the leaves from five samples were taken using sensitive balance and the average was recorded. Then obtained yield per plot was converted to per hectare.

Dry herbage yield (kg/plot): Dry leaf yield per plot was obtained from the harvested row and converted in to yield (kg/plot). All plants in the central rows of each 5 selected sampling area in 50cm length was harvested and dry leaf yield per plot was estimated by taking composite sample of the leaves and dried in oven at 105°C for 3 hours until a constant weight was reached and then result was recorded. Then obtained weight was converted to per hectare/

Fresh herbage yield (kg/ha): calculated from fresh herbage yield obtained per plot.

Dry herbage yield (kg/ha): calculated from dry herbage yield obtained per plot.

Disease and pest: no pest and disease problem were seen on the crop throughout its growth period. Thus, was not recorded.

Essential oil content (%): it was determined on fresh weight basis from 300g of fresh leaves that were harvested from the middle 4 rows of plots. To get essential oil weight 300g composite sample of fresh herbage weight was used for essential oil extraction by hydro distillation method at each harvesting as described by Rao *et al*. (2005).

$$\text{Percentage of essential oil} = \frac{\text{Essential oil weight(g)}}{\text{Fresh weight(g)}} \text{x100}$$

Essential oil yield (kg/ha): it was calculated from essential oil content.

$$\text{Essential oil yield}\left(\frac{\text{kg}}{\text{ha}}\right) = \frac{\text{Essential oil content X Fresh herbage yield}\left(\frac{\text{kg}}{\text{ha}}\right)}{100}$$

The moisture content of leaf: The moisture content of leaf was determined by taking 10 grams of spearmint from each plot (fresh weight) then the samples were dried in an oven at 105°C for 3 hours then the dry weight was determined and moisture content was calculated as % using the following equation:

$$\text{Moisture Content (\%)} = \frac{\text{Fresh weight(g)} - \text{Dry weight(g)}}{\text{Fresh weight(g)}} \text{ x 100}$$

Data Analysis

All the measured parameters were subjected to analysis of variance (ANOVA) appropriate to factorial experiment in RCBD according to the Generalized Linear Model (GLM) of SAS version 9.0 (SAS, 2004) and interpretations were made following the procedure described by Gomez and Gomez (1984). Whenever the effects of the factors were found to be significant, the mean separation was done by using LSD test at 5% probability level.

Economic Analysis

The economic feasibility of tillage frequency and nitrogen fertilizer rates was evaluated and analyzed (CIMMYT, 1988). Economic analysis was done using the prevailing market prices for inputs at planting and for outputs at the time crop was harvested. The gross field benefit included (the product of field price per kg and the mean adjusted yield for each treatment), the total variable input costs included the sum of variable input cost (cost of tillage, cost of urea and its application). Net benefit based on total variable input cost was calculated as the difference between the gross field benefit and the total variable cost. The average yield was adjusted down words by 10% to reflect the difference between yields of the experimental site and that the farmers could obtain from the same treatment. This is because better management practices were used under experimental condition.

The costs of urea fertilizer and tillage were taken at time of planting and the price of spearmint dry herb per kilogram was taken from WGARC agricultural extension market survey report. Labor cost per treatment for fertilizer application was recorded and used for this analysis. In partial budget analysis, spearmint stem was not used since it is not the economic part of the plant. Similarly essential oil yield was not used since there was not its market price in Ethiopia during this study.

The net return was calculated as total gross return minus total variable cost according to CIMMYT (1988).

NB= (DHYxP)-TVC

Where NB = Net benefit, DHY = Adjusted dry herb yield per hectare, P = Field price per unit of the herb yield and TVC = Total variable cost.

The dominance analysis procedure as described in CIMMYT (1988) was used to select potentially profitable treatments from the range that was tested. The discarded and selected treatments using this technique were referred to as dominated and undominated treatments, respectively. Marginal rate of return was calculated by using the formula;

$$\text{MRR (\%)} = \frac{\text{Change in NB (NBb−NBa)}}{\text{Change in TVC (TVCb−TVCa)}} \text{x}100$$

Where; MRR = Marginal rate of return, NBa = Net benefit with the immediate lower total variable cost, NBb = Net benefit with the next higher total variable cost, TVCa = the immediate lower total variable cost and TVCb = the next highest total variable cost.

The fertilizer cost was calculated for the cost of each fertilizer of urea (1020 Birr 100 kg^{-1}) during planting time. The price of spearmint herb was 10 Birr kg^{-1} (WGARC agricultural Extension market survey report).

RESULTS AND DISCUSSION

Properties of the Experimental Soil

The laboratory analysis results indicated that the experimental soil has pH of 6.71 (Table 1). Spearmint grows well in soil ranging from sandy loam to clay loam and performs well under near neutral pH; the soil pH result was in the range of its growth. The organic carbon content of 1.87% is moderate for this crop. The total N percent of 0.1564 is low for spearmint. Available P of 1.29 ppm and cation exchange capacity (meq /100g soil) of 13.03 are low for the crop. The clay, sand and silt were 38%, 24% and 28%, respectively. Thus, the soil textural class is clay loam. When the results of the analysis are compared with the broad ratings made by Metson (1961), most of the values are in the lower range for plant growth.

Table-1: The result of soil sample analysis before planting

NO	Soil parameters	Result	Remark	References
1.	pH	6.71	Slightly acidic	Landon (1991)
2.	Organic carbon content (%)	1.87	Moderate	Cottenie (1980)
3.	Total nitrogen (%)	0.1564	Low	EthioSIS(2014)
4.	Available phosphorous (ppm)	1.29	Low	EthioSIS(2014)
5.	Cation exchange capacity (meq /100g soil)	13.03	Low	Landon (1991)
6.	Soil texture			
	Clay%	38		
	Sand%	24		
	Silt%	28		
	Textural class	Clay loam		

Phenological and Growth Parameter

Days to flowering

The analysis of variance revealed that tillage frequency and N rate showed highly significant (p<0.01) effect and the interaction significant (p<0.05) effect on days to 50 % flowering (Appendix Table 1). Longest days (94) to reach 50% flowering had been recorded from plants treated with the highest nitrogen rate (200 kg N ha^{-1}) and thrice tillage frequency; followed by second longest days (93.33) to reach 50% flowering when plants treated with thrice tillage and 150 kg N ha^{-1}. On the other hand, zero N (0 kg N ha^{-1}) and once tillage frequency hastened days to flowering (Table 2). The result obtained from this study revealed that the days to flowering were delayed with increment of both tillage frequency and nitrogen fertilizer rates which could be due to the delaying effect of nitrogen fertilizer.

Table-2: Interaction effect of tillage frequency and nitrogen fertilizer rates on days to 50% flowering of spearmint at Wondo Genet.

Tillage frequency	Nitrogen rates (kg ha^{-1})				
	0	50	100	150	200
Once tillage	83.33^{g}	84.33^{ghi}	85.00^{fghi}	85.67^{efgh}	86.67^{ef}
Twice tillage	84.00^{hi}	86.00^{efg}	87.33^{de}	87.00^{e}	89.33^{cd}
Thrice tillage	87.00^{e}	90.00^{bc}	91.00^{b}	93.33^{a}	94.00^{a}
LSD (0.05)	1.69				
CV (%	1.16				

LSD (0.05) = Least Significant Difference at 5% probability level; CV= Coefficient of Variation. Means in table with the same letters are not significantly different at 5% level of significance.

Plant height (cm)

The analysis of variance revealed that tillage frequency and N rates showed very highly significant ($p<0.001$) effect and their interaction was showed significant ($p< 0.05$) effect on plant height (Appendix Table 1).

The tallest plant (78.97cm) was recorded at 200 kg N ha^{-1} rate with three times tillage while the shortest plant (41.60cm) was recorded at N zero (0 kg N ha^{-1}) and one time tillage (Table 3). Generally, as the N rates per hectare and tillage frequency increased the plant height also increased. This might be due to the availability of more growth resources at higher nitrogen rates that ensured favorable condition for the elongation of spearmint plant with optimum vegetative growth. Repeated tillage that facilitates the root penetration, good aeration and soil porosity helped the plants to grow taller. In line with this result, Khurshid *et al*. (2006) reported taller plants in conventional tillage plots as compared to minimum tillage on maize. Also, tillage practices influence soil physical, chemical and biological characteristics, which altered plant growth (Ozpinar and Cay, 2006; Rashidi and Keshavarzpour, 2009). It is established fact that nitrogen is very essential for plant growth because it is a main constituent of proteins, nucleic acid, certain hormones and chlorophyll, which are all important for plant growth (Hopkins, 1997). Similarly, Praszna (1992) on the pepper mint and Ahsan (1999) on the spearmint found that nitrogen fertilization increased the height of plants. The current result is also similar with the work by Brown (2003) and Singh *et al*. (1998) who reported that plant height of spearmint increased by increased application of nitrogen fertilizer.

Table-3: Interaction effect of tillage frequency and nitrogen rates on plant height (cm) of spearmint at Wondo Genet.

Tillage frequency	Nitrogen rates (kg ha^{-1})				
	0	50	100	150	200
Once tillage	41.60^{h}	46.39^{g}	54.67ef	56.26^{e}	65.60^{c}
Twice tillage	52.27^{f}	57.73^{d}	58.60^{d}	64.93^{c}	71.28^{b}
Thrice tillage	56.40^{de}	64.80^{c}	65.89^{c}	70.53^{b}	78.97^{a}
LSD (0.05)	2.9612				
CV (%)	2.93				

LSD (0.05) = Least Significant Difference at 5% probability level; CV= Coefficient of Variation. Means in table with the same letters are not significantly different at 5% level of significance.

Yield Components and Yield of Spearmint

Number of tillers

Tillage frequency, N rates and their interaction had very highly significant ($p< 0.001$) effect on tiller number (Appendix Table 1).

The significantly highest (385.09) number of tillers per plot was recorded at 200 kg N ha^{-1} rate with three times tillage while the lowest (158.41) number of tillers per plot was obtained at nitrogen zero (0 kg N ha^{-1}) and once-tillage (Table 4). The result indicated that as the nitrogen rates per hectare and tillage frequency increased the number of tillers also increased. This might be due to the availability of more growth resources in higher rates of nitrogen and repeated tillage that facilitate the root penetration, good aeration and soil porosity that helps the plant to produce high number of tillers per plot. Thus, adequate supply of soil nutrients, moisture, and oxygen might have encouraged the plant to produce higher number of tillers per plot. Also the result confirms that repeated tillage is crucial for crop establishment, growth and ultimately to yield (Atkinson *et al*., 2007).

Table-4: Interaction effect of tillage frequency and nitrogen rates on number of tillers per plot of spearmint at Wondo Genet.

	Nitrogen rates (kg ha^{-1})				
Tillage frequency	0	50	100	150	200
Once tillage	158.41^{k}	176.41^{jk}	202.72^{hi}	226.24^{fg}	238.00^{f}
Twice tillage	175.71^{jk}	184.59^{ij}	262.59^{e}	284.21^{d}	302.25^{d}
Thrice tillage	185.11^{d}	211.53^{gh}	327.57^{c}	361.92^{b}	385.09^{a}
LSD (5%)	19.065				
CV (%)	4.64				

LSD (0.05) = Least Significant Difference at 5% level significance; CV= coefficient of variation; Means in the table with the same letter are not significantly different at 5% level of significance.

Fresh stem weight per hectare (kg)

The main effect of tillage frequency had significant ($P < 0.05$) and nitrogen rates had highly significant ($P < 0.01$) effect on fresh stem weight per hectare. However, the interaction effect was not significant (Appendix Table 1).

The highest (2972.58 kg ha^{-1}) and the lowest (2708.67 kg ha^{-1}) fresh stem weight per hectare were obtained from plants grown with three and one-time tillage, respectively (Table 5). Even if there was no significant difference between twice and thrice tillage, the increase in yield with repeated tillage indicates that repeated tillage is better than one times tillage.

The highest (3022.70 kg ha^{-1}) fresh stem weight per hectare was obtained at 200 kg N ha^{-1} while the lowest (2510.90 kg ha^{-1}) fresh stem weight per hectare was obtained at no nitrogen (0 kg N ha^{-1}) (Table 5). The results is in conformity with that of Patra *et al* in 1998 who observed that the highest herb in mint with application of NPK.

Table-5: Main effects of tillage frequency and nitrogen fertilizer rates on fresh stem weight per and dry stem weight per hectare of spearmint at Wondo Genet.

Treatments	Fresh stem weight (kg ha^{-1})	Dry stem weight (kg ha^{-1})
Tillage frequency		
Once tillage	2708.67b	1113.84
Twice tillage	2844.52ab	1089.99
Thrice tillage	2972.58a	1038.57
LSD(0.05)	186.47	NS
N levels (kg ha^{-1})		
0	2510.90b	971.30
50	2935.10a	1134.50
100	2813.10a	1080.80
150	2927.90a	1099.30
200	3022.70a	1118.10
LSD	240.73	NS
CV (%)	9.60	19.14

LSD (0.05) = Least Significant Difference at 5% probability level; CV= Coefficient of Variation. Means in table with the same letters are not significantly different at 5% level of significance.

Dry stem weight per hectare (kg)

The dry stem weight per hectare was not significantly affected by both main factors and their interaction (Appendix Table 1).

Even though dry stem weight per hectare was statistically not significant when the tillage frequency increased from once tillage to three times tillage the dry stem weight increased from 1038.57 to 1113.84(Table 5). Similarly, when the nitrogen fertilizer rate increased from no N (0 kg N ha^{-1}) to the higher rate (200kg N ha^{-1}) the dry stem weight increased from 971.30 to 1118.10(Table 5) These results agree with that of Singh et *al.* (1989) that herbage and oil yields of spearmint (*Mentha spicata)* increased with N application.

Fresh leaf to stem ratio

The main effects and the interaction effect had highly significant ($p < 0.01$) effect on fresh leaf to stem ratio (Appendix Table 2).

Three times tillage when combined with 200 kg N ha^{-1} gave highest (4.40) fresh leaf to stem ratio and it is on par with 3.81 which was obtained when thrice tillage was used with 100kg N ha^{-1} while the lowest (2.33) fresh leaf to stem ratio was obtained from two-time tillage at 50 kg N ha^{-1} (Table 6). The maximum fresh leaf to stem ratio at thrice tillage and higher N rate might be due to suitable condition and appropriate doses of N for mint plant This result is in conformity with those of Patra *et al* (1998) who observed that highest leaf to stem ratio due to NPK rate.

Table-6: Interaction effect of tillage frequency and nitrogen fertilizer rates on fresh leaf to stem ratio of spearmint at Wondo Genet.

Tillage frequency	Nitrogen rates (kg ha^{-1})				
	0	50	100	150	200
Once tillage	2.60 ^{d}	2.41 ^{d}	2.43^{d}	2.65^{d}	2.48^{d}
Twice tillage	2.72 ^{d}	2.33 ^{d}	2.57^{d}	2.71^{d}	2.89^{cd}
Thrice tillage	2.42 ^{d}	2.80 ^{d}	3.81^{ab}	3.58^{d}	4.40^{a}
LSD (0.05)	0.724				
CV (%)	15.36				

LSD (0.05) = Least Significant Difference at 5% probability level; CV= Coefficient of Variation. Means in table with the same letters are not significantly different at 5% level of significance.

Dry leaf to stem ratio

Highly significant (P<0.01) effect due to tillage frequency and nitrogen fertilizer rates and significant (P<0.05) effect due to their interaction were obtained on dry leaf to stem ratio (Appendix Table 2). The highest (2.67) dry leaf to stem ratio was recorded due to thrice tillage and 150 kg N ha^{-1} which was at par with 2.64, 2.52 and 2.16 which were obtained when thrice tillage with 200 and 100 kg N ha^{-1} and twice tillage with 200 kg N ha^{-1} was used respectively. While the lowest (1.32) dry leaf to stem ratio was recorded due to once tillage and 50 kg N ha^{-1} (Table 7).

Table-7: Interaction effect of tillage frequency and nitrogen fertilizer rates on dry leaf to stem ratio of spearmint at Wondo Genet.

Tillage frequency	Nitrogen rates (kg/ha)				
	0	50	100	150	200
Once tillage	2.06^{bcd}	1.32^{e}	1.83^{cde}	1.64^{cde}	1.80^{cde}
Twice tillage	1.70^{cde}	1.59^{de}	1.61^{cde}	1.91^{cd}	2.16^{abc}
Thrice tillage	1.65^{cde}	1.60^{de}	2.52^{ab}	2.67^{a}	2.64^{a}
LSD (0.05)	0.5583				
CV (%)	17.45				

LSD (0.05) = Least Significant Difference at 5% level; CV = Coefficient of Variation
Means in the table with the same letter are not significantly different at 5% level of significance.

Fresh herbage biomass per hectare (kg)

Analysis of variance showed tillage frequency, nitrogen rates and interaction effect had highly significant (p < 0.01) effect on fresh herbage biomass per hectare of spearmint (Appendix Table 2).

Three times tillage combined with highest nitrogen rate 200kg N ha^{-1} gave significantly highest (15808.50 kg ha^{-1}) fresh herbage biomass per hectare. The lowest (8248.40 kg ha^{-1}) was obtained due to one-time tillage and no nitrogen (Table 8). In general, fresh herbage biomass increased with increasing rates of N and tillage frequency. This is due to the fact that adequate supply of N is associated with high photosynthetic activity, vigorous growth (Tisdale *et al.*, 2003). High rate of plant growth can be achieved only when sufficient quantities of nitrogen are ready (Mengel, 1979). Since mint is a heavy feeder of plant nutrients and takes up substantial quantities of N the maximum fresh leave weight at higher N rate might be due to appropriate doses of N for mint plant. Also, these results are in conformity with those of. Singh *et al.* (1989) who reported that herbage and oil yields of spearmint (*Mentha spicata* L.*)* increased with N application.

Table-8: Interaction effect of tillage frequency and nitrogen rates on fresh herbage biomass per hectare (kg) of spearmint at Wondo Genet.

Tillage frequency	Nitrogen rates (kg/ha)				
	0	50	100	150	200
Once tillage	8248.40^{h}	9526.10^{fgh}	9387.20^{fgh}	9734.30^{efg}	10471.80^{ef}
Twice tillage	8886.00^{gh}	9569.70^{efgh}	10288.70^{ef}	10855.60^{de}	11970.60^{cd}
Thrice tillage	9690.60^{efg}	10255.40^{ef}	13250.10^{bc}	14308.50^{b}	15808.50^{a}
LSD (0.05)	1322.70				
CV (%)	7.31				

LSD (0.05) = Least Significant Difference at 5% probability level significance; CV= coefficient of variation; NS= non-significant. Means in the table with the same letter are not significantly different at 5% level of significance.

Dry herbage biomass per hectare (kg)

The main effect of tillage frequency and N rate showed significant (P < 0.05) effect on dry herbage biomass weight per hectare of spearmint. However, the interaction effect was not significant (Appendix Table 2).

The highest (2973.58 kg ha^{-1}) and the lowest (2709.68 kg ha^{-1}) dry herbage biomass per plot were obtained from three times and one-time tillage, respectively. Herbage biomass increased as tillage frequency increased (Table 9). This might be due to repeated tillage that created favorable condition for increasing the dry herbage biomass per hectare. The 200 kg N ha^{-1} gave the highest

(3023.70kg) dry herbage biomass of spearmint as compared to all other rates. There was no significant difference among the N rates. Surprisingly, all N rates gave significantly equal biomass as compared to control. The lowest (2511.80kg/ha) dry herbage biomass was obtained due to 0 kg N ha^{-1} (Table 9). These results agree with that of Singh et *al.* (1989) that herbage and oil yields of spearmint (*Mentha spicata)* increased with N application. Takebe *et al*. (1995) reported that increment in leaf dry weight of spinach may be due to a combination of nitrogen with plant matter produced during photosynthesis such as glucose, ascorbic acid, amino acids and protein.

Table-9: Main effect of tillage frequency and nitrogen rates on dry herbage biomass per hectare and essential oil content of spearmint at Wondo Genet.

Treatments	Dry herbage biomass /ha(kg)	Essential oil content (%)
Tillage frequency Once tillage	2709.68b	0.31
Twice tillage	2845.50ab	0.30
Thrice tillage	2973.58a	0.28
LSD(0.05)	186.45	NS
N levels (kg ha^{-1})		
0	2511.80b	0.30
50	2936.10a	0.293
100	2814.10a	0.293
150	2928.90a	0.29
200	3023.70a	0.29
LSD	240.71	NS
CV (%)	8.77	16.04

LSD (0.05) = Least Significant Difference at 5% probability level significance; CV= coefficient of variation; NS= non-significant. Means in the table with the same letter are not significantly different at 5% level of significance.

Fresh herbage yield per hectare (kg)

The analysis of variance (Appendix Table 3) ***indicated that*** tillage frequency, nitrogen rates and the interaction effect had very highly significant ($p< 0.001$) effect on fresh herbage yield per hectare.

The significantly highest fresh herbage yield per hectare (12852.54 kg ha^{-1}) was obtained from three-time tillage at 200kg N ha^{-1} while the lowest fresh leaf weight per plot (5951.87 kg ha^{-1}) was obtained from one-time tillage at 0 kg N ha^{-1}. In general, fresh herbage yield per hectare increased as tillage frequency and N rate increased (Table 10). The highest fresh herbage yield per hectare with repeated tillage and higher nitrogen rate might be due to good soil condition and availability of more resources. This result is in conformity with the work of Patra *et al* in 1998 who reported that the highest herb in mint with NPK doses of 150: 60:60 kg ha^{-1} respectively. This improvement of vegetation growth may be due to the element of nitrogen which involved in many biological processes inside the plant, including photosynthesis and encourages vegetation growth so increase the growth of plants, elongate, enlarge and brighten leaves (Abu Dahi and Alyunis, 1988). High rate of plant growth can be achieved only when sufficient quantities of nitrogen are ready (Mengel, 1979). Since mint is a heavy feeder of plant nutrients and takes up substantial quantities of N the maximum fresh leave weight at higher N rate might be due to appropriate doses of N for mint plant. Also, these results are in conformity with Singh *et al.* (1989) who reported that herbage and oil yields of spearmint (*Mentha spicata* L.*)* increased with N application. Others (Ram *et al.*1995: Patra *et al.*1998: Anwar *et al.*2002 and Kiran *et al.*2003) reported that the highest herbage yield in mint due to increased rates of nitrogen.

Table-10: Interaction effect of tillage frequency and nitrogen fertilizer rates on fresh herbage yield per hectare (kg ha^{-1}) of spearmint at Wondo Genet.

Tillage frequency	Nitrogen rates (kg ha^{-1})				
	0	50	100	150	200
Once tillage	5951.87 f	6733.13 def	6627.42de	7052.42def	7459.83de
Twice tillage	6485.71ef	6689.64 def	7396.03de	7966.84cd	8874.44c
Thrice tillage	6854.37 def	7123.13 def	10467.38b	11151.30b	12852.54 a
LSD (5%)	1326.9				
CV (%)	9.95				

LSD (0.05) = Least Significant Difference at 5% level; CV= Coefficient of Variation
Means in the table with the same letter are not significantly different at 5% level of significance.

Dry herbage yield per hectare (kg)

The analysis of variance (Appendix Table 3) ***indicated that*** tillage frequency, nitrogen rates and the interaction effect had very highly significant (P< 0.001) effect on dry herbage yield per hectare of spearmint.

The significantly highest dry herbage yield per (3113.44 kg ha^{-1}) was obtained from three-time tillage at 200 N kg ha^{-1} while the lowest herbage yield (1496.55 kg ha^{-1}) was obtained from one-time tillage at 0 N kg ha^{-1}(Table 11). The higher dry herbage yield per hectare with more tillage and higher nitrogen rate might be due to good soil condition and availability of more resources. This result is in line with that of Chang (1987) who founds that increase in nitrogen fertilization caused increasing of dry matter in two types of mint. Also, similar result was reported by (Clark and Manary, 1980) in peppermint and Duriyaprapan *et al* (1986) in Japanese mint. Tei *et al.* (2000) reported that increasing rate of nitrogen fertilizer application significantly increased dry matter weight of leaves Lettuce.

Table-11: Interaction effect of tillage frequency and nitrogen fertilizer rates on dry herbage yield kg ha^{-1} of spearmint at Wondo Genet.

Tillage frequency	Nitrogen rates (kg ha^{-1})				
	0	50	100	150	200
Once tillage	1496.55^{g}	1598.02^{fg}	1718.94^{defg}	1888.60^{de}	1931.12^{d}
Twice tillage	1571.09^{fg}	1657.16^{efg}	1768.31^{def}	1892.47^{de}	2350.19^{c}
Thrice tillage	1728.81^{defg}	1647.8 1^{efg}	2838.62^{b}	2738.16^{b}	3113.44^{a}
LSD (5%)	254.35				
CV (%)	7.62				

LSD (0.05) = Least Significant Difference at 5% level; CV= Coefficient of Variation. Means in the table with the same letter are not significantly different at 5% level of significance.

Essential Oil

Essential oil content (%)

The essential oil content was not significantly affected by tillage frequency and nitrogen fertilizer rates and their interaction (Appendix Table 3).

Essential oil yield per hectare (kg)

The analysis of variance indicated that the interaction effect of tillage frequency and nitrogen fertilizer rates had significant ($p<0.05$) effect on essential oil yield of spearmint (Appendix Table 3).

Three-time tillage and nitrogen fertilizer rate at 200 kg N ha^{-1} produced highest essential oil yield (57.97 kg ha^{-1}) while the lowest (22.10 kg ha^{-1}) was due to once tillage with no N (Table 12). The higher essential oil yield with increasing rate of fertilizer application and repeated tillage might be due to higher growth rate that resulted in more yield. Lower production of oil yield at N zero might be due to unavailability of nutrients for proper production during growth period (Chattopadhyay and Gupta, 1999). Similarly, Piccaglia *et al* (1993), reported that some agronomic factor such as planting date, nitrogen and phosphorus inputs, crop age affected the essential oil content of mint.

Table-12: Interaction effect of tillage frequency and nitrogen fertilizer rates on essential oil yield of spearmint at Wondo Genet

Tillage frequency	Nitrogen rates (kg ha^{-1})				
	0	50	100	150	200
Once tillage	22.10^{e}	22.44^{e}	27.06^{cde}	30.48^{cde}	25.13^{de}
Twice tillage	25.51^{de}	32.29^{bcde}	31.49^{bcde}	28.06^{cde}	30.48^{cde}
Thrice tillage	35.44^{bcd}	27.27^{cde}	42.72^{b}	37.71^{bc}	57.97^{a}
LSD (5%)	11.4				
CV (%)	21.46				

LSD (0.05) = Least Significant Difference at 5% level; CV= Coefficient of Variation. Means in the table with the same letter are not significantly different at 5% level of significance.

Economic Analysis

Partial budget analysis revealed that the highest net benefit (20223.58 Birr ha^{-1}) with marginal rate of return (432.01%) was recorded from three times tillage at the nitrogen fertilizer rate of 100 kg N ha^{-1} (Table 13). The dominated treatments according to the dominance analysis were eliminated from further economic analysis. To identify treatments with the optimum return to the farmer's investment, marginal analysis was performed on non-dominated treatments. For a treatment to be considered as a worthwhile option to farmers, the marginal rates of return need to be at least between 50% and 100% (CIMMYT, 1988). Thus, to draw farmers' recommendations from marginal analysis in this study, 100% return to the investment is reasonable minimum acceptable rate of return. Therefore, Marginal rate of return obtained when three times tillage and 100 kg N ha^{-1} were used is above the minimum acceptable rate of return (Table 13).

The result revealed that using three times tillage and 100 kg N ha^{-1} is cost effective as compared to others and can be recommended for spearmint production in Wondo Genet and other areas with similar agro-ecology condition.

Table-13: Partial budget analysis for tillage frequency and N fertilizer rates

Treatments		Adjusted herb yield downward by 10 % (ETB ha^{1})	N fertilizer cost (ETB ha^{-1})	Fertilizer application cost (ETB ha^{-1})	Tillage cost (ETB ha^{-1})	Gross benefit (ETB ha^{-1})	Total variable cost (ETB ha^{-1})	Net benefit (ETB ha^{-1})	MRR (%)
TF	N fertilizer rates (kg N ha^{-1})								
1	0	1346.90	0	0	800	13468.96	800	12668.96	
1	50	1438.22	1112	350	800	14382.18	2262	12120.18	D
1	100	1547.05	2224	700	800	15470.46	3724	11746.46	D
1	150	1699.74	3336	1050	800	16997.40	5186	11811.40	D
1	200	1738.05	4448	1400	800	17380.08	6648	10732.08	D
2	0	1413.98	0	0	1600	14139.82	1600	12539.82	D
2	50	1491.44	1112	350	1600	14914.80	3062	11852.44	D
2	100	1591.48	2224	700	1600	17032.24	4524	11390.80	D
2	150	1703.22	3336	1050	1600	21152.72	5986	11046.24	D
2	200	2115.17	4448	1400	1600	15559.30	7448	13703.72	3.15%
3	0	1555.93	0	0	2400	14830.30	2400	13159.30	D
3	50	1481.03	1112	350	2400	25547.58	3862	10968.30	D
3	100	2554.76	2224	700	2400	25547.58	5324	20223.58	432.01%
3	150	2464.34	3336	1050	2400	24643.44	6786	17857.44	D
3	200	2802.10	4448	1400	2400	28020.96	8248	19772.96	D

Where D = dominated treatments; Cost of urea 1020.00 ETB 100 kg^{-1} or 11.12 ETB kg^{-1} of N; Labor cost for N fertilizer application = 5-person day ha^{-1}, at 35 ETB day^{-1}; sale price of spearmint dried leaves 10 ETB kg^{-1} (WGARC agricultural economics and extension process market survey report). TF= tillage frequency

NB: The economic analysis was made by excluding essential oil yield due to absence of current market price of spearmint essential oil in Ethiopia

SUMMARY AND CONCLUSION

The study results of this experiment showed that main effect of tillage frequency significantly affected fresh stem weight per hectare (FSWPH) and dry herbage biomass per hectare (DHBPH). Three-time tillage gave the highest FSWPH (2972.58kg ha^{-1}) and DHBPH (2973.58kg ha^{-1}). Similarly, the main effect of nitrogen fertilizer rates was highly significant on FSWPH and DHBPH. The highest (3022.70 kg ha^{-1}) fresh stem weight per hectare and the highest (3023.70 kg ha^{-1}) dry herbage biomass per hectare were obtained from the highest N rate.

There were significant interaction effect of tillage frequency and nitrogen fertilizer rates on days to flowering, plant height and dry leaf to stem ratio. Delayed (94 days) days to flowering, tallest (78.97cm) plant and highest (57.97 kg ha^{-1}) essential oil yield per hectare were due to three times tillage at 200 kg N ha^{-1}. Highest (2.67) dry leaf to stem to ratio was due to three times tillage at 150 kg N ha^{-1}.

Interaction of tillage frequency and N fertilizer rates showed a highly significant effect on fresh leaf to stem ratio and fresh herbage biomass per hectare. Three times tillage at 200kg N ha^{-1} produced the highest (4.40) fresh leaf to stem ratio and the highest (15808.50 kg ha^{-1}) fresh herbage biomass per hectare.

Fresh herbage yield per hectare and dry herbage yield per hectare were very highly significantly affected by the interaction effects of tillage frequency and nitrogen fertilizer rates. The highest (12852.50 kg ha^{-1}) fresh herbage yield per hectare and the highest (3113.40 kg ha^{-1}) dry herbage yield per hectare were obtained at three times tillage with 200kg N ha^{-1}.

Partial budget analysis revealed that the highest net benefit (20223.58 Birr ha^{-1}) with marginal rate of return (432.01%) was recorded from three times tillage at 100 kg N ha^{-1}. The result revealed that using three times tillage and 100 kg N ha^{-1} is cost effective as compared to others.

Therefore, as a conclusion it is possible to say that under Wondo Genet and similar areas the highest and economically feasible herb could be produced using three times tillage and 100 kg N ha^{-1}. However, the experiment needs to be repeated over location and years with the consideration of different varieties.

ACKNOWLEDGEMENT

I would like to express my deepest and heartfelt thanks to my major advisor Dr. Ketema Belete for his keen interest, consistent guidance, critical review and commenting throughout the course of this research starting from proposal development up to the final thesis write up. I also would like to extend my thanks to my co-advisor Prof. Tamado Tana, for his invaluable and precious comments, critical review and constant encouragements.

My gratitude also goes to my Institute Ethiopian Institute of Agricultural Research (EIAR) for allowing me the study leave and full financial support. I am grateful to my center the Wondo Genet Agricultural Research Center (WGARC) for technical and material supports during the execution of the research work. I would also like to extend my thanks to the staff members of the Center particularly to technology development, crop process, socioeconomics, natural products laboratory and land and water management process for their field, material and technical supports.

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APPENDICES

Appendix Table 1 Mean squares of ANOVA for days to flowering (DTF), plant height (PH), tiller number per plot (TNP), fresh stem weight per hectare (FSWPH), dry stem weight per hectare (DSWPH) of spearmint as affected by tillage frequency (TF) and nitrogen fertilizer rates (NR).

Source of variation	DF	DTF	PH	TNP	FSWPH	DSWPH
REP	2	0.62	210.55	5860.64	40430.15	340384.46
TF	2	147.36***	782.75***	33350.00***	246070.95*	22193.37
NR	4	33.86***	605.72***	32943.48***	261271.62**	37374.84
TF*NR	8	2.36*	9.58*	2589.87***	358193.49	32181.89
ERROR	28	1.027	3.13	129.94	62149.03	42784.80
CV (%)		1.16	2.93	4.64	8.77	19.14

DF = Degree of freedom*** very highly significant, **=highly significant, * =significant.

Appendix Table-2: Mean squares of ANOVA for fresh leaf to stem ratio (FLSR), dry leaf to stem ratio (DLSR), fresh herbage biomass per hectare (FHBPH) and dry herbage biomass per hectare (DHBPH) of spearmint as affected by tillage frequency (TF) and nitrogen fertilizer rates (NR).

Source of variation	DF	FLSR	DLSR	FHBPH	DHBPH	
REP	2	0.25	1.56	1354348.09	246030.94	15626.49
TF	2	2.64***	1.04**	40974862.18***	261227.85*	16591.79*
NR	4	1.16**	0.66**	20273689.67***	358200.57*	28746.72**
TF*NR	8	0.76**	0.31*	3278332.98**	68732.17	
ERROR	28	0.187	0.11	625391.70	62140.38	
CV (%)		15.36	17.45	7.31	8.77	

DF = Degree of freedom ***=very highly significant, **=highly significant, * =significant.

Appendix Tabl-3: Mean squares of ANOVA for fresh herbage yield per hectare (FHYH), dry herbage yield per hectare (DHYH), essential oil content (EOC), essential oil yield per hectare (EOYH) of spearmint as affected by tillage frequency (TF) and nitrogen fertilizer rates (NR).

Source of variation	DF	FHYH	DHYH	EOC	EOYH
REP	2	779722.35	8765.87	0.01626	156.95
TF	2	34953482.95***	2015250.87***	0.00437	425.23***
NR	4	16404195.95***	1243072.54***	0.00027	154.08**
TF*NR	8	3928912.19***	856836.618***	0.00183	52.77*
ERROR	28	629493.8	23127.91	0.0022	17.73
CV (%)		9.95	7.62	16.04	17.88

DF = Degree of freedom ***=very highly significant, **=highly significant, * =significant