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Effects of Water Stress, Nitrogen, Magnesium and their Interactions on Some Growth Characteristics and Essential Oil content of Rosemary (*Rosmarinus officinalis* L.)

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Abstract:
A factorial experiment was applied with four replicates on rosemary plants (*Rosmarinus officinalis* L.) grown in pots inside the glasshouse of the Department of Biology, College of Science, Salahaddin University, Erbil, Iraq, during April, 2019 to July, 2020, to determine the effects of soil moisture content (SM1: 100% and SM2: 60% field capacity), nitrogen fertilizer (N1: 100, N2: 200 and N3: 300kg/hectare), and magnesium fertilizer (Mg1: 0.0, Mg2: 30 and Mg3: 60kg/hectare) and their interactions on some growth characteristics and essential oil content of rosemary plants. Two cuttings were taken from rosemary shoots (on March, 2020 and July, 2020) after 12 and 15 months of planting respectively. Results showed that cutting 1: SM2 decreased plant height, number of branches, Shoot fresh weight (FW), shoot dry weight (DW), leaves DW & stem DW. N3 increased plant height, number of branches, Shoot FW, shoot DW, leaves DW, stems FW & stem DW. Interaction treatment SM1N3Mg3 increased plant height, Shoot FW, shoot DW, leaves DW, stems FW and stem DW, while in cutting 2: SM2 decreased shoot DW, stems FW and stem DW. N3 increased Shoot FW and stem DW. Mg3 increased Root FW, but decreased stems FW. SM1N3Mg1 increased stem DW. In cutting 1+ cutting 2, SM2 decreased accumulative stem DW and biological yield FW. N3 increased accumulative Shoot FW; Accumulative leaves DW, accumulative stem FW, accumulative yield FW and biological yield DW**.** Mg3 increased biological yield FW, while SM1N3Mg3 treatment increased accumulative shoot DW, accumulative leaves DW, biological yield FW, and biological yield DW. In the second harvest, SM2 and Mg2 decreased rosemary essential oil %, N3 and SM1N3Mg2 increased EO% and concrete content, while SM1Mg2 increased EO.

Keywords: Rosemary, Water Stress, Nitrogen, Magnesium, Essential oil.

Introduction:
Rosemary (*Rosmarinus officinalis* L.) is an aromatic medicinal plant, grown under a wide range of climates, endogenous to Europe, Asia and Africa, mainly in areas surrounding the Mediterranean Sea[1] . The plant is one of the Mediterranean aromatic shrubs containing phytochemicals with flavoring and pharmaceutical uses. The plant is impressive and handsome at all times, especially when covered with its lovely flowers that attract butterflies and bees (Fig. 1). Rosemary is a member of Lamiaceae family and well known for its biologically active essential oils [2] .The plant is cultivated mainly for essential oil production, food industry, medicine and in cosmetics[3]. The volatile oil of rosemary is used as perfume in soaps, shampoos and ointments. Morocco, Spain, USA, and Tunisia are considered as leading countries in production of rosemary essential oil[4]. Rosemary contains different chemical compounds such as phenolic acids, flavonoids, essential oils, triterpenic acids and triterpenic alcohols[5]. These chemical components, such as essential oils, are present in small concentrations in the plant tissues and organs. Rosemary production depends upon several biotic and abiotic factors such as soil moisture content, nutrient elements availability, environmental conditions such as light intensity and duration and others [6,7].

Soil moisture content is the most important factor in plant producing; plants absorb about 500 g of water to produce every gram of organic matter. Water makes up most of the mass of plant cells and water is considered a medium that most of the biochemical reactions and activities occur in through the plant life [8], therefore water stress affects negatively on plant growth, development and production. It was reported that water deficit altered the morphology of rosemary plants, reduced growth parameters, oil yield, and photosynthetic productivity [9,10].

Figure 1. Rosemary plant (shoots and flowers).

Nitrogen fertilization is considered the main factor for increasing plant production [11], it plays an important role in various physiological processes. Nitrogen imparts dark-green color in plants, promotes leaves, stem, roots and other plant tissues growth and development and considered an essential constituent of proteins, amino acids, and chlorophyll. Nitrogen affected positively on the plant growth and increased their content of effective compounds such as volatile oils [12,13]. Magnesium (Mg) is one of the essential elements in plant nutrition because of its effectiveness on many physiological processes in the plant, such as photosynthesis and enzyme activation [14] , in addition to the presence of magnesium ion in the center of the chlorophyll molecule[15] .Magnesium plays important roles in many physiological activities such as formation and development of sink organs like seeds and roots[16]. Mg deficiency mostly occurs in the regions where highly acidic weathered soils are spread with its more removal from soils takes place [17]. Magnesium deficiency affects negatively on photosynthesis and carbohydrate partitioning in plants [18].

Material and Methods:

A factorial pot experiment (2x3x3) was applied according to Completely Randomized Design (CRD) with four replications. The first factor was soil moisture (SM) (100% and 60% field capacity (FC)), the second factor was Nitrogen fertilizer (100, 200 and 300kg/ha), and the third factor was Magnesium (0.0, 30 and 60kg/ha). A sample of the soil used in the experiment was prepared after air drying, then grind and passed through a sieve with holes diameter of 2 mm. The soil sample was analyzed in the central laboratory of the College of Agriculture/ University of Mosul- Iraq (Table 1). Some soil minerals were estimated using X-ray Fluorescence (XRF) apparatus[19,20]. Nitrogen was estimated by Kjeldahl method, Potassium estimated by Spectrophotometer method, Mg and total phosphorus determined as mentioned by [21]. The field capacity (FC) of the soil was estimated using the method described [22] which was 35%. Soil texture was evaluated using the pipette method [23]. Organic matter was estimated in dry burning method [24], and pH was calculated using a PH meter, and the electrical conductivity (EC) of the soil was measured using an EC meter [25].

Table 1. Some chemical and physical properties of the soil used in the study.

	Parameters	value
physical properites	Soil Texture	Sandy loam
	Soil Structure	Sand:70.80 %
		Clay:7.95 %
		Silt:21.25 %
	PH	7
	EC	1.00 (ml s cm-1)
chemical properites	N	0.35 %
	P	4.29 ppm
	K	4743.445 ppm
	Ca	101.892 (g kg-1)
	Mg	15 ppm
	Mn	740.379 ppm
	Fe	34560.802 ppm
	Zn	58.220 ppm

Rosemary plants were obtained from nurseries of Erbil Governorate, classified and identified by the herbarium of Biology Department/ College of Education/ University of Salahaddin- Erbil. Cuttings for implanting occurred in mid-April by selecting a healthy looking rosemary plants (more than one year old) with lots of young new growing branches on it [26]. using a sharp knife to take 7.5cm tall cuttings from young shoots just below the leaf joint at the stem. Leaves were stripped from the lower 4 cm, pulling them off by fingers; the cuttings were immersed two minutes in a solution (1000 ppm) of Indole-3-Butiric acid [27]. Pots were irrigated as needed according to field capacities. After 14 days of planting, the thinning and replanting processes were done to all pots in the study.

Nitrogen fertilizer doses (100, 200 and 300 kg/hectare) were prepared from urea (46% N) and Magnesium doses (0.0, 30 and 60 kg/hectare) were prepared from Magnesium oxide MgO (56% Mg). Fertilizers were foliar applied on rosemary plant shoots once, except the nitrogen fertilizer which was applied in two equal half doses, the first half was applied in the same time of spraying other fertilizers and the second half was applied two months before harvesting, using hand sprayer. Tween 40 was used at 1:1000 (V: V) to the spray solution as a surfactant. Irrigation was carried out as needed using tap water according to the field capacities [28,29]. Plant shoots were harvested by cutting the shoots 15 cm above the ground on April, after twelve months of planting (1st cutting) and July (2nd cutting) respectively. Shoot fresh weights were registered and then dried in perforated paper bags (with holes) for ten days at room temperature with continuous stirring on both sides [26].

Plant growth characteristics:

The following growth parameters were registered for cutting 1 and cutting 2**.**

Plant height (HT) cm:

Number of branches (No.B) (branch/plant):

Branches (with 15 cm long and over) were recorded.

Stem diameter (St. D) mm:

Stem diameter was determined using hand caliper micrometer at the maturity stage before harvest.

Shoot fresh weight (Sh. FW) (g/plant):

Shoots were cut from the soil surface point in 1st cutting to leave the branches grow until the 2nd cutting time, then weighted using electronic precision balance (KD-TBED-600 max: 600g, min: 0.2g, d= 0.01g).

Leaves, and stem fresh weight (L &St. FW) (g/plant)

Leaves, and stem dry weight (L &St. DW) (g/plant):

The samples were air-dried in paper bags for ten days with constant stirring on both sides then weighted.

Shoot dry weight (Sh. DW) (g/plant)

Root fresh weight (RFW) (g/ plant):

Root fresh weights were calculated after washing the roots by tap water to remove all the soil granules then weighted.

Root dry weight (RDW) (g/plant):

Root dry weight was measured as the same as shown above in shoot dry weight, recorded at the end of growth periods in the 2nd cutting only.

Biological yield of fresh weight (Bio. YFW g / plant):

Bio.YDW (g /plant) = (shoots fresh weight (g/ plant Cut.1) + shoots fresh weight (g/ plant Cut.2) + roots fresh weight (g. /plant)

Biological yield of dry weight (Bio.YDW g/ plant)
Determination of Essential oil and concrete content in rosemary plant leaves (cut2):
Ten g of dry leaves (cut2) were extracted with 100 ml of n-hexane as a solvent in a Soxhlet apparatus for two hours, n-hexane was evaporated by rotary evaporator and rosemary concrete (a waxy, greenish semi-solid material) was obtained. The concrete was weighted for each sample, then dissolved in 15ml of Ethanol 95 % , alcoholic solution was cooled and filtered through filter paper at -18°C in freezer, ethanol with volatile oil (essential oils) passed throw the filter paper, while the fixed oil and wax particles were stay on the filter paper. The weight of concrete was recorded, also RMEO was determined using spectrophotometer at 300nm, using the calibration curve (Fig.2), constructed by dissolving pure RMEO in ethanol at 1:4 (V: V), then a series of standard solutions were prepared, which were measured spectrophotometrically, ethanol 95% was used as blank [30,31].

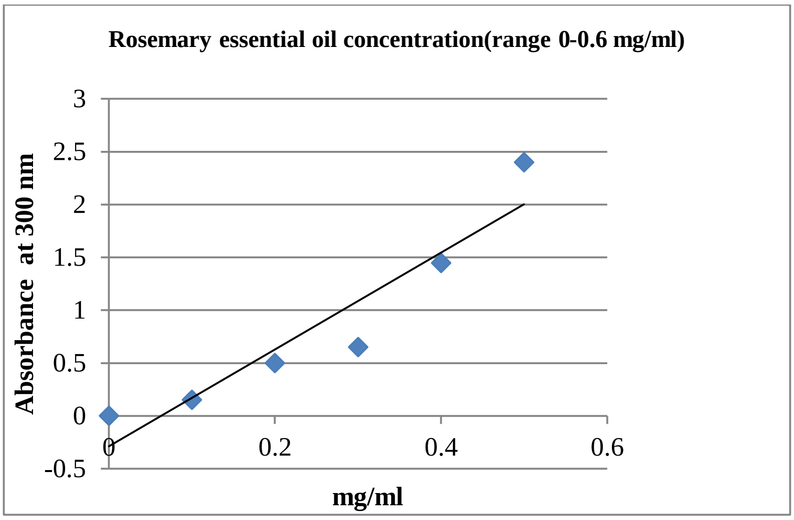

Figure 2. Calibration curve for evaluation rosemary essential oil concentration.

The concrete and EO% in rosemary leaves in (cut 2) were calculated according the following equations:
Concrete % = [concrete weight (g) / Dry weight of the sample (g)] × 100
RMEO yield % = [Essential oil weight (g) / Dry weight of the sample (g)] × 100

Statistical Analysis:
Data was analyzed statistically according to statistical package for the social sciences (SPSS) program, Version 24 and the means were compared using Duncan Multiple Range Test at probability 0.05 of significance.

Results and Discussions:
1. First cutting (Cut.1):
Effects of Soil Moisture, Nitrogen and Magnesium application and their interactions on plant height cm. (PH):
Table 2 shows that water deficit (soil moisture 60% FC) decreased plant height significantly (37.6cm) compared to SM1 (100% FC) which registered 38.2 cm. This result is in agreement with results obtained by[32]. Water deficit also affected negatively on stomatal conductance and cellular turgor pressure, therefore affects negatively on plant growth, cell expansion and plant height.
Nitrogen applied at 300kg/hectare N3 caused a significant increase in PH 38.9 cm, this result is in agreement with results of [33,34], but it didn't agree with results of [35]. The interaction treatment SM2N1 decreased the PH significantly to 34.9 cm; N1Mg1 also decreased the rosemary PH significantly to 35 cm, which was in term with results of [36]. Triple interaction treatment SM2N1Mg1 decreased the PH significantly (31.62cm) compared to other triple interaction treatments.
Effects of Soil Moisture, Nitrogen and Magnesium application and their interactions on number of branches (No.B), (branch/plant):
Water deficiency caused decrease in No. B of rosemary plants significantly to 4.47 compared to 5.0 for SM1 when water was abundant. It was reported that water deficiency reduced the growth parameters of rosemary plants, such as No.B (10). Nitrogen shortage N1&N2 decreased No.B significantly 4.458 & 4.250 respectively the result is in agreement with results of [35]. Interaction treatment decreased No.B significantly to 3.750. Interaction treatment SM2Mg1 also decreased No.B to 4.0 compared to 5.417 branches for SM1Mg2.

Interaction treatments N1Mg1and N2Mg1decreased No. B significantly to 3.875 and 3.750 respectively. Triple interaction treatments SM2N1Mg1 and SM1N2Mg1 decreased also No.B significantly to 2.75 and 3.75 respectively (Table 2). It was reported that water deficiency decrease plant height, number of branches and fresh and dry weights of plant significantly [37].

Effects of Soil Moisture, Nitrogen and Magnesium application and their interactions on shoot fresh weight (Sh. FW g/plant):

Table 2, shows that SM2 decreased rosemary shoot fresh weight significantly 23.613g. Researchers demonstrated that the shortage in soil moisture content decreases plant growth characteristics such as plant weight and plant height 32. N3 increased the plant Sh. FW significantly to 30.23g compared to N1&N2 21.128 &23.059g respectively. Researchers showed that nitrogen application caused significant increases in the accumulated dry mass of the aerial plant parts [38]. Interaction between soil moisture and nitrogen doses affected significantly on Sh. FW, so SM1N3 was superior and registered the highest Sh. FW 33.014g. Interaction treatments N3Mg1, N3Mg2 and N3Mg3 also increased the Sh. FW significantly. Triple interaction treatment SM1N3Mg3 also increased the Sh. FW significantly to 35.655g and was superior compared to other triple interaction treatments.

Effects of Soil Moisture, Nitrogen and Magnesium application and their interactions on shoot dry weight (Sh. DW g/ plant):

Table 2 shows that SM2 decreased rosemary Sh. DW significantly (8.805g) compared to SM1 which registered 9.479g. N3 increased the plant Sh. DW significantly to 11.063g. Interaction between soil moisture and nitrogen doses effected significantly on Sh. DW and SM1N3 was superior and registered the highest Sh. DW 11.9 g. Interaction treatments N_3Mg_1, N_3Mg_2 and N_3Mg_3 increased the Sh. DW significantly. Triple interaction treatments $SM1N_3Mg_3$ & $SM1N_3Mg_1$ also increased the Sh. DW significantly to 13.075 &11.48g respectively. Results are in agreement with those obtained by [39,40].

Effects of Soil Moisture, Nitrogen and Magnesium application and their interactions on leaves dry weight (LDW g/ plant):

Table 2 shows that SM2 decreased rosemary leaves dry weight significantly 7.613g compared to SM1 which registered 8.162 g, but N3 increased the plant LDW significantly to 9.489g and the result does not agree with the results of [41]. Interaction between SM and N doses affected significantly on LDW, SM1N3 was superior and registered the highest LDW (10.168g). Interaction treatments N3Mg1, N3Mg2 and N3mg3 increased the LDW significantly. Triple interaction treatment SM1N3Mg3 also increased the LDW significantly to 11.193g.

Effects of Soil Moisture, Nitrogen and Magnesium application and their interactions on stems dry weight (St. DW g/ plant):

Nitrogen fertilizer at 300kg/ha increased rosemary stem dry weight significantly (1.574g). SM1N3 also increased LDW significantly (1.792g). Interaction treatments N3Mg1, N3Mg2 and N3Mg3 also increased the LDW significantly. Triple interaction treatments SM1N3Mg1 and SM1N3Mg3 increased the LDW significantly to 1.903g and 1.883g respectively.

Effects of Soil Moisture, Nitrogen and Magnesium application and their interactions on basal stem diameter (St. D mm):

Significant drop in stem diameter was registered in SM2 3.49mm compared to 3.74mm in SM1, which was in term with the results obtained by [10], who reported that deficit irrigation significantly reduced growth parameters. Interaction treatment SM2N1 also registered a significant decrease in St. D 3.24 mm. But triple interaction treatment SM1N3Mg3 caused a significant increase in St. D of rosemary plants 3.995mm, which was the highest value, while the lowest value was recorded in triple interaction treatment SM2N1Mg1 3.02mm, and results did not match with results of [36].

Table 2. Effects of Soil Moisture, Nitrogen, Magnesium and their interactions on some vegetative growth characteristics and yield cut1 in rosemary plants.

Treatments	plant height (cm)		No. of branches/plant		shoots FW g/plant cut1		shoots DW g/plant cut1		leaves DW g/plant cut1		stems g/plant DW cut1		stem diameter mm (cut 1)	
SM1(100%)F.C.	38.181	a	4.97	a	25.999	a	9.479	a	8.162	a	1.317	a	3.738	a
SM2(60%)F.C.	37.556	b	4.47	b	23.613	b	8.805	b	7.613	b	1.192	a	3.492	b

N1(100 kg/ha)	36.396	b	4.46	b	21.128	b	7.906	b	6.860	b	1.047	b	3.508	a
N2(200 kg/ha)	38.292	ab	4.25	b	23.059	b	8.456	b	7.313	b	1.143	b	3.622	a
N3(300 kg/ha)	38.917	a	5.46	a	30.230	a	11.063	a	9.489	a	1.574	a	3.714	a
Mg1(0.0 kg/ha)	37.330	a	4.54	a	24.562	a	8.956	a	7.696	a	1.260	a	3.638	a
Mg2(30 kg/ha)	38.430	a	4.96	a	25.196	a	9.315	a	8.046	a	1.270	a	3.662	a
Mg3(60 kg/ha)	37.830	a	4.67	a	24.660	a	9.155	a	7.920	a	1.234	a	3.543	a
SM1N1	37.920	a	5.17	a	23.408	bc	8.667	bc	7.549	bc	1.118	b	3.775	a
SM1N2	37.580	a	4.25	ab	21.573	c	7.810	c	6.768	c	1.043	b	3.553	ab
SM1N3	39.040	a	5.50	a	33.014	a	11.960	a	10.168	a	1.792	a	3.885	a
SM2N1	34.880	b	3.75	b	18.848	c	7.146	c	6.170	c	0.976	b	3.242	b
SM2N2	39.000	a	4.25	ab	24.545	bc	9.103	bc	7.859	bc	1.243	b	3.691	a
SM2N3	38.790	a	5.42	a	27.447	b	10.167	ab	8.810	ab	1.357	b	3.543	ab
SM1Mg1	37.750	a	5.08	ab	25.483	a	9.134	a	7.787	a	1.173	a	3.757	a
SM1Mg2	39.210	a	5.42	a	27.098	a	10.003	a	8.663	a	1.200	a	3.772	a
SM1Mg3	37.580	a	4.42	ab	25.416	a	9.300	a	8.035	a	1.203	a	3.684	a
SM2Mg1	36.920	a	4.00	b	23.641	a	8.778	a	7.605	a	1.348	a	3.520	a
SM2Mg2	37.670	a	4.50	ab	23.295	a	8.628	a	7.428	a	1.339	a	3.553	a
SM2Mg3	38.080	a	4.92	ab	23.903	a	9.009	a	7.806	a	1.265	a	3.403	a
N1Mg1	35.000	b	3.88	c	20.413	b	7.475	c	6.509	c	0.966	c	3.430	a
N1Mg2	37.380	ab	5.00	abc	21.325	b	8.043	bc	6.994	bc	1.049	bc	3.505	a
N1Mg3	36.810	ab	4.50	abc	21.646	b	8.201	bc	7.076	bc	1.125	bc	3.590	a
N2Mg1	37.940	ab	3.75	c	22.476	b	8.123	bc	7.001	bc	1.121	bc	3.696	a
N2Mg2	38.560	ab	4.13	bc	24.676	ab	9.146	abc	7.888	abc	1.259	abc	3.711	a
N2Mg3	38.380	ab	4.88	abc	22.025	b	8.100	bc	7.051	bc	1.049	bc	3.458	a
N3Mg1	39.060	a	6.00	a	30.796	a	11.270	a	9.578	a	1.693	a	3.789	a
N3Mg2	39.380	a	5.75	ab	29.588	a	10.758	ab	9.256	ab	1.501	ab	3.770	a
N3Mg3	38.310	ab	4.63	abc	30.308	a	11.163	a	9.634	a	1.529	ab	3.583	a
SM1	38.370	a	5.00	a-c	24.91	b-f	9.065	a-e	7.845	a-d	1.220	abc	3.84	a

N1 Mg1					0								3	bc
SM1 N1 Mg2	38.750	a	6.00	ab	25.423	a-f	9.583	a-e	8.418	a-d	1.165	abc	3.638	a-d
SM1 N1 Mg3	36.620	ab	4.50	a-c	19.893	def	7.353	b-e	6.385	bcd	0.968	bc	3.845	abc
SM1 N2 Mg1	36.620	ab	3.75	bc	19.463	def	6.858	cde	5.938	cd	0.920	bc	3.655	a-d
SM1 N2 Mg2	39.250	a	4.50	a-c	24.558	b-f	9.100	a-e	7.838	a-d	1.263	abc	3.790	abc
SM1 N2 Mg3	36.880	a	4.50	a-c	20.700	c-f	7.473	b-e	6.528	bcd	0.945	bc	3.213	bcd
SM1 N3 Mg1	38.250	a	6.50	a	32.075	ab	11.480	a	9.578	ab	1.903	a	3.773	abc
SM1 N3 Mg2	39.630	a	5.75	ab	31.313	abc	11.325	ab	9.735	ab	1.590	ab	3.888	abc
SM1 N3 Mg3	39.250	a	4.25	a-c	35.655	a	13.075	a	11.193	a	1.883	a	3.995	a
SM2 N1 Mg1	31.620	b	2.75	c	15.915	f	5.885	e	5.173	d	0.713	c	3.018	d
SM2 N1 Mg2	36.000	ab	4.00	a-c	17.228	ef	6.503	de	5.570	cd	0.933	bc	3.373	a-d
SM2 N1 Mg3	37.000	a	4.50	a-c	23.400	b-f	9.050	a-e	7.768	a-d	1.283	abc	3.335	a-d
SM2 N2 Mg1	39.250	a	3.75	bc	25.490	a-f	9.388	a-e	8.065	a-d	1.323	abc	3.738	abc
SM2 N2 Mg2	37.880	a	3.75	bc	24.795	b-f	9.193	a-e	7.938	a-d	1.255	abc	3.633	a-d
SM2 N2 Mg3	39.880	a	5.25	a-c	23.350	b-f	8.728	b-e	7.575	bcd	1.153	abc	3.703	abc
SM2 N3 Mg1	39.880	a	5.50	ab	29.518	a-d	11.060	abc	9.578	ab	1.483	abc	3.805	abc
SM2 N3 Mg2	39.130	a	5.75	ab	27.863	a-e	10.190	a-d	8.778	abc	1.413	abc	3.653	a-d
SM2 N3 Mg3	37.380	a	5.00	a-c	24.960	b-f	9.250	a-e	8.075	a-d	1.175	abc	3.170	cd

The means in each column followed by the same letters are not significantly different at P≤ 0.05 according to Duncan's Multiple Range Test.

2. Second Cutting (Cut.2)

Effects of Soil Moisture, Nitrogen and Magnesium application and their interactions on shoots fresh weight (Sh. FW g/ plant):

Table 3 shows that all the factors and their interactions have no significant effects on shoot fresh weights of rosemary except the interaction treatment SM2N1 which reduced the Sh. FW significantly to 49.88 g compared to 57.82g for SM1N1. These results are in agreement with that obtained by [38] about *Mentha citrate* plants.

Effects of Soil Moisture, Nitrogen and Magnesium application and their interactions on shoots dry weight (Sh. DW g/ plant):

Table 3 illustrates that SM2 caused significant decreases in shoot dry weight of rosemary plants (35.0g) but N3 caused a significant increase in Sh. DW 37.65g. Interaction treatment SM2N1 caused significant decrease in Sh. DW 32.54g but N3Mg1 caused significant increase in Sh. DW 38.89g compared to 33.38g for N1Mg3.Triple interaction MS1N3Mg1 caused a significant increase in Sh. DW of rosemary plants 39.8g.

Effects of Soil Moisture, Nitrogen and Magnesium application and their interactions on leaves fresh weight (LFW g/ plant):

N2 caused significant increase in leaves fresh weight of rosemary plants (40.56g) and results are in agreement with that obtained by [41]. Interaction treatment SM2Mg3 increased LFW significantly to 40.72g. N2Mg1 also increased LFW significantly 43.81g. Triple interaction treatments SM2N2Mg1 and SM2N2Mg3 also caused significant increases in LFW 44.91 and 44.70g respectively compared to 26.90g for SM1N3Mg1.

Effects of Soil Moisture, Nitrogen and Magnesium application and their interactions on leaves dry weight (LDW g/ plant):

Table 3 reveals that soil moisture contents 100% and 60% FC did not show difference in their effect on leaves dry weight and results were not in term with those of [42] about *Eragrostis curvula* plants which showed that the dry weight was affected negatively by water stress. N2 and N3 caused significant increases in LDW and both interaction treatments SM1N3and SM2N3 increased the LDW significantly, while the interaction treatment SM2N1 showed the lowest value of LDW. Interaction treatment N3Mg3 caused a significant increase in LDW of rosemary plants 25g.

Effects of Soil Moisture, Nitrogen and Magnesium application and their interactions on basal stem diameter (St. D mm):

Table 3 shows that N3 caused a significant decrease in stem diameter 9.8 mm and results disagreed with results obtained by[43,44] about *Jatropha curcas* and Broccoli. Interaction treatment SM2N3 significantly decreased St. D of rosemary plants 9.399mm. All interaction treatments SM Mg, N Mg and SM N MG affected positively on St. D of rosemary plants.

Table 3. Effect of Soil Moisture, Nitrogen, Magnesium and their interactions on the yield in cut 2 and on the stem diameter.

Treatments	shoots FW	g/plant	shoots DW	g/plant	leaves FW	g/plant	leaves DW	g/plant	stem diameter mm (cut 2)	
SM1(100%)F.C.	53.569	a	36.26	a	37.299	a	23.762	a	10.323	a
SM2(60%)F.C.	53.072	a	35.00	b	38.295	a	23.487	a	10.142	a
N1(100 kg/ha)	53.848	a	34.01	b	37.304	ab	22.767	b	10.055	ab
N2(200 kg/ha)	54.297	a	35.22	b	40.560	a	23.505	ab	10.860	a
N3(300 kg/ha)	51.816	a	37.65	a	35.528	b	24.601	a	9.783	b
Mg1(0.0 kg/ha)	53.286	a	35.86	a	36.480	a	23.497	a	10.209	a
Mg2(30 kg/ha)	52.842	a	35.51	a	37.572	a	23.652	a	10.121	a
Mg3(60 kg/ha)	53.833	a	35.52	a	39.340	a	23.725	a	10.367	a
SM1N1	57.821	a	35.48	ab	39.393	ab	23.365	ab	10.146	ab
SM1N2	51.528	ab	35.38	ab	38.649	ab	23.531	ab	10.656	ab
SM1N3	51.357	ab	37.92	a	33.857	b	24.389	a	10.166	ab
SM2N1	49.875	b	32.54	b	35.215	b	22.169	b	9.964	ab
SM2N2	57.065	a	35.07	ab	42.471	a	23.480	ab	11.063	a
SM2N3	52.276	ab	37.38	a	37.200	ab	24.813	a	9.399	b
SM1Mg1	52.476	a	36.55	a	33.921	b	23.626	a	10.384	a
SM1Mg2	54.557	a	36.24	a	40.017	a	23.898	a	9.914	a

SM1Mg3	53.673	a	35.99	a	37.961	ab	23.761	a	10.669	a
SM2Mg1	54.097	a	35.16	a	39.039	ab	23.368	a	10.033	a
SM2Mg2	51.128	a	34.78	a	35.127	ab	23.405	a	10.328	a
SM2Mg3	53.992	a	35.05	a	40.720	a	23.688	a	10.065	a
N1Mg1	52.708	a	33.87	bc	36.935	abc	22.424	b	9.859	a
N1Mg2	53.875	a	34.78	bc	36.055	bc	23.526	ab	10.231	a
N1Mg3	54.961	a	33.38	c	38.921	abc	22.351	b	10.075	a
N2Mg1	53.830	a	34.81	bc	40.500	ab	23.369	ab	10.928	a
N2Mg2	51.400	a	35.23	abc	37.370	abc	23.349	ab	10.730	a
N2Mg3	57.660	a	35.63	abc	43.810	a	23.799	ab	10.921	a
N3Mg1	53.321	a	38.89	a	32.005	c	24.699	ab	9.840	a
N3Mg2	53.251	a	36.51	abc	39.290	ab	24.080	ab	9.403	a
N3Mg3	48.876	a	37.55	ab	35.290	bc	25.024	a	10.105	a
SM1 N1 Mg1	56.500	a	34.95	abc	38.775	abc	23.000	a	10.060	a
SM1 N1 Mg2	59.830	a	37.14	abc	42.460	ab	24.375	a	10.090	a
SM1 N1 Mg3	57.133	a	34.36	abc	36.943	a-d	22.720	a	10.288	a
SM1 N2 Mg1	48.978	a	34.91	abc	36.088	a-d	23.338	a	10.685	a
SM1 N2 Mg2	50.300	a	35.80	abc	36.940	a-d	23.535	a	10.400	a
SM1 N2 Mg3	55.308	a	35.42	abc	42.920	ab	23.720	a	10.883	a
SM1 N3 Mg1	51.950	a	39.80	a	26.900	d	24.540	a	10.408	a
SM1 N3 Mg2	53.540	a	35.76	abc	40.650	ab	23.785	a	9.253	a
SM1 N3 Mg3	48.580	a	38.20	ab	34.020	bcd	24.843	a	10.838	a
SM2 N1 Mg1	48.915	a	32.79	bc	35.095	a-d	21.848	a	9.658	a
SM2 N1 Mg2	47.920	a	32.42	c	29.650	cd	22.678	a	10.373	a
SM2 N1 Mg3	52.790	a	32.40	c	40.900	ab	21.983	a	9.863	a
SM2 N2 Mg1	58.683	a	34.71	abc	44.913	a	23.400	a	11.170	a
SM2 N2 Mg2	52.500	a	34.67	abc	37.800	abc	23.163	a	11.060	a
SM2 N2 Mg3	60.013	a	35.84	abc	44.700	a	23.878	a	10.960	a
SM2 N3 Mg1	54.693	a	37.99	abc	37.110	a-d	24.858	a	9.273	a
SM2 N3 Mg2	52.963	a	37.25	abc	37.930	abc	24.375	a	9.553	a
SM2 N3 Mg3	49.173	a	36.91	abc	36.560	a-d	25.205	a	9.373	a

The means in each column followed by the same letters are not significantly different at P≤ 0.05 according to Duncan's Multiple Range Test.

Effects of Soil Moisture, Nitrogen and Magnesium application and their interactions on stem fresh weight (St. FW g/ plant):

Water deficit decreased rosemary stems fresh weight significantly 14.8g. N2 and Mg3 also decreased St. FW significantly to13.7 and 12.879g respectively. Interaction treatments SM1N2, SM2Mg3 and SM2Mg1 also decreased St. FW significantly to12.879g, and13.33g respectively. Triple interaction treatments SM2N1Mg3 and SM2N3Mg3 also decreased St. FW significantly (Table 4).

Effects of Soil Moisture, Nitrogen and Magnesium application and their interactions on stems dry weight (St. DW g/plant):

Table 4 shows that SM2 caused significant decrease in stems dry weight (11.51g) compared to 12.50g for SM1, but N3 increased St. DW significantly to 13.05g. Interaction treatment SM1N3 increased St. DW significantly to 13.53g. SM2Mg2 and SM2Mg3 caused a significant decrease in St. DW to11.37 and11.36g. N3Mg1 and SM1 N3 Mg1 also increased St. DW significantly to 14.19g and 15.255g respectively.

Effects of Soil Moisture, Nitrogen and Magnesium application and their interactions on roots fresh weight (RFW/plant):

Table 4 shows that Mg3 increased roots fresh weights significantly to 44.74g compared to Mg1 (29.65g). Interaction treatment SM1MG3 caused RFW increased significantly to 46.47g, and Results were in conformity with the findings of [45] on *Trigonella foenum*.

Effects of Soil Moisture, Nitrogen and Magnesium application and their interactions on roots dry weight (RDW / plant):

Mg3 caused significant increase in Roots dry weight of rosemary to 18.67g compared to Mg1 (15.32 g). Nitrogen didn't effect on RDW of rosemary plants, therefore the results were not agreed with findings of [48] in *Elaeis guineensis*, Jacq) and [49].

Table 4. Effect of Soil Moisture, Nitrogen, Magnesium and their interactions on the yield cut2.

Treatments	stems g/plant FW		stems g/plant DW		roots g/plant FW		roots g/plant DW	
SM1(100%)F.C.	16.269	a	12.50	a	39.567	a	17.247	a
SM2(60%)F.C.	14.777	b	11.51	b	32.923	a	16.396	a
N1(100 kg/ha)	16.544	a	11.24	b	29.238	a	17.035	a
N2(200 kg/ha)	13.737	b	11.72	b	38.480	a	16.174	a
N3(300 kg/ha)	16.288	a	13.05	a	41.080	a	17.255	a
Mg1(0.0 kg/ha)	16.806	a	12.36	a	29.649	b	15.315	b
Mg2(30 kg/ha)	15.270	ab	11.86	a	34.065	ab	16.481	ab
Mg3(60 kg/ha)	14.492	b	11.80	a	44.793	a	18.668	a
SM1N1	18.428	a	12.12	b	33.679	a	17.528	a
SM1N2	12.879	c	11.85	b	44.498	a	16.482	a
SM1N3	17.500	ab	13.53	a	40.611	a	17.732	a
SM2N1	14.660	bc	10.37	c	24.796	a	16.543	a
SM2N2	14.594	bc	11.59	bc	32.463	a	15.866	a
SM2N3	15.076	bc	12.57	ab	41.511	a	16.778	a
SM1Mg1	18.555	a	12.92	a	37.050	ab	16.784	ab
SM1Mg2	14.540	b	12.34	ab	34.787	ab	15.845	ab
SM1Mg3	15.713	ab	12.23	ab	46.465	a	19.113	a
SM2Mg1	15.058	b	11.80	ab	22.248	b	13.846	b
SM2Mg2	16.001	ab	11.37	b	33.403	ab	17.118	ab
SM2Mg3	13.272	b	11.36	b	43.120	ab	18.223	a
N1Mg1	15.773	bc	11.44	b	21.394	a	14.560	a
N1Mg2	17.820	ab	11.25	b	28.373	a	17.184	a
N1Mg3	16.040	bc	11.03	b	37.946	a	19.363	a
N2Mg1	13.330	c	11.44	b	37.470	a	14.853	a
N2Mg2	14.030	bc	11.88	b	29.764	a	15.539	a
N2Mg3	13.850	bc	11.83	b	48.208	a	18.130	a
N3Mg1	21.316	a	14.19	a	30.083	a	16.533	a
N3Mg2	13.961	bc	12.43	b	45.486	a	16.721	a
N3Mg3	13.586	bc	12.53	b	48.224	a	18.511	a
SM1 N1 Mg1	17.725	bcd	11.95	bcd	27.388	a	16.985	a
SM1 N1 Mg2	17.370	bcd	12.77	abc	32.858	a	15.768	a
SM1 N1 Mg3	20.190	ab	11.64	bcd	40.793	a	19.833	a
SM1 N2 Mg1	12.890	cd	11.57	bcd	47.503	a	16.463	a
SM1 N2 Mg2	13.360	cd	12.27	bcd	35.390	a	15.040	a
SM1 N2 Mg3	12.388	cd	11.70	bcd	50.600	a	17.943	a
SM1 N3 Mg1	25.050	a	15.26	a	36.260	a	16.905	a
SM1 N3 Mg2	12.890	cd	11.98	bcd	36.557	a	16.728	a
SM1 N3 Mg3	14.560	bcd	13.36	ab	48.003	a	19.563	a
SM2 N1 Mg1	13.820	cd	10.94	bcd	15.400	a	12.135	a
SM2 N1 Mg2	18.270	bc	9.74	d	23.888	a	18.600	a
SM2 N1 Mg3	11.890	d	10.42	cd	35.100	a	18.893	a
SM2 N2 Mg1	13.770	cd	11.31	bcd	27.438	a	13.243	a
SM2 N2 Mg2	14.700	bcd	11.50	bcd	24.138	a	16.038	a

SM2 N2 Mg3	15.313	bcd	11.96	bcd	45.815	a	18.318	a
SM2 N3 Mg1	17.583	bcd	13.13	ab	23.905	a	16.160	a
SM2 N3 Mg2	15.033	bcd	12.88	abc	52.183	a	16.715	a
SM2 N3 Mg3	12.613	cd	11.70	bcd	48.445	a	17.460	a

The means in each column followed by the same letters are not significantly different at P≤ 0.05 according to Duncan's Multiple Range Test.

3. Accumulative yield (Cut.1+2):

Effects of Soil Moisture, Nitrogen and Magnesium application and their interactions on accumulative shoots fresh weight (Accu. Sh. FW g/plant):

SM2 decreased accumulative shoot fresh weight of rosemary significantly to 76.5g and the results are in conformity with the findings of [48] but N3 caused a significant increase in Accu. Sh. FW to 82.24g. Interaction treatment SM1N3 increased Accu. Sh. FW significantly to 84.76g and Triple interaction SM2N1Mg1 caused significant decreases in Accu. Sh. FW to 64.83 (Table 5).

Effects of Soil Moisture, Nitrogen and Magnesium application and their interactions on accumulative shoots dry weight (Accu. Sh. DW/plant):

Table 5 shows that N3 caused significant increase in Accu. Sh. DW of rosemary to 48.80g compared to N1 (41.87g) but interaction treatment SM2N1 decreased Accu. Sh.DW to39.6g. Interaction treatment N3Mg3 increased Accu. Sh. DW significantly to50.16g and similar results were given by [36]. Triple interaction treatment SM1N3Mg3 caused a significant increase in Accu. Sh. DW to 51.8g.

Effects of Soil Moisture, Nitrogen and Magnesium application and their interactions on accumulative leaves dry weight (Accu. LDW/plant):

Table 5 shows that N3 increased accumulative leaves dry weight of rosemary significantly to 34.16 g and interaction treatments SM1N3 and N3Mg3 also caused significant increase in Accu.LDW to 34.69g and 34.85g respectively. Triple interaction SM1N3Mg3 caused significant increases in Accu. LDW to 36.42g compared to SM2N1Mg1 (27.02g).

Table 5. Effect of Soil Moisture, Nitrogen, Magnesium and their interactions on the yield in cut1+2.

Treatments	Accumulative shoots g/plant FW		Accumulative shoots g/plant DW		Accumulative leaves g/plant DW	
SM1(100%)F.C.	79.696	a	45.80	a	31.966	a
SM2(60%)F.C.	76.548	b	43.77	a	31.095	a
N1(100 kg/ha)	74.770	b	41.87	b	29.619	b
N2(200 kg/ha)	77.356	ab	43.68	b	30.819	b
N3(300 kg/ha)	82.240	a	48.80	a	34.155	a
Mg1(0.0 kg/ha)	77.848	a	44.81	a	31.193	a
Mg2(30 kg/ha)	77.832	a	44.78	a	31.690	a
Mg3(60 kg/ha)	78.686	a	44.76	a	31.710	a
SM1N1	81.229	ab	44.15	bc	30.914	cd
SM1N2	73.102	bc	43.19	cd	30.298	cd
SM1N3	84.758	a	50.05	a	34.687	a
SM2N1	68.310	c	39.59	d	28.324	d
SM2N2	81.610	ab	44.17	bc	31.339	bc
SM2N3	79.723	ab	47.55	ab	33.623	ab
SM1Mg1	77.958	a	45.68	a	31.413	a
SM1Mg2	81.654	a	46.24	a	32.562	a
SM1Mg3	79.476	a	45.47	a	31.925	a

SM2Mg1	77.738	a	43.94	a	30.973	a
SM2Mg2	74.010	a	43.32	a	30.819	a
SM2Mg3	77.895	a	44.06	a	31.494	a
N1Mg1	73.120	a	41.34	d	28.933	d
N1Mg2	74.581	a	41.58	d	30.498	cd
N1Mg3	76.608	a	42.69	cd	29.428	d
N2Mg1	76.306	a	42.93	cd	30.370	cd
N2Mg2	76.076	a	43.73	cd	31.236	bcd
N2Mg3	79.685	a	44.38	bcd	30.850	cd
N3Mg1	84.118	a	47.26	abc	34.276	ab
N3Mg2	82.839	a	48.98	ab	33.336	abc
N3Mg3	79.765	a	50.16	a	34.852	a
SM1 N1 Mg1	81.410	ab	44.01	bcd	30.845	b-e
SM1 N1 Mg2	85.253	a	46.73	abc	32.793	a-d
SM1 N1 Mg3	77.025	ab	41.72	cd	29.105	cde
SM1 N2 Mg1	68.440	ab	41.77	cd	29.275	b-e
SM1 N2 Mg2	74.858	ab	44.90	a-d	31.373	a-e
SM1 N2 Mg3	76.008	ab	42.89	cd	30.248	b-e
SM1 N3 Mg1	84.025	a	51.28	ab	34.118	abc
SM1 N3 Mg2	84.853	a	47.09	abc	33.520	abc
SM1 N3 Mg3	85.397	a	51.80	a	36.423	a
SM2 N1 Mg1	64.830	b	38.68	d	27.020	e
SM2 N1 Mg2	63.910	b	38.65	d	28.203	de
SM2 N1 Mg3	76.190	ab	41.45	cd	29.750	b-e
SM2 N2 Mg1	84.173	a	44.10	bcd	31.465	a-e
SM2 N2 Mg2	77.295	ab	43.86	bcd	31.100	b-e
SM2 N2 Mg3	83.363	a	44.57	a-d	31.453	a-e
SM2 N3 Mg1	84.210	a	49.05	abc	34.435	ab
SM2 N3 Mg2	80.825	ab	47.44	abc	33.153	a-d
SM2 N3 Mg3	74.133	ab	46.16	a-d	33.280	a-d

The means in each column followed by the same letters are not significantly different at P≤ 0.05 according to Duncan's Multiple Range Test.

Effects of Soil Moisture, Nitrogen and Magnesium application and their interactions on accumulative stems yield dry weight (Accu. St. DW / plant):

SM2 decreased accumulative stems yield dry weight significantly to 12.68g compared to SM1 (13.83g), but N3 increased Accu. St. DW significantly to 14.65 g, but the results do not agree with the results of [41]. Interaction treatments SM2N1 and SM2Mg3 decreased Accu. St. DW significantly to 11.27g and 12.50 respectively, but N3Mg1 increased Accu. St. DW significantly to 15.89g. Triple interaction SM1N3Mg1 caused significant increase in Accu. St. DW to 17.16g (10.44g).

Effects of Soil Moisture, Nitrogen and Magnesium application and their interactions on Biological yield fresh weight (Bio. YFW/plant):

SM2 decreased Biological yield fresh weight significantly to 109.47g compared to SM1 (119.66g), but N3 increased Bio. YFW significantly to 123.85g as shown in [49] and Mg3 also increased Bio. YFW significantly to 123.48g compared to Mg1 (107.5g). Interaction treatments SM2N1and SM2Mg1 decreased Bio. YFW significantly to 93.11g and 99.99g respectively. N2Mg3, N3Mg2 and N3Mg3 increased Bio. YFW significantly to 127.89, 129.35 and 127.99 respectively. Triple interaction SM2N1Mg1decreased Bio. YFW significantly to 80.23g.

Effects of SM, N and Mg on Biological yield dry weight (Bio.YDW/plant):

N3 caused significant increase in Bio. YDW to 66.06g. Interaction treatments SM1N3, N3Mg1 and N3Mg3 increased Bio. YDW significantly to 67.79g, 66.70 and 67.50g respectively, and similar findings have been reported by [36]. Triple interaction SM1N3Mg3 increased Bio. YDW significantly to 71.36g compared to SM2N1Mg1 by 50.81g (Table 6).

Table 6. Effect of Soil Moisture, Nitrogen, Magnesium and their interactions on the yield in cut 1+2.

Treatments	Accumulative stems g/plant DW		Biological yield g/plant FW		Biological yield g/plant DW	
SM1(100%)F.C.	13.830	a	119.66	a	63.044	a
SM2(60%)F.C.	12.676	b	109.47	b	60.167	a
N1(100 kg/ha)	12.251	b	104.01	b	58.906	b
N2(200 kg/ha)	12.861	b	115.84	ab	59.854	b
N3(300 kg/ha)	14.646	a	123.85	a	66.056	a
Mg1(0.0 kg/ha)	13.620	a	107.50	b	60.128	a
Mg2(30 kg/ha)	13.086	a	112.72	ab	61.257	a
Mg3(60 kg/ha)	13.053	a	123.48	a	63.431	a
SM1N1	13.236	b	114.91	ab	61.678	abc
SM1N2	12.888	b	117.60	a	59.668	bc
SM1N3	15.366	a	126.46	a	67.785	a
SM2N1	11.267	c	93.11	b	56.134	c
SM2N2	12.835	b	114.07	ab	60.040	bc
SM2N3	13.927	ab	121.23	a	64.328	ab
SM1Mg1	14.271	a	115.01	ab	62.468	a
SM1Mg2	13.676	ab	118.02	ab	62.083	a
SM1Mg3	13.543	ab	125.94	a	64.581	a
SM2Mg1	12.968	ab	99.99	b	57.788	a
SM2Mg2	12.496	b	107.41	ab	60.432	a
SM2Mg3	12.564	b	121.02	ab	62.282	a
N1Mg1	12.410	b	94.51	b	55.903	b
N1Mg2	12.188	b	102.95	ab	59.870	ab
N1Mg3	12.156	b	114.55	ab	60.946	ab
N2Mg1	12.563	b	113.78	ab	57.785	b
N2Mg2	13.143	b	105.84	ab	59.918	ab
N2Mg3	12.879	b	127.89	a	61.859	ab
N3Mg1	15.886	a	114.20	ab	66.695	a
N3Mg2	13.928	b	129.35	a	63.985	ab
N3Mg3	14.125	ab	127.99	a	67.489	a
SM1 N1 Mg1	13.165	bcd	108.80	abc	60.995	abc
SM1 N1 Mg2	13.933	bc	118.11	abc	62.493	abc
SM1 N1 Mg3	12.610	bcd	117.82	abc	61.548	abc
SM1 N2 Mg1	12.490	bcd	115.94	abc	58.228	bc
SM1 N2 Mg2	13.528	bc	110.25	abc	59.940	abc
SM1 N2 Mg3	12.645	bcd	126.61	ab	60.835	abc
SM1 N3 Mg1	17.158	a	120.29	abc	68.180	ab
SM1 N3 Mg2	13.568	bc	125.70	ab	63.815	ab
SM1 N3 Mg3	15.373	ab	133.40	a	71.360	a

SM2 N1 Mg1	11.655	cd	80.23	c	50.810	c
SM2 N1 Mg2	10.443	d	87.80	bc	57.247	bc
SM2 N1 Mg3	11.703	cd	111.29	abc	60.345	abc
SM2 N2 Mg1	12.635	bcd	111.61	abc	57.343	bc
SM2 N2 Mg2	12.758	bcd	101.43	abc	59.895	abc
SM2 N2 Mg3	13.113	bcd	129.18	ab	62.883	abc
SM2 N3 Mg1	14.615	abc	108.12	abc	65.210	ab
SM2 N3 Mg2	14.288	bc	133.01	a	64.155	ab
SM2 N3 Mg3	12.878	bcd	122.58	abc	63.618	abc

The means in each column followed by the same letters are not significantly different at P≤ 0.05 according to Duncan's Multiple Range Test.

4. Effects of Soil Moisture, Nitrogen and Magnesium application and their interactions on RMEO % in leaves dry weight cut2, and RMEO g/plant in leaves dry weight cut2, concrete % in leaves dry weight cut2, concrete g/plant in leaves dry weight cut2:

Effects of Soil Moisture, Nitrogen and Magnesium application and their interactions on RMEO % in leaves dry weight cut2:

Table 7 shows that soil moisture 100%FC (SM1) caused significant increase in RMEO % in leaves dry weight cut2 (5.1%) compared to SM2 (4.7%). N3 also increased RMEO % significantly to 5.3%, but Mg2 decreased RMEO % significantly to 4.5%. Interaction treatment SM1N2 and SM2Mg2 decreased RMEO % significantly, while SM1N3 showed significant increase in RMEO % (5.8%). N3Mg1 also increased RMEO % significantly to 5.7%. Triple interaction treatment SM2N2Mg2 decreased RMEO % significantly to 3.2% compared to SM1N3Mg2 (6.5).

Effects of Soil Moisture, Nitrogen and Magnesium application and their interactions on concrete % in leaves dry weight cut2:

Soil moisture deficiency (SM2) caused significant decrease in concrete% in leaves dry weight cut2 and registered 13.7%. Interaction treatment SM1N3 increased concrete% significantly to 16%. SM1Mg2 & SM2Mg1increased concrete % significantly by 15.8 & 14.9% respectively. Triple interaction treatment SM1N3Mg2 caused significant increase in concrete % by 17.9% compared to the treatment SM2N1Mg2 which registered 11.4% (Table 7).

Effects of Soil Moisture, Nitrogen and Magnesium application and their interactions on RMEO g/plant in leaves dry weight cut2:

Water deficiency (SM2) decreased the amount of RMEO g/plant significantly by 0.17g compared with 0.2g in SM1. N3 increased RMEO significantly (0.22g) compared to N1 and N2. SM1N2 and SM2Mg2 reduced RMEO significantly (0.12g) and the results were agreement with results of Said-Al Ahl [50] in *Origanum vulgare* L, but N3Mg1 and SM1N3Mg2 registered significant increase by 0.24g and 0.32g respectively. And the triple interaction SM1N3Mg2 increased the RMEO significantly to 0.32g.

Effects of Soil Moisture, Nitrogen and Magnesium application and their interactions on concrete g/plant in leaves dry weight cut2:

Water deficiency decreased the amount of concrete significantly to1.4g. N3 caused significant increase of concrete in leaves dry weight cut2 to 1.7g. Interaction treatments SM1N2 and SM2Mg2 reduced the concrete in rosemary plants significantly to1.3g and 1.1g respectively, but N3Mg2 registered significant increase (1.9g). The triple interaction treatment SM1N3Mg2 increased the concrete in leaves dry weight cut2 significantly to 2.4g.

Table 7. Effects of Soil Moisture, Nitrogen, Magnesium and their interactions on RMEO % in leaves dry weight cut2, and RMEO g/plant in leaves dry weight cut2, concrete % in leaves dry weight cut2, concrete g/plant in leaves dry weight cut2.

Treatments	RMEO % in leaves dw cut2		concrete % in leaves dw cut2		RMEO g/plant dw cut2		concrete g/plant dw cut2	
SM1(100%)F.C.	5.057	a	14.64	a	0.195	a	1.564	a
SM2(60%)F.C.	4.737	b	13.73	b	0.173	b	1.383	b

N1(100 kg/ha)	4.812	ab	13.57	a	0.173	ab	1.321	b
N2(200 kg/ha)	4.594	b	14.00	a	0.163	b	1.399	ab
N3(300 kg/ha)	5.284	a	14.98	a	0.216	a	1.699	a
Mg1(0.0 kg/ha)	5.377	a	14.63	a	0.217	a	1.557	a
Mg2(30 kg/ha)	4.509	b	14.12	a	0.161	b	1.488	a
Mg3(60 kg/ha)	4.804	ab	13.80	a	0.174	ab	1.375	a
SM1N1	5.186	ab	14.30	ab	0.203	ab	1.463	ab
SM1N2	4.153	c	13.66	ab	0.124	c	1.316	b
SM1N3	5.831	a	15.95	a	0.257	a	1.912	a
SM2N1	4.437	bc	12.85	b	0.142	bc	1.179	b
SM2N2	5.035	abc	14.33	ab	0.202	ab	1.482	ab
SM2N3	4.737	bc	14.02	ab	0.176	bc	1.487	ab
SM1Mg1	5.289	ab	14.39	ab	0.209	ab	1.474	abc
SM1Mg2	5.431	a	15.84	a	0.228	a	1.879	a
SM1Mg3	4.451	b	13.67	ab	0.147	bc	1.338	bc
SM2Mg1	5.466	a	14.87	a	0.225	a	1.639	ab
SM2Mg2	3.587	c	12.40	b	0.094	c	1.098	c
SM2Mg3	5.157	ab	13.93	ab	0.201	ab	1.411	abc
N1Mg1	5.212	ab	14.19	a	0.201	ab	1.445	abc
N1Mg2	4.535	bc	13.86	a	0.163	abc	1.440	abc
N1Mg3	4.689	abc	12.66	a	0.154	bc	1.079	c
N2Mg1	5.182	ab	15.58	a	0.201	ab	1.727	ab
N2Mg2	3.801	c	12.91	a	0.107	c	1.167	bc
N2Mg3	4.799	abc	13.50	a	0.181	abc	1.305	abc
N3Mg1	5.738	a	14.12	a	0.249	a	1.498	abc
N3Mg2	5.191	ab	15.59	a	0.214	ab	1.859	a
N3Mg3	4.923	ab	15.24	a	0.187	abc	1.740	ab
SM1 N1 Mg1	6.082	ab	13.71	a-d	0.263	abc	1.296	b-e
SM1 N1 Mg2	5.461	a-e	16.29	abc	0.236	a-g	1.953	a-d
SM1 N1 Mg3	4.016	d-g	12.90	cd	0.111	ghi	1.139	cde
SM1 N2 Mg1	3.966	efg	13.70	a-d	0.112	ghi	1.312	b-e
SM1 N2 Mg2	4.361	c-g	13.37	bcd	0.136	d-i	1.257	b-e
SM1 N2 Mg3	4.132	d-g	13.92	a-d	0.124	e-i	1.380	b-e
SM1 N3 Mg1	5.818	abc	15.78	abc	0.252	a-d	1.812	a-e
SM1 N3 Mg2	6.473	a	17.87	a	0.314	a	2.428	a
SM1 N3 Mg3	5.203	a-f	14.20	a-d	0.205	a-h	1.495	b-e
SM2 N1 Mg1	4.341	c-g	14.68	a-d	0.139	c-i	1.593	a-e
SM2 N1 Mg2	3.610	fg	11.44	d	0.091	hi	0.926	e
SM2 N1 Mg3	5.362	a-e	12.43	cd	0.197	a-i	1.018	de
SM2 N2 Mg1	6.398	a	17.45	ab	0.290	ab	2.141	ab
SM2 N2 Mg2	3.242	g	12.45	cd	0.077	i	1.077	cde
SM2 N2 Mg3	5.466	a-e	13.09	cd	0.239	a-f	1.229	b-e
SM2 N3 Mg1	5.658	a-d	12.47	cd	0.245	a-e	1.184	cde
SM2 N3 Mg2	3.910	efg	13.30	bcd	0.113	f-i	1.290	b-e
SM2 N3 Mg3	4.643	b-g	16.27	abc	0.169	b-i	1.986	abc

The means in each column followed by the same letters are not significantly different at $P \leq 0.05$ according to Duncan's Multiple Range Test.

Conclusions:

From the results of the present study, we can draw the following conclusions:

Water adequacy (SM_1) affects positively and records the highest increases in all rosemary plant growth characteristics, except the stem diameter. Nitrogen application at 300 kg/hectare increases all growth characteristics. Water deficiency (SM2) affects negatively and decreases growth characteristics. Magnesium application at 60kg/hectare increases the roots fresh weight, roots dry weight and biological yield. The interaction treatment SM1N3 increases most of the growth characteristics of rosemary plants. Triple interaction treatment SM1N3Mg3 increases growth characteristics and plant biomass in cut1 and in cut1+2, except the number of branches/plant. Rosemary plants require 100% field capacity of water supply in order to gain the highest plant growth and biomass. Application of nitrogen and magnesium (at 300 and 60 kg/hectare respectively to rosemary plants) is necessary for high plant growth and biomass and to enable plants avoiding the adverse effects of water deficiency.

Water deficiency affects negatively on rosemary essential oils%, but nitrogen supply mitigates the negative effects of water deficiency on essential oils. Interactions between adequate nutrient elements affects positively on rosemary essential oils. Further studies are necessary to determine the water stress line under which rosemary plants can't naturally grow and develop to avoid adverse effects on plant growth and development. More studies are necessary about the combined nutrient elements doses and their interactions to determine the proper fertilizer combinations and getting the highest plant growth, biomasses, essential oils and good quality.

Authors' declaration:

-Conflicts of Interest: None.

-We hereby confirm that all the Figures and Tables in the manuscript are mine ours. Besides, the Figures and images, which are not mine ours, have been given the permission for re-publication attached with the manuscript.

-Ethical Clearance: The project was approved by the local ethical committee in Erbil Polytechnic University.

Authors Contribution:

NMAK, conduct the experiment, take measurements, conduct analyses, collect data, analyze the statistics, write the manuscript, send it to the journal, and follow up on the amendments. AG AS designed the research, plan the theoretical and practical parts of the experiment, supervise the work, and check the writing of the research.

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تأثير الإجهاد المائي والنيتروجين والمغنيسيوم وتداخلاتهم على بعض خصائص النمو ومحتوى الزيت الاساسي في نباتات إكليل الجبل (*Rosmarinus officinalis* L.)

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الخلاصة:

تم تطبيق تجربة عاملية بواقع أربعة مكررات على نباتات إكليل الجبل (*Rosmarinus officinalis* L.) في البيت الزجاجي التابع لقسم علوم الحياة في كلية العلوم ، جامعة صلاح الدين - أربيل - العراق ، خلال الفترة الزمنية نيسان 2019 - تموز 2020 لدراسة تأثير محتوى رطوبة التربة عند المستويين (SM1 100٪ و SM2 60٪ من السعة الحقلية) ، وتأثيرالرش الورقي لسماد النيتروجين بالتراكيز N1 : 100 ، N2: 200وN3 : 300كغم. هكتار $^{-1}$ ، وتأثير سماد المغنيسيوم بالتراكيز Mg1: 0.0 ، Mg2: 30، وMg3 : 60كغم. هكتار $^{-1}$ وتداخلاتهم في بعض خصائص النمو ومحتوى الزيت الاساسي الطيار في نبات إكليل الجبل. تم اجراء حصادين للنباتات المدروسة (الاول في اذار 2020 والثاني في تموز 2020) أي بعد 12 و 15 شهرًا من الزراعة على التوالي. أظهرت النتائج في الحصاد الاول، ان SM2 أدت الى إنخفاض معنوي في إرتفاع النبات ، عدد الأفرع ، الوزن الرطب ، الوزن الجاف للنبات ، الوزن الجاف للأوراق والوزن الجاف للساق. كما ان N3 ادى الى حدوث زيادة معنوية في ارتفاع النبات ، عدد الافرع ،الوزن الطري والجاف للمجموع الخضري ، الوزن الجاف للأوراق، الوزن الطري والجاف للسيقان. أما معاملة التداخل SM1N3Mg3 فقد سببت زيادة معنوية في إرتفاع النبات ،الوزن الطري والجاف للمجموع الخضري و الوزن الجاف للاوراق و الوزن الطري والجاف لسيقان النباتات ، اما في الحصاد الثاني فقد ادى عجز الماء(SM2) الى انخفاض الوزن الجاف للمجموع الخضري والوزن الطري والجاف للسيقان. معاملة النتروجينN3 سببت زيادة معنوية في الوزن الطري للمجموع الخضري والوزن الجاف للسيقان. واظهر المغنيسيوم Mg3 زيادة معنوية في الوزن الطري للجذور ، ولكنه سبب انخفاضا معنوياً في الوزن الطري للسيقان. كما سببت معاملة التداخل الثلاثي SM1N3Mg1 زيادة معنوية في الوزن الجاف للسيقان. وبالنسبة للحصاد التراكمي (الاول+الثاني) فقد اظهرت السعة الحقلية 60% (SM2) انخفاضا معنويا في الوزن التراكمي الجاف للسيقان والحاصل البيولوجي الطري. أما عند تركيزالنتروجينN3 فقد حدثت زيادة معنوية في الحاصل التراكمي الطري للمجموع الخضري والوزن الجاف التراكمي للاوراق والوزن التراكمي الطري للسيقان والحاصل البيولوجي الجاف. تركيز المغنيسيوم Mg3 اظهر زيادة معنوية في الحاصل البيولوجي الطري. التداخل الثلاثي SM1N3Mg3 أظهر زيادة معنوية في الوزن الجاف للحاصل التراكمي للمجموع الخضري والحاصل التراكمي للوزن الجاف للاوراق والحاصل البيولوجي الطري والجاف.وفي الحصاد الثاني، سبب المحتوى الرطوبي SM2 وMg2 انخفاضا معنويا في النسبة المئوية للزيت الأساسي الطيار (EO٪) ، أما N3 و ومعاملة التداخل الثلاثي SM1N3Mg2 فقد سببا زيادة معنوية في EO% ومحتوى ال Concrete ، وأدت معاملة التداخل الثنائي SM1Mg2 الى زيادة معنوية في محتوى الزيت الاساسي ومحتوى ال Concrete.

الكلمات المفتاحية: إكليل الجبل، الشد المائي، النتروجين، المغنيسيوم، الزيت الاساسي.