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Optimal Soil Moisture Depletion Levels for the Production of *Vernonia* (*Vernonia galamensis* L.) and it's Effect on Growth, Yield and Yield Components

Gadissa M[1]*, Woldemichael A[2] and Yimer F[3]

[1]*Wondo Genet Agricultural Research Center, Shashemene, Ethiopia*
[2]*School of Biosystem and Environmental Engineering, Hawassa Institute of Technology, Ethiopia*
[3]*Wondo Genet College of Forestry and Natural Resource Management, Hawassa University, Ethiopia*

Abstract

The field experiment was carried out at Wondo Genet Agricultural Research Center 07°03'19'' to 07°04'00'' N latitude and 38°30'08'' to 38°31'02' E longitude during 2015/16 dry season. The experiments were arranged in a randomized complete block design with three replications. Seven soil moisture depletion levels (30, 40, 50, 60, 70, 80 and 100% of the total available water of the soil) were used. The result indicated that different soil moisture depletion levels had very highly significant (p<0.001) effect on days to flowering, days to seed set, days to maturity, plant height, number of branches per plant, number of capsules per plant, thousand seed weight and seed yield. It was also affected oil yield highly significantly (p<0.01). Moreover, different soil moisture depletion levels significantly (p<0.05) influenced water use efficiency. However, different soil moisture depletion levels showed no significant difference in the oil content of *Vernonia. Vernonia* grown under 100% SMDL took a shorter number of days to 50% flowering, days to seed setting and days to maturity. On the other hand, 30% SMDL took the longest days to flowering, seed setting and days to maturity. The maximum plant height, number of branches per plant and number of capsule per plant were 162.7 cm, 150 and 196.8 at 30% SMDL, respectively. The highest seed yield (2213 kg ha^{-1}) and oil yield (711.8 kg ha^{-1}) were obtained at 60% soil moisture depletion level. However, the highest water use efficiency based on oil yield (0.15 kg/m^3) was obtained at 100% SMDL irrigation is set when soil moisture content touches PWP. Thus, the optimal seed yield, oil yield and WUE could be achieved when 493.4 mm seasonal net irrigation depth of water applied with scheduling at 60% SMDL for the production of *Vernonia* at Wondo Genet and similar agro-ecological areas.

Keywords: *Vernonia*; Depletion level; Irrigation; Soil moisture

Introduction

Ethiopia is characterized by a wide range of agro-climatic conditions, which account for the enormous diversity of biological resources. Probably the most important aspect of these rich resources is the origin and diversity of various agricultural crops and wild species in the country [1]. *Vernonia* is an annual herb that belongs to the family of Asteraceae - which was known to be originated from East Africa [2].

Vernonia galamensis spp. *galamensis* var. Ethiopia is a new annual industrial oilseed. It grows naturally in the southern and southeastern parts of Ethiopia (Hararghe, Sidamo, Arsi, Bale and Shewa) [3]. It was first identified in eastern Ethiopia by Perdue [4] at 7 km south-east of Harar town. It is adaptable to areas with as little as 500 mm annual rainfall [5]. This weedy plant is locally known as "Ferenkudela", Dunfare", "Kefatheogie", and "Noya" which have different names in different localities [1].

Vernonia seed oil has unique chemical and physical properties that will permit its use in the formulation of reactive diluents, products to serve as solvents that become part of the dry paint surface and do not evaporate to pollute the air [6]. The seeds contain up to 40% epoxy oil and this oil has up to 80% vernolic acid (cis-12,13-epoxyoleic acid) [7].

Epoxy oils are important in the oleochemical industry for the manufacture of plastic formulations, protective coatings, lubricants, and other products. Current industrial techniques are expensive, generate large amounts of chemical waste, and produce high viscosity oil [8]. A naturally low-viscosity, epoxy oil is now available from *Vernonia* seeds. The low viscosity and polymerizing characteristics of this oil make it especially valuable as a solvent in industrial coatings and paints, for environments where fumes from traditional solvents are hazardous or polluting [9]. Some of the products that are being developed from *Vernonia* oil are degradable lubricants and lubricant additives, epoxy resins, adhesives, insecticides and insect repellants, crop-oil concentrates, and the formulation of carriers for slow-release pesticides [7].

Currently, investors are very much interested to cultivate the new industrial crop in the country for export and local processing. This new industrial crop could significantly diversify Ethiopian agriculture and create markets that are essentially noncompetitive with existing crops. Its production would also provide a reliable domestic source of essential industrial feedstocks such as unique oils, many of which are currently imported [2,5,8-13].

So irrigation is essential for the cultivation of *Vernonia* to cultivate in the moisture-stressed area. In areas where total seasonal rainfall is adequate on average, it may be poorly distributed during the year and vary from year to year. Where traditional rain-fed farming is a high-risk enterprise, irrigation can help to ensure stable agricultural production. Therefore, this study was conducted to determine optimal soil moisture depletion level and seasonal water requirement for the production of *Vernonia* under irrigation condition.

***Corresponding author:** Muleta Gadissa, Wondo Genet Agricultural Research Center, Shashemene, Ethiopia, Tel: +251915681140; E-mail: muletagadissa@gmail.com

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Materials and Methods

Description of the study area

The study was carried out at Wondo Genet Agricultural Research Center (WGARC) during 2015/16 dry season. Geographically it is located between 07°03' 19" to 07° 04' 00" N latitude and 38°30' 08" to 38° 31'01.8" E longitudes with an average altitude of 1800 m.a.s.l. The study area is about 264 km south of the capital, Addis Ababa. The soil type of the study area is sandy clay loam with the textural class of the top surface soil (0-20 cm depth) with pH of 6.4. Mean annual rainfall of the area is 1069.2 mm among which 72% falls from April to September with an average minimum and maximum temperature of 11.8 and 26.2°C, respectively.

Soil physical characteristics

The laboratory analysis revealed that the soil textural class of the experimental area was ranged from clay loam to clay. The bulk density of the soil of the experimental site showed a variation with depth. It varied between 1.10 and 1.24 (g/cm^3), generally; the topsoil surface has slightly lower bulk density than the subsurface may be due to high organic matter contents. In general, the weighted average bulk density of the soil was found 1.16 (g/cm^3).

Soil moisture content at field capacity and permanent wilting point measurements were analyzed using pressure plate apparatus by applying a suction of 0.33 and 15 bars, respectively to a saturated soil sample. The observed soil moisture content at FC (field capacity) and PWP (permanent wilting point) on volume base were varied with soil depth between 25.82 to 39.63 and 16.22 to 28.5%, respectively.

The total available water (TAW) that is the amount of water that a crop can extract from its root zone was directly related to variation in FC and PWP. As a result, the high value of TAW was found in the soil depth of 60 to 90 cm; whereas the minimum values were observed at 0 up to 15 cm soil depth. The result showed that TAW varied from varied between 14.4 to 33.39 mm along the soil depth.

Seasonal crop water requirement

The amount of irrigation depth and frequency was determined based on the soil moisture depletion level for each treatment. Therefore, the amount of irrigation water to be applied for each treatment during irrigation was the amount of water calculated based on soil depletion level with the effective root zone as net irrigation depth [14].

$$I = \left(FC - PWP\right) p * Z$$

Where:

I=net irrigation depth (mm)

FC=Moisture content of the soil at field capacity (volume base) (%)

PWP=Moisture content of the soil at permanent wilting point (volume base) (%)

P=Depletion level of the treatment (decimal)

Z=Effective root depth (cm).

The net depth of irrigation was calculated on the bases of available moisture-holding a capacity of the soil in its different layers and the soil moisture extraction pattern of the crop in its effective root zone depth. Once the net irrigation depth is known, the gross irrigation depth was determined by dividing the net irrigation depth to the application efficiency which was taken as 70% application efficiency for furrow irrigation under medium soil texture [15].

$$Ig = \frac{I}{ea}$$

Where:

I=Net irrigation depth (mm)

E_a=application efficiency (decimal)

I_g=gross irrigation depth (mm).

Determination of effective rainfall was computed using the CropWat model based on the following formula of 'dependable rainfall' (FAO/AGLW formula) using daily rainfall data recorded at Wondo Genet collage of natural resource metrology station and effective rainfall deducted from the net irrigation depth of next irrigation date.

The moisture level of each treatment was monitored after irrigation based on daily soil moisture observation. The calculated amount of irrigation water was applied measuring with Parshall flume which was installed 10 m away from the experimental field (Table 1).

The amount of irrigation water applied to each treatment during the experimental period is shown a decreasing trend as the depletion level increased. The highest amount of irrigation water (564.2 mm) was applied in the 30% SMDL (soil moisture depletion level), which was irrigated frequently while the lowest (295.0 mm) was applied in the treatment 100% SMDL which was irrigated with wider irrigation interval. This leads to a reduction of 269.2 mm as the depletion level increased from 30 to 100% SMDL.

There was the total amount of water used by the crop was in the range 500 mm annual rainfall of previous reports [5] for *Vernonia* at different agro-ecology. The reduction in irrigation water depth might be due to the increase in soil moisture depletion levels leads to a reduction in the day to maturity. The earliness in the day to maturity leads to a reduction in a frequency of irrigation. Therefore, the amount of irrigation could be reduced similarly in the higher depletion level treatments.

Treatments and experimental design

The treatments were arranged in a randomized complete block design with three replications. Each treatment was assigned to the experimental plots having an area of 10.8 m^2 (3 m × 3.6 m) with the spacing of 1.5 m between plots and 3.00 m between replications having a total experimental area of 513 m^2.

Treatment	Effective rainfall (mm)	Net irrigation water applied (mm)	Gross irrigation water applied (mm)
30% SMDL	46.9	564.2	852.9
40% SMDL	46.9	542.5	821.9
50% SMDL	46.9	533.1	808.4
60% SMDL	46.9	493.4	751.8
70% SMDL	46.9	462.1	707.0
80% SMDL	46.9	397.6	614.9
100%SMDL	46.9	295.0	468.3

Table 1: Effective rainfall, net irrigation, gross irrigation water applied and total amount of water applied.

A seed of *Vernonia* was sown at a depth of 1 cm at high density to ensure adequate emergency and thinning was done after two weeks from emergency to maintain the prescribed population density. The space between plants and rows was 60 cm × 60 cm apart to obtain a total population density of 27,777 plants ha^{-1} [16]. Accordingly, each experimental plot consists of five rows and six plants per row with a total of 30 plants per plot. Different crops have different optimum depletion levels in which 50% soil moisture depletion level is commonly used for many crops [17]. Based on this seven soil moisture depletion levels (30, 40, 50, 60, 70, 80 and 100% SMDL) were used as experimental treatments. Treatments were randomly assigned to each plot in the replication.

Treatments: Irrigation is set when at

T_1:- 30%, T_2:- 40%, T_3:-50% T_4:- 60%, T_5:- 70%, T_6:- 80% and T_7:- 100% soil moisture is depleted.

Normal cultural practices like weeding, pest and disease controlling, tapping (when the plants height reach 50 cm tall, the upper 2.5 to 5.0 cm of the plants were removed to stimulate branching from the base of the plants), and watering (before the beginning of treatment, three common light irrigations were supplied to all plots to ensure better plant establishment) were done.

Data collection

Sample size was determined using the margin of error of the plot mean (Gomez and Gomez), [18]

Which $n = \frac{(Z_a{}^2)(\delta_s)}{(d^2)(\bar{x})^2}$

Where:

n=Required sample size

Za=Value of the standardized normal variant corresponding to the level of significance α (obtained from statistical table)

δs=Sampling variance

d=Margin of error expressed as a fraction of the plot mean.

Based on the above equation six plants were selected for a sample from the central part of the plot excluding the border for data collection on growth, yield and yield components of *Vernonia*. Data on days to flowering, seed setting and days to 50% maturity were recorded from the date of planting to the date on which 50% of the plants in a plot were opened flower, produced seed and matured. Data on plant height (cm) was measured in centimetre from sample plants starting from the base of the plant to tip of the main stem during the onset of maturity and the mean was calculated to have a single value per plant. Data on the number of branches per plant (NBPP), number of capsule per plant (NCPP) were counted in the field. The selected six samples were harvested 166 days after planting for Seed yield (kg/ha), Weight of thousand seed (1000SW) was counted by seed counter and weighed by using sensitive balance. Data on seed oil content (%), Seed oil yield (kg/ha), Oleoresin (fixed oil) content were determined by soxhlet (solvent extraction) method at Wondo Genet Agricultural Research Center, Natural product Laboratory. Moreover, based on the obtained yields and amount of irrigation used, water use efficiency was calculated using the following formula.

$$WUE = \frac{Y}{I}$$

Where:

WUE: Water use efficiency (kg/m^3)

Y: Oil yield of *Vernonia* (kg/ha) and

I: Total net irrigation water applied (m^3/ha).

Crop water use efficiency is the yield harvested in kilogram per total water used. Crop water use efficiency is the ratio of crop yield to the amount of water depleted by the crop in the process of evapotranspiration using the above equation [19].

Data analysis

Data collected were statistically analyzed using statistical analysis system (SAS) software version 9.2 [20] using the general linear programming procedure (GLM). Mean separation using least significant difference (LSD) at 5% probability level was employed to compare the differences among the treatments mean.

Result and Discussion

Effect of different depletion level on phenology of *Vernonia*

Analysis of variance for the number of days to flowering, seed setting and days to maturity revealed that *Vernonia* was very highly significantly (P<0.001) affected by different soil moisture depletion levels. Maximum days to flowering, days to seed setting and days to maturity of 124, 146 and 156, respectively observed at 30% SMDL treatment. However, 30% was not statistically higher than 40 and 50% SMDL treatments in the day to flowering. Moreover, in the day to seed set, 30% SMDL was not statistically higher than 40% SMDL treatments.

On the other hand, the minimum days to flowering, days to seed setting and days to maturity of 95, 116 and 125, respectively at 100% SMDL treatment. 100% SMDL was statistically inferior to all other treatments in the day to flowering and day to maturity, although in days to seed setting it was not statistically earlier than 80% SMDL treatment. When the soil moisture depletion level increased from 30 to 100% SMDL days to flowering, seed setting and maturity date were decreased by 23%, 20% and 19.4%, respectively. The study revealed that increasing soil moisture depletion level from 30 to 100% SMDL leads to an earlier day to maturity by a month.

These results indicate that moisture stress causes early flowering, pod formation and maturity of the plant. These percentages of flowering and pod abscission were found different in different irrigation treatment (Table 2). These results indicate that percentage of flower and pod abscission increased with increasing moisture stress which was supported by Hossain et al. [21].

Results obtained under the present investigation are in line with those obtained by Ahmed et al. [22], regarding number of days to 50% flowering, seed setting and maturity, for faba bean where it was noticed that plants try to escape from unfavorable stress conditions by ending their life a few days earlier than those under normal or high soil moisture conditions. A similar result has also been reported by Al-Suhaibani [23] who indicated that soil water stress leads to significant decrease in the number of days to maturity. That is due to plants under higher soil moisture depletion levels are subject to soil moisture stress before the next irrigation. Different plants pose different mechanism to combat with moisture stress like physiological, morphological and biochemical process. That might be due to its different physiological process that affects days to flowering, days to seed setting and days to physiological maturity.

Plant height

Different Soil moisture depletion levels very highly significantly

Treatment	DFW	DSS	MD	PH (cm)
30% SMDL	124^{a}	146^{a}	156^{a}	162.7^{a}
40% SMDL	120^{a,b}	142^{a,b}	152^{a,b}	159.2^{a,b}
50% SMDL	119^{a,b}	136^{b,c}	148^{b,c}	151.1^{b,c}
60% SMDL	114^{b}	135^{b,c}	142^{c}	147.3^{c}
70% SMDL	113^{b}	131^{c,d}	135^{d}	143.8^{c,d}
80% SMDL	104^{c}	124^{d,e}	132^{d}	135.1^{d,e}
100% SMDL	95^{d}	116^{e}	125^{e}	128.9^{e}
LSD$_{0.05}$	7.9	7.7	6.3	10.1
CV (%)	3.9	3.3	2.5	3.9

^{a,b,c,d,e}Means followed by the same letters within columns do not differ significantly at p<0.05 probability level according to LSD. DFW: days to 50% flowering, DSS: days to 50% seed setting, MD: Days to 50% maturity.

Table 2: Effects of different soil moisture depletion levels on yield and yield Components of *Vernonia* (*Vernonia galamesis*. L).

Treatment	NBPP	NCPP	TSW (g)	SY (kg/ha)
30% SMDL	150^{a}	196.8^{a}	4.5^{c,d}	1676^{c,d,e}
40% SMDL	146^{a}	191.0^{a}	5.5^{b}	1926^{b}
50% SMDL	134^{b}	185.2^{a}	5.8^{a,b}	2130^{a}
60% SMDL	127^{b}	156.6^{b}	6.4^{a}	2213^{a}
70% SMDL	101^{c}	154.1^{b}	4.7^{c}	1787^{b,c}
80% SMDL	100^{c}	137.1^{c}	3.9^{d,e}	1472^{d}
100% SMDL	91^{c}	124.7^{c}	3.4^{e}	1361^{d}
LSD$_{0.05}$	10.3	16.0	0.7	199.9
CV (%)	4.8	5.5	8.5	6.3

^{a,b,c,d,e}Means followed by the same letters within columns do not differ significantly at p<0.05 probability level according to LSD.

NBPP: Number of Branches Per Plant; NCPP: Number of Capsules Per Plant; TSW: Thousand Seed Weight; SY: Seed Yield.

Table 3: Effect of different Soil moisture depletion level on yield and yield components of Vernonia.

(p<0.001) affected plant height. The maximum plant height (162.7 cm) was observed at 30% SMDL. However, it was not significantly higher than 40% SMDL. On the other hand, minimum plant height (128.9 cm) was observed at 100% SMDL. However, this was not significantly lower than 80% SMDL (Table 2). The data reveal that as the SMDL increase plant height was reduced. As the SMDL increase from 30% to 100% SMDL, plant height was reduced by 20.8%. Similar results were reported for the different crop under different soil moisture depletion levels and moisture stress conditions. This result agreed with the result of Mahamed et al. [24] who reported that plant height of bread wheat was reduced when the SMDL increased [25] and similar reports were also reported by Ranawake et al. [26] who reported that significant reduction in length between stressed and watered plant.

The decrease in shoot length under water stress conditions was reported by Yousef [27] on chamomile plants, Kumar et al. [28] on chrysanthemum plant, Khalil et al. [29] on *Mentha piperita,* L., Hussain et al. [30] on *Helianthus annuus* L. Such decrease in shoot length in response to drought either due to decrease in cell elongation resulting from water shortage which led to a decrease in each of cell turgor, cell volume and eventually cell growth and/or due to blocking up of xylem a and phloem vessels thus hindering any translocation [31].

Number of branches per plant

The analysis of variance revealed that the number of branches per plant was very highly significantly (p<0.001) influenced by different soil moisture depletion levels. A maximum number of branches per plant (150) were obtained at 30% SMDL which was statistically similar with 40% SMDL treatment. On the other hand, a minimum number of branches per plant (91) were observed at 100% SMDL treatment (Table 3). This was not statistically lower than 70 and 80% SMDL treatments. The study revealed that as soil moisture depletion level increased from 30 to 100% SMDL, the number of branches per plant was decreased gradually. This leads to a decrease of 39.3% in a number of branches per plant. The result showed that as the water stress increased the number of branches and leaves per plant decreased; this indicated that water stress had a direct effect on initiation of the branch and this was also underlined [26]. That stress affects the crop phenology, leaf area development and a number of leaves of mungbean. This is in line with former reports on different crops. For example, similar results were reported on faba beans [32], cowpea [33] and pea [34]. These results also consistent with the work [35] on Stevia rebaudiana, [36] on rose plants. Such reduction in the number of leaves due to water stress can be attributed to its direct effect on cell division, which arose from a reduction in a nucleic acid synthesis which enhanced its breakdown [37].

Number of capsules per plant

Different soil moisture depletion levels had a very highly significantly (p<0.001) influence on a number of capsules per plant. The maximum capsule per plant (196.8) was recorded at 30% soil moisture depletion level. This was statically similar with capsule per plant obtained at 40 and 50% SMDL treatments. On the other hand, a minimum number of capsules per plant (124.7) were observed at 100% SMDL treatment (Table 3). This was not statistically lower than a number of capsules per plant observed at 80% SMDL treatment. The data revealed that as the soil moisture depletion level increased from 30% SMDL to 100% SMDL, the number of capsules per plant reduced by 36.6%.

The number of capsules per plant increased as soil moisture depletion level decreased. This result may be due to the frequent irrigation improved soil moisture availability for the crop near the crop root zone which leads to frequent higher transpiration. These results are confirmed by those of Gan et al. [38] and Singh et al. [39] who concluded that plants produced 16% more pods per plant during post depletion period than the plants that remained at the low water status.

Thousand seed weight

Different soil moisture depletion levels had a very highly significant ($p<0.001$) effect on 1000 seed weight. Higher thousand seed weight (6.4 g) was recorded at 60% SMDL treatment. However, this was not statistically higher than 50% SMDL. On the other hand, the minimum thousand seed weight (3.4 g) was observed at 100% SMDL treatment. This was statistically similar to thousand seed weight observed at 80% SMDL treatment. As soil moisture depletion level increase and decrease beyond 60% SMDL, thousand seed weight was gradually decreased. Increasing soil moisture depletion level from 60% to 100% leads to a decrease of 46.9% in thousand seed weight. Whereas decreasing soil moisture depletion level from 60 to 30% leads to a reduction of 29.7% in thousand seed weight (Table 3).

The result showed that irrigating when the soil moisture depletion level reaches 60% it seems the optimum level for thousand seed weight. It was observed that thousand seed weight was decreased under drought as well as under over irrigation. These findings are in line with those of Malik and Anwar [40] who reported that 100 seed weight and seed yield have been increased by irrigation in chickpea. These findings also in line with that of Hassan and Sarkar [41] who concluded that application of further irrigation gradually decreased yield, yield components and water use efficiency, causing the wastage of irrigation water in chickpea.

Seed yield

Different soil moisture depletion level had very highly significantly ($P<0.001$) influenced seed yield. The maximum seed yield (2213 kg ha^{-1}) was recorded in 60% SMDL treatment. However, this result was not statistically higher than 50% SMDL. On the other hand, the minimum seed yield (1361 kg ha^{-1}) was obtained at 100% SMDL. This was statistically similar with 30 and 80% SMDL treatment. As soil moisture depletion level increase and decrease away from 60% SMDL, seed yield was slowly decreased. Increasing soil moisture depletion level from 60% to 100% leads to a decrease of 38.5% seed yield. Whereas declining of soil moisture depletion level from 60 to 30% leads to a reduction of 24.3% in seed yield (Table 3).

It might be due to the reasons that drought conditions retarded the plant growth processes which eventually produced low 1000-seed weight and low seed yield. These results are in conformity with Basu and Singh [42] reported decreased seed yield under drought conditions Better yield at 60% SMDL might be due to normal moisture supply which helped in root enhancement, capsule setting, and higher 1000seed weight.

Nielsen [43] reported that chickpea exhibited the greatest rate of increase in yield with an increase in water use. Over-irrigation decreased seed yield by 24.3% when irrigated at 30% SMDL. It might be due to the fact that frequent irrigation leads to shallow root and enhance vegetative growth rather than seed yield. These findings are confirmed by the results of Hassan and Sarkar [41] who concluded that application of further irrigation in chickpea gradually decreased yield and water use efficiency, causing the wastage of irrigation water.

Vernonia oil yield

The analysis of variance revealed that oil yield of Vernonia was highly significantly ($p<0.01$) influenced by different soil moisture depletion levels. The maximum oil yield (711.8 kg ha^{-1}) was recorded at 60% SMDL. However, this was statistically similar to the value obtained at 30%, 40%, 50%, and 70% SMDL treatments. On the other hand, minimum oil yield (448.1 kg ha^{-1}) was observed at 100% SMDL which was statistically similar to the value obtained at 80% SMDL (Table 4). As soil moisture depletion level increase and decrease beyond 60% SMDL, oil yield was gradually decreased. Increasing soil moisture depletion level from 60% to 100% leads to a decrease of 38.0% oil yield. Whereas, reducing soil moisture depletion level from 60 to 30% leads to a reduction of 23.9% in oil yield. The reason for the reduction of oil yield with increasing severe water regime was reducing seed yield and oil percentage due to water deficit. These results confirmed results of Naderi et al. [44]. According to the reducing of yield in water regime conditions in addition as oil, the yield is depended to the seed yield, we observed reduction of oil yield by the seed yield reduction, thus sufficient irrigation is used to increase the seed yield and oil yield [45].

Vernonia oil content

The analysis of variance revealed that Oil content was not significantly ($p>0.05$) affected due to different soil moisture depletion levels. However, the average oil content ranged from 31.27% to 34.35%. Farahvash et al. [46] and Mohammadi et al. [47] showed that drought stress didn't have a significant effect on sunflower oil content; similarly Mula Ahmed et al. [48] also found that water stress had an insignificant effect on oil content. The result found by Bashir and Mohamed [49], oil content of sunflower increased with increasing the amount of irrigation disagrees with this *Vernonia* result.

Water use efficiency

Water use efficiency based on oil yield was significantly ($p<0.05$) influenced by different soil moisture depletion levels. The highest water use efficiency (0.15 kg/m^3) was obtained at 100% SMDL which was statically similar with the result obtained at 50, 60, 70 and 80% SMDL treatments. Whereas, the lowest water use efficiency (0.096 kg/m^3) was obtained at 30% SMDL. This was statically similar with the result obtained at 40, 50 and 80% SMDL (Table 4).

Generally, as the soil moisture depletion level increased from 30 to 100% SMDL, water use efficiency was increased even though it was not linear. The maximum water use efficiency at 100% SMDL may be due to the low amount of irrigation water applied which is the denominator in water use efficiency. On the other hand, 60% SMDL treatment showed the second higher in water use efficiency may be due to higher oil yield which is the nominator in water use efficiency.

Water use efficiency increased by 36.8% when the soil moisture depletion level increased from 30% to 100% SMDL. However, seed yield and oil yield were decreased when soil moisture depletion level

Treatment	OY (kg/ha)	OC (%)	WUE (kg/m^3)
30% SMDL	541.6^{b,c}	32.25^{a}	0.096^{c}
40% SMDL	602.4^{b}	31.27^{a}	0.104^{b,c}
50% SMDL	703.7^{a}	33.37^{a}	0.132^{a,b}
60% SMDL	711.8^{a}	31.82^{a}	0.144^{a}
70% SMDL	613.6^{a,b}	34.35^{a}	0.139^{a,b}
80% SMDL	484.2^{c}	32.88^{a}	0.121^{a,b,c}
100% SMDL	448.1^{c}	32.90^{a}	0.152^{a}
$LSD_{0.05}$	100.9	3.48ns	0.04
CV (%)	9.7	6.0	15.5

[a,b,c]Means followed by the same letters within columns do not differ significantly at $p<0.05$ probability level according to LSD.

OY: Oil Yield; OC: Oil Content; WUE: Water Use Efficiency.

Table 4: Effect of different soil moisture depletion level on yield and yield components of *Vernonia galamesis L.*

decreased beyond 60% to 100% SMDL. Therefore, the increased water use efficiency beyond 60% SMDL leads to a compromise in the reduction of oil yield and seed yield. These results are similar to those of Narang at al. [50] who also reported a loss of grain yield by increasing SMDL.

The study clearly showed that seed yield and oil yield was increased until the soil moisture depletion level increased to 60% SMDL. However, beyond this level, both seed yield and oil yield were reduced gradually. On the other hand, water use efficiency was gradually increased until the soil moisture depletion level increased to 100% SMDL. Therefore, based on the economic yield of vernonia like seed yield and oil yield, 60% SMDL *(RAW=0.6TAW)* treatment was the threshold value for the production of *Vernonia* at Wondo Genet and similar agro-ecology and soil type.

Conclusion and Recommendation

Agricultural water scarcity is the most critical constraint for the development of agriculture in arid and semi-arid climates. Hence, effective use of available water with appropriate irrigation scheduling has a significant implication on irrigated agriculture. Based on this study, vernonia grew under 100% SMDL took a shorter number of days to reach 50% flowering, seed setting and days to mature while, 30% SMDL took the longest days to flowering, fruit setting and days to mature from planting date. The maximum plant height, number of branches per plant and number of capsules per plant 162.7 cm, 150 and 196.8 were obtained from 30% SMDL respectively. The highest seed yield (2213 kg ha^{-1}) and oil yield (711.8 kg ha^{-1}) were obtained from 60 % soil moisture depletion level. The lowest seed yield (1361 kg ha^{-1}) and oil yield (448.1 kg ha^{-1}) were obtained from 100 % soil moisture depletion level. The highest water use efficiency on oil yield (0.15 kg/m^3) was obtained at 100% SMDL whereas the minimum water use efficiency was recorded at 30% SMDL.

In order to obtain maximum seed yield, oil yield and WUE in water scarcity conditions, a total of 493.38 mm water is recommended at 60% SMD level for vernonia production. Even though the maximum WUE was obtained at 100%SMDL it was statistically similar with the water use efficiency obtained at 60% SMDL thus, the optimal seed yield, oil yield and WUE could be achieved if recommended seasonal water amount of 493.38mm scheduled at 60% SMDL to be grown around Wendo Genet and similar agroecology. Therefore, irrigation of Vernonia at 60% soil moisture depletion level is an optimum depletion level based on the current finding based on seed yield, oil yield and water use efficiency.

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