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Effect of Irrigation Intervals and Manure Rates on Agronomic Parameters of Dill at Different Agro-ecological Zones of Bhutan

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ABSTRACT

The effect of different irrigation intervals and manure rates on agronomic parameters of dill were evaluated under three agro-ecological zones of Bhutan: ARDC-Bajo located at 1200 m asl, ARDC–Wengkhar at 1,700 m asl, and NCOA–Yusipang at 2700 m asl. The split-plot design arranged in randomized complete blocks with three replications was employed. The four levels of irrigation interval (control, every 3 days, every 7 days, and every 14 days) were allotted to main plots and four levels of manure (Control, 4 tons/acre, 8 tons/acre and 12 tons/acre) were allocated to subplots. The results showed that dill can be successfully grown in all agro-ecological zones under study. Fresh yield obtained at ARDC-Wengkhar (1.92 tons/acre) was significantly higher compared to that at NCOA-Yusipang (0.52 tons/acre) but not significant to that at ARDC-Bajo (1.41 tons/acre). Interaction of irrigation interval and manure rate significantly influenced plant height (P=0.02) and stem diameter (P=0.03) at NCOA–Yusipang, and stem per plant (P=0.02) at ARDC-Wengkhar. The irrigation interval of 3 days produced significantly better results except for the fresh to dry weight ratio at NCOA-Yusipang. Irrigation interval of 7 days yielded better results at ARDC-Bajo and ARDC-Wengkhar except for FDR at ARDC-Wengkhar. The increase in irrigation interval beyond 7 days resulted in 62% and 25% lower fresh yields at ARDC-Bajo and NCOA-Yusipang respectively. In contrast, irrigation at 3 days interval at ARDC–Wengkhar decreased the yield by 55% compared to 7 days interval. The manure treatments did not influence any of the parameters assessed at all sites. However, MR 8 tons/acre at NCOA–Yusipang, MR Control at ARDC-Wengkhar and MR 12 tons/acre at ARDC-Bajo yielded higher fresh yields compared to other manure treatments. We recommend the combined application of IR 7 days x MR 12 tons/acre, IR 7 days x MR 4 tons/acre, and IR 3 days x 8 tons/acre at ARDC–Bajo, ARDC-Wengkhar and NCOA–Yusipang respectively. Further, this research provides a reference guide for agricultural extensionists during promotional, advocacy and capacity development programs.

Keywords: *Anethum graveolens; Irrigation Interval; Manure Rate; Split-plot Design*

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1. Introduction

Dill (*Anethum graveolens* L.) is an erect, annual aromatic herb belonging to the Apiaceae family which grows up to 50 to 150 cm tall. It is grown in the Mediterranean region, Europe, central and southern Asia (Kaur & Arora, 2010). The herb contains essential oils (2-4%), carbohydrates (36%), protein (15.68%), fiber (14.80%), ash (9.8%), fatty oil, and minerals (Carrubba, Catalano, & Bontempo, 2010; Kaur & Arora, 2010). The herb is reported to have a wide range of medicinal uses such as antispasmodic, carminative, diuretic, stimulant and stomachic (Charles, 2012). It is also used to add flavour to different Egyptian foods, bread, pickles, and soup (Charles, Simon, & Widrlechner, 1995; Elsayed, Glala, Abdalla, El-Sayed, & Darwish, 2020; Hassan, 2015).

In the Bhutanese traditional food and farming system, people usually grow and consume only a few herbs such as coriander, chives, and spring onions. The cultivation of western culinary herbs including dill is very limited and the small domestic requirements were met through imports from Thailand and India. The increased tourist inflow, pizza huts and pastry in urban towns and awareness of the health benefits of herbs amongst Bhutanese have increased the demand for herbs in the country. As there were no officially released varieties, it was very challenging for the Department of Agriculture to promote the commercial cultivation of herbs in the country. The need for the introduction and evaluation of varieties of herbs including dill has become urgent and necessary.

There are many factors affecting the successful cultivation of crops such as seed variety and quality, planting time, planting methods, spacing, intercultural operations including plant nutrients and water requirements. In the context of climate change, plant nutrient and water availability are the most important factors to achieve good plant growth, development, and potential yield (Gerami, Moghaddam, Ghorbani, & Hassani, 2016) that facilitates dissolutions and uptake of micronutrients by the plants (Ghassemi-Golezani, Rezaeipour, & Alizadeh-Salteh, 2016; Naomi, Mwanarusi, & Musyoka, 2014). Delfine, Tognetti, Desiderio, and Alvino (2005) estimated that on average, the decrease of yield due to water shortage is more than 25% in the world. Also, water deficiency induces various physiological and metabolic responses resulting in stomatal closure, a decline in growth rate, accumulation of solute and antioxidants, reduction in photosynthesis and transpiration, and the expression of stress-specific genes (Jones & Tardieu, 1998; Tsamaidia, Dafererab, Karapanosa, & Passama, 2017). In terms of aromatic herbs, water scarcity directly contributes to decreased plant height, fresh and dry weight, reduce leave area, oil yield and composition (Baher, Mirza, Ghorbanli, & Bagher Rezaii, 2002; Charles et al., 1995; Simon, Reiss-Bubenheim, Joly, & Charles, 1992; Zehtab-Salmasi, Javanshir, Omidbaigi, Alyari, & Ghassemi-Golezani, 2001).

In addition, fertilization is reported to be one of the major factors affecting growth and development including yield, and quality of dill (Elsayed et al., 2020). The excessive use of chemical fertilizer in the recent past has resulted in health and environmental hazards (Sharma & Singhvi, 2017). He also argued that the use of organic alternatives could be the answer to reducing such destruction to nature and human health. Organic manure improves soil's physical, chemical, and biological properties and enhances the moisture retention capacity and nutrient uptake (Rostaei, Fallah, Lorigooini, & Abbasi Surki, 2018). Studies have also shown that the application of organic manure can increase quantity as well as the quality of crops. However, studies related to enhanced use of irrigation water and organic manure for sustainable herb farming are largely missing particularly in the Bhutanese context. Further, Bhutan with its development philosophies deeply rooted in love for nature and sustainable development goals, it has become necessary to develop alternative solutions in terms of efficient water use and organic manure without compromising the final output. Hence, the present study investigated i) optimum irrigation interval and manure rate for production of dill, ii) study their respective as well as combined influence on agronomic parameters, and iii) study the performance of dill under three agro-ecological zones of Bhutan.

2. Materials and Method

2.1 Study sites

The study was conducted from 11 March 2021 to 15 July 2021 in three agro-ecological zones of Bhutan. The Agriculture Research and Development Centre, Bajo (ARDC-Bajo) represents low altitude (1200 masl) located at latitude of 27^{o}29'25.0' N and longitude of 89^{o}53'51'' E. The Agriculture Research and Development Centre, Wengkhar (ARDC-Wengkhar) represents mid-altitude (1700 masl) located at latitude of 27^{o}16'25" N and longitude of 91^{o}16'13" E. The National Centre for Organic Agriculture, Yusipang (NCOA Yusipang) representing high altitude (2,700 masl) located at latitude of 27^{o}27'49.1" N and longitude of 89^{o}42'41.3" E. ARDC Bajo falls under the humid subtropical region with clay type of soils, while ARDC Wengkhar and NCOA Yusipang fall under the dry sub-tropical region with loamy clay soils and warm temperate region with sandy clay soils respectively.

2.2 Study Design

The performance of dill was evaluated using four levels of irrigation intervals: i) No irrigation, ii) at sowing and every after three days, iii) at sowing and every after seven days, iv) at sowing and every after 14 days and four levels of manure rate i) 0 tons/acre, ii) 4 tons/acre, iii) 8 tons/acre, iv) 12 tons/acre using split plot based on randomized complete block design with three replicates. The irrigation interval treatments were allotted as main plots and manure rates as the sub-plots. The field was ploughed, levelled, and divided into plots measuring 2×1 m with buffer distance between treatments and replications at 25 cm and 50 cm respectively. The manure treatments were then administered as per the result of randomization of treatments in STAR Software (Statistical Tool for Agriculture Research) version 2.0.1. The manure was thoroughly incorporated into the soils before sowing the seeds. The dill seed (2 seeds each) introduced from Corona seeds Inc., USA was sown at 1 to 2 cm depth with the plant to plant and row to row distance of 30 cm. The first irrigation was uniformly provided at field capacity for all the treatment plots to facilitate seed germination. A total of 10 plants in each treatment plot were maintained by randomly removing one of the plants between 10-15 days after the seed germination. The crop was harvested when the leaves were still tender. The details of trial management including intercultural operations are provided in Table 1. Weeding was done depending upon the weed pressure, while the irrigation was given at field capacity at prescribed treatment intervals.

Table 1. Record of trial management and intercultural operations at three study sites

Activities	ARDC Bajo	ARDC Wengkhar	NCOA Yusipang
Sowing Date	11 March, 2021	27 April, 2021	9 April, 2021
Germination (DAS*)	13	23	13
Crop duration (DAS)	76	80	75
Number of hand weeding	3	3	2
Number of irrigations applied for each treatment			
a) Control	0	0	0
b) 3 days interval	25	27	25
c) 7 days interval	11	12	10
d) 14 days interval	6	6	6

*DAS: Days After Sowing

2.3 Data collection and preparation

The data for different parameters like plant height, stem diameter, number of stems per plant, and fresh weight were recorded at the time of harvest. The data collection was done from 50 % of the total plant population from all the treatment plots and in the case where the plant population is less than 50%, data were recorded from all the live/standing plants. The plant height was measured from the ground surface to the tip of the main shoot using a measuring tape, while the stem diameter was measured just above the collar region using a vernier calliper. Similarly, the fresh weight of the sample plants was measured using a digital weighing balance. The sample plants from all the treatment plots were tagged and dried for a week using a solar dryer after which the dry weights were measured. However, the dry weight of the sample plants could not be measured at ARDC-Bajo due to technical issues with the dryer and was therefore excluded from statistical analysis and inference in this article. The fresh yield per plot (kg/plot) and per acre (ton/acre) were calculated using the formula (i) and ii) respectively. The same formulae were used to obtain dry yield per plot (kg/plot) and per acre (ton/acre). The mean value and standard deviation of the mean in parenthesis are presented.

$$py = \frac{w * n}{1000} \qquad \text{(i)}$$

Whereas,

py is the plot yield in kg,
w is the average fresh or dry weight of sample plants in grams,
n is the total number of live/standing plants in respective treatment plots.

$$y = \frac{py * 4047}{2 * 1000} \qquad \text{(ii)}$$

Whereas,

y is the fresh or dry yield per acre in tons
py is the fresh or dry plot yield in kg

2.4 Data analysis

Data were statistically analyzed in R statistical software (R Core Team, 2021) using a two-way analysis of variance (ANOVA) for split-plot experimental designs provided by the r-package ‘agricolae’ (de Mendiburu, 2019) followed by mean separation using Tukey Honest Significance Difference test. The differences in the agronomic parameters between study sites were analyzed using one-way analysis of variance (ANOVA) taking sites as treatments. The alpha value was set at $P = 0.05$ to detect statistically significant differences between all the comparisons made in this article. The graphical representations of the statistical data were implemented using r-package ‘ggplot2’ (Valero-Mora, 2010) and seaborn library in Python

(Bisong, 2019). A correlation analysis between agronomic parameters was investigated using the Pearson Correlation algorithm in pandas library in Python (McKinney, 2011).

3. Results and Discussion

3.1 Effect of irrigation interval, manure rate and their interaction on agronomic parameters of dill at ARDC-Bajo

The result presented in Table 2 showed that both the irrigation interval (IR) and manure rates (MR) did not significantly influence any of the agronomic parameters. However, in the case of irrigation interval treatments, 7 days irrigation interval treatment yielded better outputs compared to other treatments while the least was obtained from the control indicating irrigation did influence though not significantly. All the parameters followed a similar trend where the yields increased with longer intervals of irrigation up to 7 days and then decreased.

The overall decrease in all the parameters of dill plants with a decrease of irrigation interval beyond 7 days could be due to a decrease in the cell enlargement and leaf senescence resulting from reduced turgor pressure. It could also be due to reduced photosynthesis activity resulting from alteration in crop canopy when irrigation was applied at a lower interval. Similar findings were reported in oregano and parsley where the decreased interval of irrigation resulted in a decrease in yield and other agronomic parameters (Gerami et al., 2016; Petropoulos, Daferera, Polissiou, & Passam, 2008). On the other hand, the poor performance of dill plants under no irrigation treatment could be due to limited water availability at the rhizosphere to facilitate nutrient uptake (Shao, Chu, Jaleel, & Zhao, 2008). It could also be due to the mechanism where the plant biomass was significantly reduced to increase water uptake under water-stressed conditions (Gerami et al., 2016; Tsamaidia et al., 2017). Shao et al. (2008) also reported that the reduction in the plant biomass and agronomic traits under the water-stressed condition is due to inhibition of physiological and biochemical processes, such as photosynthesis, respiration, ion uptake, carbohydrates, nutrient metabolism, and hormones. While our findings conform with other reports (Gerami et al., 2016; Ghassemi-Golezani et al., 2016; Gwari, Gambo, & Kabura, 2014; Petropoulos et al., 2008), such studies require precise control over various climatic to draw concrete conclusions.

In the case of manures, taller plant height (35.77 cm), bigger stem diameter (14.36 mm), a higher number of stems per plant (11.87) and higher fresh yield (2.03 tons/acre) were recorded in 12 tons/acre treatment. The least values were obtained from the control treatment. This implies that comparably higher available nitrogen in 12 tons/acre treatment has resulted in higher fresh yield and better results in almost all the agronomic parameters. The better overall results in the 12 tons/acre treatment could be due to which the application of more organic manure created better conditions for biological processes in the root zone which facilitated balanced nutrient availability for plants in addition to better water holding capacity, better soil physical and chemical properties in comparison to other treatments. An interesting finding was reported by Gerami et al. (2016) where the yield and agronomic traits of oregano were reported to increase with an increase in organic manure up to 20 tons/hectare, and decrease when it is applied beyond 30 tons/hectare.

Further, the ANOVA (data not presented) showed non-significant interaction effects of treatments (IR x MR) on all the agronomic parameters recorded. However, the treatment combination of IR 7 days with MR 12 tons/acre yielded the highest fresh yield (3.79 tons/acre) in comparison to all other treatment combinations. The lowest fresh yield (0.43 tons/acre) was obtained from a treatment combination of IR Control and MR 8 tons/acre. The higher fresh yield in IR 7 days with MR 12 tons/acre treatment combination could be due to the combined effect of treatments enhancing the availability of water and nutrient uptake for better growth compared to other treatment combinations. The poor yield in IR Control and MR 8 tons/acre treatment plot could be due to the poor availability of dissolved nutrients for plant uptake as no irrigation was applied. Our results contrast with the research of Heidarian, Rokhzadi, and Mirahmadi (2018) who reported significant combined effects of irrigation and manure. The finding suggests that the combined application of irrigation at 7 days interval and manure rate at 12 tons/acre could be recommended for cultivation of dill under ARDC–Bajo condition.

Table 2. Effect of irrigation interval, and manure rate on yield and agronomic parameters of dill at ARDC-Bajo

Treatments	Plant height (cm)	Stem diameter (mm)	Stems per plant (No.)	Fresh Yield (ton/acre)
Irrigation Interval (IR)				
Control	30.22 (6.39)	11.26 (3.44)	9.65 (1.84)	0.76 (0.63)
3 Days	31.27 (5.09)	12.71 (3.04)	10.40 (1.83)	2.04 (0.90)
7 Days	39.15 (8.96)	14.73 (4.04)	13.15 (3.91)	2.06 (1.89)
14 Days	31.107 (6.67)	10.98 (3.10)	9.75 (1.75)	0.78 (0.57)
P-value	*0.27*	*0.37*	*0.23*	*0.15*
Manure Rate (MR)				
Control	30.99 (2.57)	11.57 (1.19)	10.15 (0.95)	1.10 (0.22)
4 tons/acre	33.28 (2.28)	11.89 (0.89)	10.63 (0.64)	1.27 (0.30)
8 tons/acre	31.66 (1.66)	11.85 (0.86)	10.30 (0.59)	1.24 (0.30)
12 tons/acre	35.77 (2.22)	14.36 (1.14)	11.87 (1.01)	2.03 (0.54)
P-value	*0.24*	*0.07*	*0.12*	*0.07*

Values in parentheses indicate standard deviation of the mean

3.2 Effect of irrigation interval, manure rate and their interaction on agronomic parameters of dill at ARDC-Wengkhar

The results (Table 3) showed that the irrigation interval (IR) and manure rate (MR) did not significantly affect any of the agronomic parameters. In terms of irrigation intervals, IR 7 days yielded better results in comparison to other irrigation treatments except for the fresh to dry weight ratio (FDR), while the least values were obtained from IR 3 days except for FDR. It was observed that all the parameters followed a similar trend. Their values increased from IR 3 days to IR 7 days and then decreased with the application of IR at 14 days. The decrease in the yield at IR 3 days could be due to the combined effect of rainfall and excessive/frequent irrigation resulting in waterlogged conditions affecting the yield and parameters negatively. A comparatively better result in IR 7 days implies that the combination of rainfall and irrigation at 7-days interval is the best practice of irrigation under ARDC–Wengkhar condition, while lower values obtained under no irrigation condition (control) could mean that the rainfall alone is not enough to enhance nutrient dissolution and uptake for proper growth and development of dill plants.

Although the literature on dill is scarce, past reports on beans and anise (Hassan, Abou El-kasem, & El-kassas, 2021), sugar beet (Heidarian et al., 2018) and oregano (Gerami et al., 2016) have reported the influence of soil type and texture on the soil microbial diversity (Obayomi et al., 2021).

Surprisingly, MR Control yielded better results (although not statistically significant) in all the agronomic parameters except for FDR compared to other treatments. This could be due to abundant residual nutrients from the previous crop cultivated in the trial site. In addition, the agronomic parameters are negatively affected by an increasing amount of manure application. This could be due to the presence of residual nutrients in the soil, and the addition of organic manures could have crossed the threshold for optimal growth and development. Similar findings were reported in past research on oregano and onion (Gerami et al., 2016; Lee, 2012).

The statistical model did not detect any significant interaction effect of the treatments (data not shown) except for the number of stems per plant at $P = 0.02$ (Figure 1). The result showed that the combined application of IR 14 days and MR 4 tons/acre obtained taller plant height (74.70 cm), higher fresh yield/acre (3.47 tons/acre) and higher FDR (13.20), while the combined application of IR 3 days and MR 8 tons/acre obtained lowest values for stem diameter (6.21

mm), stem numbers (5.63) and dry yield (0.04 tons/acre). The poor results in the treatment combination of IR 3 days and MR 8 tons/acre could be due to frequent irrigation (every 3 days) at field capacity in addition to natural rain resulting in waterlogged conditions creating unfavourable conditions at the rhizosphere for optimal plant growth. The result also suggests that the combined application of IR 14 days and MR 4 tons/acre could be the best practice for dill cultivation under ARDC-Wengkhar region.

Table 3. Effect of irrigation interval and manure rate on agronomic parameters of dill under ARDC-Wengkhar

Treatments	Plant height (cm)	Stem diameter (mm)	Stems per plant (No.)	Fresh yield (ton/acre)	Dry yield (ton/acre)	FDR#
Irrigation Interval (IR)						
Control	55.43 (16.31)	10.98 (3.10)	8.49 (1.46)	1.87 (1.33)	0.24 (0.18)	7.77 (0.80)
3 Days	48.18 (21.30)	10.28 (4.62)	7.85 (2.48)	1.13 (1.07)	0.14 (0.15)	9.18 (3.04)
7 Days	65.21 (22.82)	12.23 (3.79)	9.50 (2.23)	2.51 (1.90)	0.31 (0.22)	8.00 (0.98)
14 Days	60.13 (24.90)	11.08 (3.26)	8.68 (1.99)	2.40 (1.79)	0.25 (0.19)	9.74 (4.29)
P-value	*0.57*	*0.65*	*0.51*	*0.35*	*0.64*	*0.26*
Manure Rate (MR)						
Control	60.64 (16.30)	11.76 (3.75)	9.20 (1.76)	2.36 (1.16)	0.30 (0.14)	8.08 (0.87)
4 tons/acre	57.90 (21.78)	11.57 (3.08)	9.03 (2.08)	1.91 (1.57)	0.21 (0.17)	9.60 (4.41)
8 tons/acre	52.95 (27.50)	10.35 (4.80)	8.16 (2.79)	2.08 (2.12)	0.26 (0.26)	8.96 (3.05)
12 tons/acre	57.45 (22.42)	10.89 (3.19)	8.12 (1.56)	1.56 (1.56)	0.19 (0.18)	8.05 (0.89)
P-value	*0.76*	*0.69*	*0.21*	*0.44*	*0.65*	*0.51*

Fresh weight to Dry weight Ratio; Values in parentheses indicate standard deviation of the mean

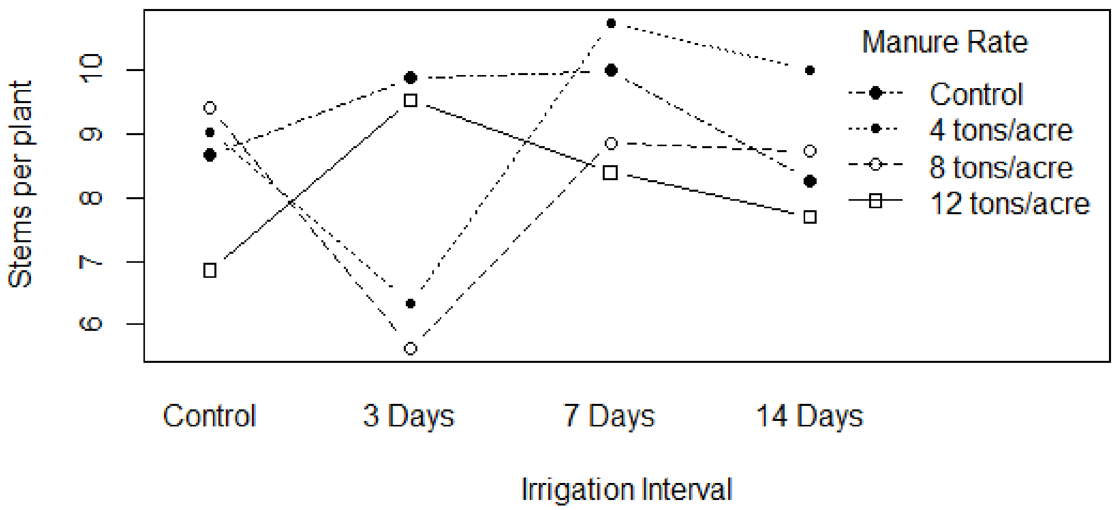

Figure 1. Interaction effect of irrigation interval and manure rate on the number of stems per plant at ARDC-Wengkhar

3.3 Effect of irrigation interval, manure rate and their interaction on agronomic parameters of dill at NCOA-Yusipang

The results (Table 4) showed significant effects of irrigation intervals on all the parameters assessed except for stem diameter under NCOA-Yusipang condition. The plant height, stems per plant, fresh yield and dry yield were significantly better in the IR 3 days treatment compared to control treatment but not significantly different from other treatments. Further, the control treatment yielded comparable outcomes to IR 14 days treatment. Although not statistically significant, IR 3 days obtained a larger stem diameter followed by IR 14 days and IR 7 days. The least stem diameter was obtained in the control treatment. The agronomic parameters followed a similar trend in which they increased to a maximum at IR 3 days and decreased with decreasing irrigation interval. The better performance of dill with the application of irrigation at 3 days interval could be due to meeting the optimal moisture requirement in addition to rainfall during the growing period under NCOA–Yusipang condition. Our results agree with the past reports on potato (Abou El-Khair, E.E., Nawar, & Ismail, 2011), onion (Gwari et al., 2014) and safflower (Khalil, Dagash, & Yagoub, 2013; Mohamed, Mariod, Yagoub, & Dagash, 2013).

The results (Table 4) also showed that plants treated with 8 tons/acre performed comparably better than other treatments (although not statistically significant) in all the parameters except for the number of stems per plant and FDR, while 4 tons/acre treatment yielded minimum values in almost all the parameters except fresh and dry yield. The highest number of stems per plant was obtained from the control treatment. All the parameters followed a similar trend in the order 8 tons/acre > control > 12 tons/acre > 4 tons/acre except for the stems per plant and fresh and dry yield. The non-significant results between all the manure treatments could be because the residual nutrient in the soil is already optimum for proper growth and development and the incorporation of additional manure did not make any difference. The effect of residual nutrients from organic manure applied in the previous year even at a very low rate is documented by Riley (2015). The higher stems per plant in the control treatment could be explained by shorter plants with slimmer diameters resulting in higher lateral shoots in the plants.

The ANOVA showed significant interaction effects of treatments (Figure 2) only for plant height *(P=0.02)* and stem diameter *(P=0.03)* and not for other parameters (data not shown). A significantly taller plant was obtained from the treatment combination of IR 3 days and MR 12 tons/acre (59.70 cm) compared to other treatment combinations. Plants of wider stem diameter were recorded in the treatment combination of IR 3 days and MR 8 tons/acre (10.80 mm) which were significantly different from other treatments while the least was obtained from the treatment combination of IR control and MR 4 tons/acre (4.85 mm). Although not statistically significant, the highest fresh yield of 0.856 tons/acre was obtained from IR 7days and MR 12 tons/acre treatment combinations, while the lowest was from IR control and MR 4 tons/acre treatment combinations (0.13 tons/acre).

Similarly, the maximum dry yield was obtained from the treatment combination of IR 3 days and MR 8 tons/acre (0.18 tons/acre), while the lowest dry yield was obtained from IR control and MR 4 tons/acre (0.02 tons/acre) treatment combination. The results imply that the best practices in terms of irrigation and nutrient management for dill under NCOA-Yusipang conditions could be the application of irrigation at field capacity at 3 days interval in combination with 8 tons/acre organic manure.

Table 4. Effect of irrigation interval, and manure rate on agronomic parameters of dill under NCOA-Yusipang

Treatments	Plant height (cm)	Stem diameter (mm)	Stems per plant (No.)	Fresh yield (ton/acre)	Dry yield (ton/acre)	FDR [#]
Irrigation Interval (IR)						
Control	40.70 (7.33) [b]	6.50 (2.23)	6.42 (1.03) [b]	0.26 (0.19) [b]	0.05 (0.03) [b]	5.59 (0.45) [a]
3 Days	57.20 (4.49) [a]	10.20 (1.62)	7.80 (0.69) [a]	0.73 (0.30) [a]	0.14 (0.06) [a]	5.09 (0.45) [ab]
7 Days	55.90 (6.38) [a]	8.96 (1.79)	7.73 (0.92) [a]	0.63 (0.25) [a]	0.12 (0.05) [a]	4.86 (0.42) [b]
14 Days	47.20 (7.40) [ab]	9.13 (1.75)	7.25 (0.77) [ab]	0.47 (0.28) [ab]	0.09 (0.05) [ab]	5.30 (0.70) [ab]
P-value	*0.02*	*0.05*	*0.03*	*0.02*	*0.01*	*0.04*
Manure Rate (MR)						
Control	50.31 (8.12)	8.77 (1.19)	7.37 (0.79)	0.50 (0.18)	0.10 (0.03)	5.15 (0.41)
4 tons/acre	48.84 (10.08)	8.37 (2.61)	7.37 (1.11)	0.52 (0.39)	0.10 (0.07)	5.33 (0.49)
8 tons/acre	52.72 (7.75)	9.08 (2.49)	7.26 (0.98)	0.56 (0.33)	0.12 (0.07)	4.96 (0.73)
12 tons/acre	49.07 (11.42)	8.54 (2.66)	7.22 (1.19)	0.51 (0.33)	0.10 (0.07)	5.39 (0.58)
P-value	*0.18*	*0.62*	*0.94*	*0.96*	*0.81*	*0.11*

[#] Fresh weight to Dry weight Ratio; Different lower-case letters in the superscript indicate statistically significant differences following the Tukey's HSD post hoc analysis at P=0.05; values in parentheses indicate standard deviation of the mean

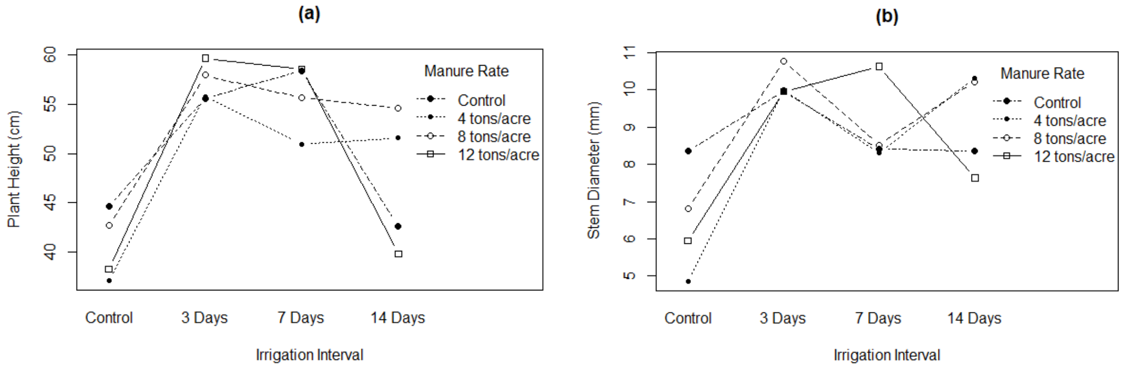

Figure 2. Interaction effect of irrigation interval and manure rate on plant height (a) and stem diameter (b) of dill at NCOA–Yusipang

3.4 Comparison of agronomic parameters of dill between three study sites

The crop gestation period was recorded highest at ARDC-Wengkhar (80 DAS) followed by ARDC-Bajo (76 DAS) and NCOA-Yusipang (75 DAS). The results of the one-way ANOVA and Tukey multiple comparison test (Table 5) showed that all the parameters under study significantly differed amongst study sites except for the survival rate. The result showed that the mean plant height was significantly taller at ARDC–Wengkhar (56.00 cm) and NCOA–Yusipang (50.24 cm) compared to that recorded at ARDC–Bajo (32.93 cm).

However, the mean plant height recorded at ARDC–Wengkhar and NCOA–Yusipang was comparable to each other. The mean stem diameter recorded at ARDC–Bajo (12.42 mm) was significantly wider compared to that at NCOA–Yusipang (8.69 mm), while it did not differ from that at ARDC-Wengkhar (10.87 mm). Similarly, a significantly higher number of stems per plant was obtained at ARDC–Bajo (10.73) in comparison to that at ARDC–Wengkhar (8.43) and NCOA–Yusipang (7.30). The stems per plant obtained at ARDC–Wengkhar was significantly higher compared to that recorded at NCOA–Yusipang. The triangulation of results suggests that the yield is directly linked to the survival percent, plant height, stem diameters and stems per plant.

The significantly higher yield at ARDC–Wengkhar (1.92 ton//acre) and ARDC–Bajo (1.41 ton/acre) is due to better results in all the parameters measured compared to NCOA–Yusipang (0.52 ton/acre). It could also be due to the geographical setting of the study sites, where the colder temperature (both day and night) during the growing season at NCOA-Yusipang limited the growth and development of dill compared to other sites which are located at comparatively lower altitudes with warmer temperature during the growing season.

Table 5. Comparison of yield and agronomic parameters of dill between study sites.

Location	Plant height (cm)	Stem diameter (mm)	Stems per plant (no)	Survival percent (%)	Fresh yield (ton/acre)
ARDC-Bajo	32.93 (7.63) [b]	12.42 (3.64) [a]	10.73 (2.82) [a]	57.15 (33.18)	1.41 (1.27) [a]
ARDC- Wengkhar	56.00 (23.31) [a]	10.87 (4.01) [a]	8.43 (2.43) [b]	72.71 (35.41)	1.92 (1.63) [a]
NCOA-Yusipang	50.24 (9.28) [a]	8.69 (2.26) [b]	7.30 (1.00) [c]	65.63 (20.62)	0.52 (0.31) [b]
P-value	<0.001	<0.001	<0.001	0.05	<0.001

Different lower-case letters in the superscript indicate statistically significant differences following Tukey's HSD post hoc analysis at P=0.05; values in parentheses indicate standard deviation of the mean

3.5 Correlation between variables under study

The correlation between different variables under study was computed using the combined dataset from all study sites. The result of Pearson correlation tests is given in Figure 3. The result suggests that all the parameters under study are positively correlated with each other with the strongest correlation between stem diameter and stems per plant ($r = 0.87$) and the weakest correlation between plant height and stems per plant ($r = 0.034$). The result showed that the fresh yield is strongly correlated with fresh weight of the plant ($r = 0.81$), followed by stem diameter ($r = 0.70$), stems per plant and survival percentage ($r = 0.63$) and plant height ($r = 0.46$). This implies that all the parameters need to be given due importance during further varietal breeding, selection, or introduction programs.

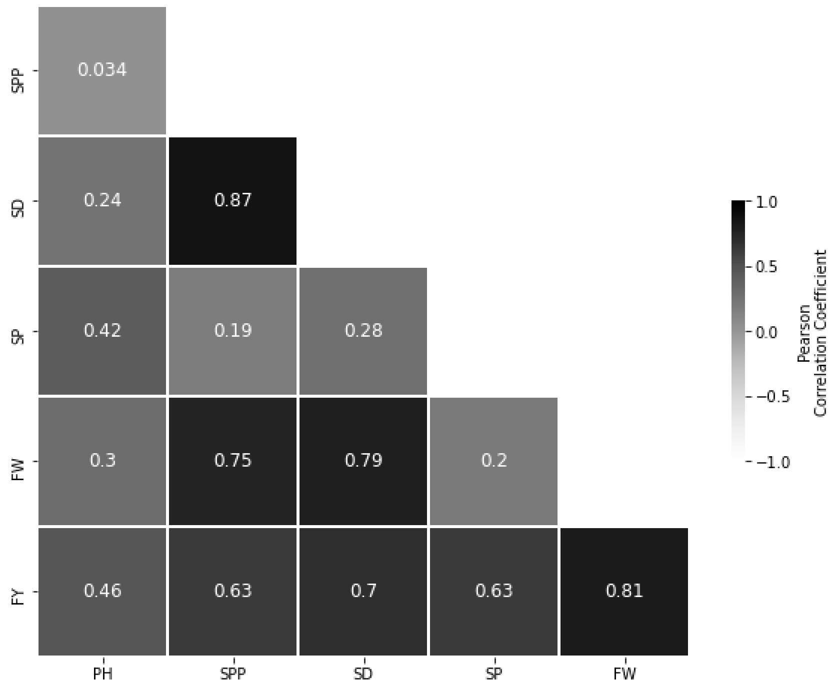

Figure 3. Correlation matrix of dill parameters of dill. FY = fresh yield, FW = fresh weight, SP = survival Percent, SD = stem diameter, SPP = stems per plant

4. Conclusion

Our findings suggest that the dill can be successfully grown under three different agro-ecological zones of Bhutan under summer conditions, while we recommend similar research under winter conditions to document response under different irrigation and nutrition regimes. Overall, the highest yield was obtained at ARDC-Wengkhar while NCOA-Yusipang obtained significantly low fresh yield compared to ARDC-Bajo and ARDC-Wengkhar.

Significant interaction effects of irrigation intervals and manure rate were observed under NCOA–Yusipang condition and not under ARDC–Bajo and Wengkhar condition. The irrigation at 3 days interval produced significantly better yield under NCOA Yusipang conditions in comparison to other irrigation treatments, while the irrigation at 7 days interval under ARDC Bajo and ARDC Wengkhar obtained better results. The decrease in the irrigation interval beyond 7 days had a negative influence on the fresh and dry yield at all study sites and irrigation at 3 days interval under ARDC – Wengkhar condition decreased the yield of dill.

The manure application did not influence any of the parameters assessed at all study sites. It was observed that manure application at 8 tons/acre yielded higher under NCOA–Yusipang condition, while the control (no application of manure) yielded better results compared to other manure treatments under ARDC–Wengkhar condition. Application of manure at 12 tons/acre under ARDC-Bajo yielded better results.

Based on the findings of our research, we recommend the combined application of IR 7 days x MR 12 tons/acre, IR 7 days x MR 4 tons/acre, and IR 3 days x 8 tons/acre under ARDC–Bajo, ARDC-Wengkhar and NCOA–Yusipang conditions, respectively. As our findings could have been affected by many other factors such as rainfall and temperature, more precise results could be obtained if such research can be conducted under controlled environment conditions such as greenhouse or climate-controlled chambers. Our findings and recommendations can be used as a reference document by agriculture extension officers for promotional and advocacy programs under three agro-ecological zones.

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