



Stress tolerance and heritability in dill (*Anethum graveolens*) lines from central and western India under contrasting soil sodicity environments

R K GAUTAM¹, M S CHAUHAN², B PANESAR³, A K NAYAK⁴, D K SHARMA⁵, A QADAR⁶ and GURBACHAN SINGH⁷

Central Soil Salinity Research Institute, Karnal, Haryana 132 001

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ABSTRACT

Dill (*Anethum graveolens* L.) crop is tolerant to salinity and its adaptation under sodic soils was not previously reported. Therefore, the present study was conducted during 2005–07 at two locations (Karnal and Lucknow) to identify sodicity tolerant genotypes and to elucidate parameters of genetic variability and nature of inter-relationships among various traits affecting the seed yield in dill in sodic soils. Eleven genotypes of dill were evaluated under three environments (normal, moderate sodic ~ pH₂ 9.5 and high sodic ~ pH₂ 9.8) during winter (*rabi*) 2005–06 and 2006–07. Among all collections, 'CSS 1' was found to exhibit highest seed yield across three years under different alkalinity locations. The trait number of inflorescence/plant showed maximum sensitivity, followed by seed yield, plant height, primary and secondary branches and plant stand in almost both stress regimes. In the moderate sodic soil there was low genotypic coefficient of variation, high heritability, high genetic advance and a positive and significant correlation of secondary branches, primary branches and inflorescence number with seed yield. These traits also exercised relatively higher direct effects. Thus, further genetic improvement in this hardy crop under high sodic environment can be achieved using indirect selections for these traits.

Key words: *Anethum graveolens*, Correlation, Dill, Heritability, Micro-plots, Path analysis, Sodic soil, Stress susceptibility index

Dill (*Anethum graveolens* L.) also called *sowa* in India is an annual plant of the Apiaceae (Umbelliferae) family native to Europe. It is cultivated for its medicinal value as well as a vegetable. Dill is widely used as fresh or frozen herbage, as a dried herb for household spice in condiments and sauces. It is a non-conventional seed spice identified as a potential crop for cultivation under saline conditions (Rao *et al.* 2000). It is also a hardy crop and thrives under low moisture conditions. It is generally cultivated in a temperate cool

climate and is a long day plant with a duration of 113–128 days. Its demand has increased tremendously because of its wider use in food, flavour, medicine and pharmaceutical industry. The dill seed oil contains higher level of dill apiole (Bandopadhyay *et al.* 1972). There are two types of oils obtained from the plant, oil of dill herb also known as dill weed (leaves and flowering tops) and oil of dill from ripe seeds. It is used for extraction of oil and is exported as such to earn foreign exchange.

Of the total 6.72 m ha area in India afflicted with salt-affected soils, about 3.77 m ha is sodic and the remaining is saline (NRSA 1996). Dill is a salt-tolerant crop and can tolerate salinity up to ECe 5 dS/m. Due to its tolerance under salinity and drought, dill could be a better choice for crop diversification, particularly by resource-poor farmers during *rabi* season. Dill is a diploid with chromosome number 2n=20 and is a highly cross-pollinated crop. Limited work has been done on genetics and breeding aspects of this crop, particularly for salt-affected soil. Present study was undertaken to study the genetic response of this species under sodic soil.

The efficacy of selection process is greatly enhanced by

¹Principal Scientist and Head (e mail: rgautampb@gmail.com) Field Crops Division, Central Agricultural Research Institute, Port Blair, Andaman & Nicobar Islands 744 101;

²Research Associate (e mail: msc3112@gmail.com); ³Senior Research Fellow (e mail: bineet.kaurl@gmail.com); ⁵Director (e mail: director@cssri.ernet.in), ⁶Principal Scientist (e mail: aliqadar@cssri.ernet.in);

⁴Principal Scientist (e mail: aknayak20@rediffmail.com), Central Rice Research Institute, Cuttack, Orissa 753 006;

⁷Agriculture Commissioner (e mail: ag.comm@nic.in), Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India, Krishi Bhawan, New Delhi 110 114

using appropriate selection indices. The understanding of genetic variability parameters and nature of association and causation of different agro-morphological traits with economic yield is of great importance for conceptualizing systematic breeding efforts.

Studies on genetic response of the crop for salinity require a field site which is homogenous in terms of salt distribution. However, natural sodic soils are often inherent in soil heterogeneity due to uneven distribution of carbonates and bicarbonates of sodium which affects the selection and breeding efficiency. To obviate such difficulties, CSSRI, Karnal has a unique and the state-of-the-art facility of precisely controlled sodic micro plots where different genotypes can be grown in a uniform sodic environment for generating precise comparisons and breeding information.

Hence, systematic studies were planned to screen germplasm collection for sodicity tolerance and to estimate various parameters of genetic variability, heritability and genetic advance for different traits across stress regimes. It also aimed at to find out inter-relationships between yield-contributing traits to assess the nature and extent of direct and indirect influence on the seed yield through path coefficient analysis.

MATERIALS AND METHODS

The micro-plot and field experiments were conducted during 2005–07 at CSSRI (Central Soil Salinity Research Institute), Karnal (sodic micro-plots each having 6 m×3 m size) and Shivri Farm, RRS, Lucknow (sodic fields). For identifying/selecting adaptable sodicity-tolerant line, data of three years across sodicity regimes and locations was considered. Two years data from sodic micro-plots were used for genetic studies. In the micro-plots, trial was conducted in randomized complete block design with three replications and each genotype was planted 3 m long with 0.5 m row-to-row spacing. The recommended cultural and plant protection practices were followed to raise the crop. Eleven diverse collections collected from Uttar Pradesh (central India) and Gujarat (western India) were evaluated under three environments (normal, moderate sodic (pH₂ 9.5) and high sodic (pH₂ 9.8) microplots. The following observations were recorded for seven quantitative traits, viz days to flowering, plant stand or survival (%), plant height, no. of primary branches, no. of secondary branches, and no. of inflorescence/plant and seed yield.

Analysis of variance for estimating the phenotypic, genotypic and environment variances was worked out (Burton 1952). Phenotypic and genotypic correlations were worked out using the method suggested by Singh and Chaudhary (1985) and path analysis as per Wright (1921) which partitioned genotypic correlations into direct and indirect effects of these variables on seed yield. The estimates of variability for traits were ranked high, moderate and low as per following:

PCV and GCV >20% (high), 10–20% (moderate), <10% (low); heritability >70% (high), 50–70% (moderate), <50% (low) and genetic advance (% mean) >30% (high), 20–30% (moderate), <20% (low).

Tolerance to salt stress has been worked out by sodicity stress susceptibility index (SSSI) on the principle of yield minimization under stress compared to non-stress environment (Fischer and Maurer 1978 Gautam *et al.* 2000). The SSSI or S values for individual genotype were calculated as:

$$S = \frac{1 - Y_s / Y_p}{D}$$

Where S = stress susceptibility index

Y_s = mean grain yield of a genotype under stress

Y_p = mean grain yield of the same genotype under non stress

D = stress intensity, which was calculated as under:

$$D = 1 - \frac{\text{Mean } Y_s \text{ of all genotypes}}{\text{Mean } Y_p \text{ of all genotypes}}$$

The higher value of 'S' means more stress susceptibility and *vice versa*. The low values of 'S' indicates those genotypes which perform well under stress with sufficient plasticity to respond to the potential environment.

RESULTS AND DISCUSSION

Estimates of genetic parameters like mean, range, genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), heritability in broad sense, genetic advance (GA%) and reduction% (R%) are presented in Table 1. The stress intensity (D) value calculated in terms of seed yield for moderate and high sodicity stress was 0.24 and 0.80, respectively which indicated three times higher degree of stress under severe sodicity compared to moderate stress.

Range and relative sensitivity of traits

Higher values of reduction (%) shows relatively more sensitivity of a particular trait towards stress environment. Generally range of absolute values for different traits was widest under normal, followed by moderate and high sodic environments. Based on% reduction in values under stress compared to control, the trait number of inflorescence/plant showed maximum sensitivity, followed by seed yield, plant height, primary and secondary branches and plant stand in the both stress regimes. The analysis of variance revealed significant variability for all traits in three environments except primary branches in both stress environments and flowering duration only under high stress.

Variability parameters and genetic advance

The magnitude of phenotypic and genotypic coefficients of variability (PCV and GCV) for different parameters in the stress environments generally exceeded their counterparts

Table 1 Range, mean, per cent decrease under stress environments and variability parameters of different dill traits under normal (N), moderate sodic (M) and high sodic (H) environments

Character	Environ.	Range	Mean	R(%)	PCV (%)	GCV (%)	h ² (bs)%	GA (%)
Days to flowering	N	98.7–103.0	100.97		1.28	0.69	–29.00	–0.76
	M	98.7–102.3	101.06	–0.09	1.21	0.99	–67.00	–1.67
	H	97.7–100.0	99.62	1.34	1.00	0.81	–66.00	–1.36
Plant stand (%)	N	19.3–27.3	24.00		11.08	4.61	–17.00	–3.94
	M	17.7–33.0	21.88	8.83	20.57	13.70	44.00	18.79
	H	4.5–21.0	11.65	51.46	38.50	31.89	69.00	54.41
Plant height (cm)	N	90.1–96.0	93.7		4.48	3.18	50.00	4.65
	M	63.7–80.3	70.00	37.92	6.67	2.33	12.00	1.67
	H	29.9–47.3	39.35	65.10	13.56	10.62	61.00	17.13
Primary branches/plant	N	6.4–10.1	7.45		13.46	9.39	49.00	13.49
	M	4.5–6.1	4.95	33.56	8.79	0.62	1.00	0.09
	H	2.3–3.4	2.97	60.13	12.33	10.19	68.00	17.34
Secondary branches/plant	N	23.5–28.5	25.93		7.24	3.45	23.00	3.38
	M	16.7–22.4	19.59	24.45	9.66	6.75	49.00	9.73
	H	4.9–12.0	9.38	63.83	25.30	16.89	45.00	23.24
Inflorescence/plant	N	57.8–85.9	77.17		11.79	5.64	–23.00	–5.56
	M	41.8–59.5	50.88	34.07	11.08	6.45	34.00	7.74
	H	7.1–21.1	14.48	81.24	31.96	16.90	28.00	18.41
Seed yield/plant (g)	N	151.3–286.3	192.24		23.42	20.45	76.00	36.79
	M	120.7–176.3	144.53	24.82	10.53	11.92	–128.00	–27.80
	H	4.2–54.0	34.11	82.26	47.81	38.09	64.00	32.53

in the normal environment which indicates that wide variability is manifested under sodicity stress for enabling the selection.

A close resemblance between the estimates of PCV and GCV suggested that the environment had little role in the expression of characters like days to flowering in high sodic environment, plant height in normal soil and seed yield in moderate sodic environment. Relatively higher GCV (38.09) and high PCV (47.81) were recorded for seed yield in high sodic environment which indicates good scope for genetic improvement of this economic trait in high sodicity. This also shows that there is little influence of environmental confounding on the trait expression and thus phenotypic selection for the seed yield is likely to be rewarding.

High PCV (23.42) than GCV (20.45) was observed for seed yield in normal soil too. Besides, high PCV was observed for plant stand (%) in both stress regimes while for secondary branches and number of inflorescence/plant only under high stress. Higher PCV than GCV indicates that the apparent variation is not only due to genotypes but also due to influence of environment.

Heritability and genetic gain

The characters which exhibit high heritability and high genetic advance (% of mean) indicate additive gene effects in their inheritance and such characters could be improved by direct selection (Panse 1957). These characters are seed yield in both normal and high sodic soil and plant stand in high sodic environment. In all, plant height, primary

branches/plant and seed yield in both high sodic and non-stress conditions, whereas plant stand under high stress only revealed moderate to higher heritability. Regarding genetic advance expressed as per cent of mean, high values were recorded for seed yield under normal as well as high sodicity whereas for plant survival only under high sodicity. Moderate genetic gain was recorded for plant survival under moderate stress while for secondary branches under higher stress. High heritability accompanied with low genetic advance (% mean) was found in plant height and secondary braches under normal and moderate sodicity, inflorescence under moderate sodic environment, indicating non-additive gene action for these traits.

Correlation and path coefficients

The phenotypic and genotypic correlations for all possible combinations of the seven quantitative traits are shown in Table 2. At phenotypic level, correlation coefficients revealed that the traits plant height under both moderate as well as high sodicity stresses exhibited significantly positive correlations with seed yield, whereas primary branches, secondary branches and inflorescence number developed positive correlation with seed yield only under high stress.

As regards other inter-trait relationships, besides seed yield, it was observed that in both normal and high stress environments, primary branches were positively correlated with secondary branches and inflorescence number, whereas number of inflorescence was also correlated with secondary

Table 2 Genotypic and phenotypic correlation coefficients among different plant characters under normal (N), moderate (M) and high (H) sodic environments

Character	Environ.	Days to flowering	Plant stand	Plant height	Primary branches	Secondary branches	Inflorescence	Seed yield
Days to flowering	N		-0.27	-0.17	-0.08	-0.23	-0.32	0.16
	M		-0.91*	-0.44	0.29	0.76*	0.2	-0.12
	H		-0.12	0.04	-0.12	-0.2	-0.07	0.14
Plant stand	N	-4.67*		-0.15	-0.57*	-0.45	-0.36	0.3
	M	1.79*		0.27	-0.18	-0.75*	-0.1	0.16
	H	0.07		0.72*	0.47	0.33	0.55	0.6
Plant height	N	0.28	0.38		0.02	0.17	0.37	0.19
	M	0.09	-0.1		-0.21	-0.2	-0.05	0.58*
	H	0.96*	-0.17		0.85*	0.76*	0.88*	0.91*
Primary branches	N	0.12	3.28*		0.53	0.55	0.63*	-0.19
	M	-14.14*	-5.72*	-4.95*		0.14	-0.24	-0.45
	H	1.1*	0.66*	-0.28		0.8*	0.76*	0.84*
Secondary branches	N	2.04*	-0.14	0.98*	-0.94*		0.85*	-0.67*
	M	-0.51	-1.47*	-1.38*	-1.05*		0.49	0.23
	H	1.16*	0.73*	0.57*	0.36		0.71*	0.78*
Inflorescence	N	-0.84*	-1.48*	1.25*	-0.38	1.16*		-0.41
	M	0.88*	-10.94*	-1.78*	-0.12	-0.52		0.39
	H	0.46	1.29*	1.12*	1.43*	-0.06		0.81*
Seed yield	N	1.76*	-2.1*	-0.46	0.27	-1.09*	-1.1*	
	M	0.05	0.07	10.56*	1.16*	0.27	0.36	
	H	0.97*	0.83*	1.2*	1.05*	0.83*	-0.27	

The values above and below the diagonal are phenotypic and genotypic correlation coefficients, respectively
* $P=0.05$ level

Table 3 Estimates of direct (*in italics*) and indirect effects at the genotypic level under normal (N), moderate (M) and high (H) sodic stress environments

Character	Environ.	Days to flowering	Plant stand	Plant height	Primary branches	Secondary branches	Inflorescence
Days to flowering	N	<i>0.17</i>	-0.78	0.62	0.88	-0.15	0.19
	M	<i>-0.17</i>	-0.30	0.02	0.82	0.17	0.09
	H	<i>-0.31</i>	-0.02	0.05	0.09	-0.11	0.02
Plant stand	N	-0.11	<i>0.24</i>	7.02	0.81	0.24	-0.93
	M	-0.23	<i>-0.13</i>	-0.01	0.72	0.17	0.02
	H	0.01	<i>0.10</i>	0.10	0.07	0.06	0.15
Plant height	N	0.94	7.16	<i>0.25</i>	2.97	-3.55	-0.31
	M	0.03	-0.03	<i>-0.33</i>	4.69	0.49	0.59
	H	0.06	-0.32	<i>-0.33</i>	-0.37	-0.24	-0.38
Primary branches	N	0.14	91.04	3.27	<i>0.27</i>	0.56	-0.41
	M	0.06	0.07	0.17	<i>-0.01</i>	0.01	0.13
	H	-0.14	0.33	0.54	<i>0.50</i>	0.58	0.64
Secondary branches	N	0.30	-0.31	4.61	-0.66	<i>-0.32</i>	0.27
	M	0.46	0.61	0.65	0.23	<i>-0.44</i>	-0.39
	H	0.14	0.23	0.29	0.46	<i>0.39</i>	0.18
Inflorescence	N	0.42	-0.13	-0.46	-0.54	-0.30	0.36
	M	0.19	0.05	0.67	4.12	-0.33	-0.38
	H	-0.02	0.52	0.41	0.46	0.16	0.36
Seed yield	N	-1.10	-1.09	0.27	-0.47	-2.10	1.76**
	M	0.36	0.27	1.15**	10.56**	0.07	0.05
	H	-0.27	0.82**	1.0**	1.20	0.83**	0.96**

Residual effect: Normal 0.82, moderate sodic 0.12 and high sodic 0.10

Table 4 Seed yield (kg/ha) of dill genotypes in sodic soils across years and locations

Year	Location	Source	2005		2006		2007			Mean	SSSI (M)	SSSI (H)	
			Lucknow (sodic field)	Lucknow (sodic field)	Karnal (sodic micro plots)		Karnal (sodic micro plots)						
Entry			9.4	9.1	7.1	9.5	9.9	7.1	9.5	9.9			
			<i>pH</i>										
'CSS 1'	Bachhranwa (Uttar Pradesh)		350	450	2 040	1 010	280	1 540	1 080	440	900	2.11	1.46
'CSS 2'	NBRI (Uttar Pradesh)		200	240	1 680	840	280	1 010	980	330	695	1.77	1.47
'CSS 3'	Sultanpur (Uttar Pradesh)		140	320	1 270	1 080	200	970	890	470	667	0.74	1.30
'CSS 4'	Tarapur (Gujarat)		190	340	1 270	1 160	210	910	610	170	608	1.22	1.45
'CSS 5'	Bamangam (Gujarat)		170	260	1 250	1 250	180	980	810	200	638	-0.07	1.50
'CSS 6'	Warsada (Gujarat)		150	340	1 480	1 040	170	1 000	790	450	678	1.59	1.31
'CSS 7'	Khanpur (Gujarat)		230	220	1 150	970	260	1 010	830	370	635	0.03	1.41
'CSS 8'	Karnal (Haryana)		250	260	1 250	1 250	110	970	890	240	653	0.18	1.56
'CSS 9'	Bharuch (Gujarat)		150	160	1 360	870	90	990	770	150	564	1.91	1.68
'CSS 10'	Daliganj (Uttar Pradesh)		310	200	2 210	930	130	1 610	870	470	841	3.23	1.55
'CSS 11'	Anand (Gujarat)		50	240	1 690	930	30	930	880	30	598	1.33	1.78

SSSI, Sodicity stress susceptibility index; D, stress intensity; D value for moderate sodic soil = 0.24; D value for high sodic soil = 0.80

branches. This is understandable because profuse branching results in more sub-branching and floral number. At high pH_2 stress only, plant stature was correlated with plant survival, primary and secondary branches as well as inflorescence number. This highlights the importance of plant height in dill in impacting seed yield as well other contributing traits specifically under severe stress.

Path coefficient analysis is a standardized partial regression coefficient which splits the correlation coefficient into the measures of direct and indirect effects. The direct and indirect effects of different characters on seed yield are presented in Table 3. The overall path analysis based on genotypic correlations revealed that primary branches followed by secondary branches and inflorescence number in the high sodic soil exhibited relatively higher positive direct effects on seed yield. Under moderate stress, the component traits showed mostly negative direct effects. Though, plant height developed positive correlations with seed yield, its direct effects were negative particularly under stress environments. This indicates that selection for plant height may not result in higher seed yield under stress conditions. The trait inflorescence number/plant exercised maximum direct effect on seed yield, followed by primary

branches, plant height and plant survival under normal soil conditions.

Under non-stress and moderate stress, none of the recorded traits appeared to be promising for indirect selection in this genetic material. However, due to their higher magnitudes of PCV, heritability, genetic advance, correlation coefficients with seed yield and direct effects, number of secondary branches, primary branches and inflorescence number emerged as useful traits for indirect selection under high sodicity conditions. Selection for seed yield *per se* would be effective due to its high PCV, heritability and genetic gain under both normal and high sodicity conditions in the tested germplasm. Therefore, phenotypic selection in dill genotypes for seed yield beyond moderate stress of $pH_2 \sim 9.5$ is expected to be rewarding.

Stress tolerance and agronomic performance of genotypes

The results of extensive evaluation of dill genotypes across diverse sodic conditions across years are shown in Table 4. On overall basis 'CSS 1', a native collection from farmer's fields in Raibareilly district in Uttar Pradesh gave consistently highest seed yield of about 9 tonnes/ha as against lowest of 5.64 tonnes/ha of 'CSS 9'. This demonstrated ample scope

of germplasm intervention in sodic soils. Due to its high yield potential in sodic soils, 'CSS 1' has been registered as unique sodicity tolerant germplasm with NBPGR, New Delhi during 2008 and has been assigned national identity number IC563951.

The stress susceptibility indices pertaining to severe sodicity environment for seed yield was very high in 'CSS 11' and 'CSS 9', ie 1.78 and 1.68, respectively indicating their more susceptibility. The S values in 'CSS 3', 'CSS 6' and 'CSS 7' were 1.30, 1.31 and 1.41, respectively which indicates their better resilience under high stress. The analyses of SSSI values across both stress regimes showed 'CSS 3' and 'CSS 7' to have better tolerance, whereas 'CSS 9' showed more susceptibility.

Though 'CSS 1' gave highest yields, its stress susceptibility indices of 2.11 and 1.46, respectively in moderate and high sodic soil were relatively on higher side. This shows that stress performance of CSS 1 was not much attributed to its tolerance but to its higher yield potential. Therefore, future efforts to cross CSS1 (high yield potential) with CSS 3 and CSS 7 (better sodicity tolerance) and selection for promising recombinants is expected to result in achieving both attributes together in a single genotype.

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