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OPTIMAL FERTILIZER REQUIREMENT OF RAINFED SUNFLOWER BASED ON VARYING SOIL MOISTURE STRESS INDICES ON SEMI-ARID VERTISOLS OF INDIA

Maruthi Sankar, G.R.*[1], Vittal, K.P.R.[1], Pharande, A.L.[2], Victor, U.S.[1], Ravindra Chary, G.[1], Ramakrishna, Y.S.[1] and Girija, A.[1]

[1] *All India Coordinated Research Project for Dryland Agriculture, CRIDA, Santoshnagar, Hyderabad-500 059, Andhra Pradesh, India*
[2] *Cooperating Centre, AICRP for Dryland Agriculture, Mahatma Phule Krishi Vidyapeeth, Solapur - 413 002, Maharastra, India*

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SUMMARY

Six field experiments were conducted on sunflower with treatments comprising of 4 dates of sowing (sown during different standard meteorological weeks viz., 28 (9-15 July), 30 (23-29 July), 32 (6-12 August) and 34 (21-26 August), 3 moisture conservation methods (ridge & furrow, skip row with furrow and flat bed) and 3 levels of fertilizer NP (40-20, 50-25 and 60-30 kg/ha) during *kharif* 1999 to 2004 at Solapur on semi-arid vertisols. Based on daily rainfall (RF), daily runoff (RO) and crop soil moisture stress index (MSI) were measured for each combination of date of sowing (DOS) and moisture conservation (MC) method in each season.

Correlation analysis indicated a positive relation of seed yield with rainfall in all 4 DOS. The relation was relatively higher for flat bed in 1st DOS, ridge & furrow in 2nd DOS, skip row with furrow in 3rd and 4th DOS. It was negatively related with RO in 1st DOS, but positively related with the other 3 DOS. The relation was higher under ridge & furrow system in 1st DOS (negative) and 4th DOS (positive), while under flat bed in 2nd and 3rd DOS. Negative relation of MSI was found with yield under all the 12 combinations of DOS and MC indicating a higher relation under skip row with furrow in 1st, 2nd and 4th DOS, and flat bed in 3rd DOS. The relation between RF and RO was positive, while MSI had negative relation with both RF and RO.

Regression models of seed yield through RF, RO, SMI, fertilizer N and P, along with fertilizer x MSI interaction were calibrated. The predictability ranged from 0.12 (ridge and furrow in 3rd DOS) to 0.91 (flat bed in 1st DOS). A ready reckon of optimal N and P doses at varying MSI levels (0.15 to 0.75) indicated that ridge and furrow method is efficient in 1st DOS with an optimal N and P ranging from 51 to 53 kg/ha and 26 to 27 kg/ha, respectively. Skip row with furrow method was efficient when crop was sown in any of the other DOS

* Corresponding author: Phone: 24530828; Fax: +91-040-24530828;
e-mail: gmsankar@crida.ernet.in

with an optimal N ranging from 38 to 66 kg/ha (2nd DOS), 44 to 73 kg/ha (3rd DOS) and 47 to 74 kg/ha (4th DOS). The optimal P ranged from 19 to 33 kg/ha (2nd DOS), 22 to 36 kg/ha (3rd DOS) and 24 to 37 kg/ha (4th DOS) for attaining maximum productivity of sunflower on semi-arid vertisols.

Key words: soil moisture stress index, dates of sowing, moisture conservation, regression models, optimization of fertilizer

INTRODUCTION

Sunflower (*Helianthus annuus*) can be grown throughout the year. It is grown in both alfisols and vertisols under rainfed conditions. It is a day neutral plant and can be grown successfully in different seasons under varying conditions of day length, provided the day temperature is favorable. It grows best with clear sky and occasional rain shower during early stages. The crop requires a cool climate during germination and seedling growth and warm non-cloudy weather and high temperature from flowering to maturity. It is resistant to drought but requires continuous availability of soil moisture for optimal performance. The relation of seed yield with rainfall and other weather variables has to be assessed under rainfed conditions in order to invest in fertilizer and other inputs (Maruthi Sankar, 1992; Maruthi Sankar and Vanaja, 2003; Maruthi Sankar *et al.,* 2004). During 2000-01, sunflower was grown on an area of 549.4 thousand ha in *kharif* with a production of 254.6 thousand tons, while in *rabi*, it was grown in an area of 785.2 thousand ha with a production of 478.4 thousand tons in the country. In *kharif*, the productivity was about 463 kg/ha, while in *rabi* it was about 609 kg/ha. It is grown in Karnataka, Maharastra, Andhra Pradesh, Tamil Nadu, Punjab, Haryana, Gujarat and other states in the country under arid, semi-arid and dry sub-humid conditions. There is a need to improve the productivity and sustainability of sunflower under rainfed conditions by improving the utilization of the received rainfall with a suitable moisture conservation practice and optimal input fertilizers (Maruthi Sankar *et al.,* 2001; Vittal *et al.,* 2003).

The fertilizer requirement of sunflower varies depending on the rainfall received during crop season (sowing to harvest), runoff and soil moisture stress parameters. An optimal dose based on a suitable soil water balance model would be more efficient compared with a general fertilizer dose. It is therefore required to derive crop season moisture stress index based on daily rainfall and runoff and calibrate optimal fertilizer requirement of sunflower (Doorenbos and Kassam, 1979; Victor *et al.,* 2003). Multiple regression models of seed yield through rainfall, runoff and soil moisture stress index together with fertilizer variables could be calibrated for both prediction of seed yield and optimization of fertilizer at varying moisture stress levels (Draper and Smith, 1973; Maruthi Sankar, 1986; Hanumantha Rao *et al.,* 1993).

An attempt is made in this paper to quantify the relations of rainfall received on different dates of sowing with the sunflower seed yield together with runoff and crop season moisture stress index based on 6 field experiments conducted in *kharif* season on semi-arid vertisols. Based on the regression models of seed yield involving

rainfall, runoff, moisture stress index and fertilizer variables, an attempt is made to derive optimal N and P fertilizer requirement of sunflower for attaining maximum productivity (Maruthi Sankar, 1986; Maruthi Sankar and Sonar, 1987; Maruthi Sankar *et al.,* 1988) and also its suitability as a contingent crop on different dates of sowing especially under delayed onset of monsoon is discussed.

MATERIALS AND METHODS

Six sunflower field experiments with the variety SS-56 were conducted during *kharif* 1999 to 2004 seasons on semi-arid vertisols at Solapur. The field experiments were conducted with treatments comprising combinations of 4 dates of sowing (DOS), 3 moisture conservation (MC) methods and 3 levels of N and P fertilizer. The crop was sown during the 28th standard meteorological week (SMW) (9-15 July), 30th SMW (23-29 July), 32nd SMW (6-12 August) and 34th SMW (21-26 August) in each *kharif* season. The MC methods tested were ridges and furrows, skip row with furrow and flat bed in each season. Three levels of fertilizer N and P were applied in the study, at 40-20, 50-25 and 60-30 kg/ha. All conventional agronomic practices were applied in the field experiments.

Table 1: Dates of sowing and harvest, rainfall and sunflower growing season during 1999 to 2004 at Solapur

Year	SMW	Date of sowing	Date of harvest	Rainfall (mm)	Growing season
1999	28	9-7-1999	11-10-1999	372.7	95
	30	23-7-1999	25-10-1999	226.4	95
	32	10-8-1999	15-11-1999	173.1	98
	34	21-8-1999	4-12-1999	168.4	106
2000	28	10-7-2000	30-9-2000	369.5	83
	30	29-7-2000	15-11-2000	391.5	120
	32	11-8-2000	15-11-2000	293.7	97
	34	25-8-2000	20-11-2000	194.6	88
2001	28	10-7-2001	2-11-2001	423.0	116
	30	26-7-2001	7-11-2001	515.2	105
	32	7-8-2001	15-11-2001	429.2	101
	34	24-8-2001	18-11-2001	501.7	87
2002	28	15-7-2002	17-10-2002	470.3	95
	30	24-7-2002	26-10-2002	432.5	95
	32	12-8-2002	15-11-2002	229.9	96
	34	23-8-2002	26-11-2002	217.4	96
2003	28	14-7-2003	29-10-2003	248.8	108
	30	29-7-2003	1-11-2003	236.8	106
	32	11-8-2003	11-11-2003	205.3	93
	34	25-8-2003	11-11-2003	85.1	79
2004	28	9-7-2004	6-10-2004	392.1	90
	30	26-7-2004	19-10-2004	348.4	86
	32	6-8-2004	30-10-2004	243.9	86
	34	20-8-2004	16-11-2004	228.6	89

The soils were vertisols with a soil reaction (pH) of 7.8 and an electrical conductivity of 0.3. The mean organic carbon (%) in the soil was 0.4% with a variation of 9.3 % and soil N was 140 kg/ha with a variation of 16% during 6 seasons. The mean soil P was 9.5 kg/ha and soil K was 320 kg/ha with a variation of 16.2% and 10%, respectively, over seasons. The field experiments were conducted in a split-split plot design with 3 replications by assigning DOS to the main plot, MC methods to the sub-plot and fertilizer levels to the sub-sub plot. The date of sowing, date of harvest, crop duration and the rainfall received between sowing and harvest during 1999 to 2004 are given in Table 1.

The crop duration ranged from 79 days during 2003 (sown in SMW 34) with a rainfall of 85.1 mm to 120 days during 2000 (sown in SMW 30) with a rainfall of 391.5 mm. The relations between crop duration and rainfall were determined and were given in Figure 1. It was observed that rainfall had a non-linear influence on crop growing season with a predictability of 0.76 during the 6 seasons of study. The linear effect of rainfall was found to be significantly higher on crop growing season up to about 275 mm of rainfall.

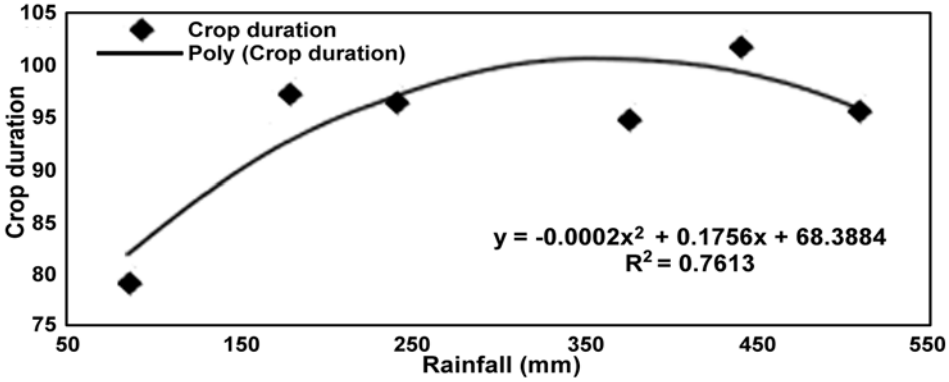

Figure 1: Effect of rainfall on sunflower growing season duration in different years

Descriptive statistics of seed yield, seasonal rainfall, runoff and moisture stress index

The seed yield of sunflower ranged from 247 to 993 kg/ha with a mean of 599 kg/ha and a variation of 35.9% over the 6 seasons when sowing during SMW 28 and adopting the ridge and furrow method for moisture conservation. It ranged from 224 to 1067 kg/ha with a mean of 516 kg/ha and a variation of 43.4% when sowing during SMW 28 and adopting the skip row with furrow method for moisture conservation. Similarly, the yield ranged from 285 to 697 kg/ha with a mean of 468 kg/ha and a variation of 27.1% when sowing during SMW 28 and adopting the flat bed method for moisture conservation. The seasonal rainfall ranged between 248.8 to 470.3 mm. The runoff ranged between 2.8 to 94.7 mm, while MSI ranged from 0.231 to 0.693 under the ridge and furrow system. Similarly, the runoff was

between 7.4 to 131.7 mm under the skip row with furrow method and 9.5 to 146.2 mm under the flat bed system, while the corresponding MSI were 0.233 to 0.7 and 0.246 to 0.703 under SMW 28.

When sowing was done during SMW 30, the seed yield of sunflower ranged from 167 to 643 kg/ha with a mean of 334 kg/ha and a variation of 37.2% under the ridge and furrow system. It ranged from 155 to 512 kg/ha with a mean of 304 kg/ha and a variation of 39.3% under the skip row with furrow method for moisture conservation. Similarly, the yield ranged from 141 to 486 kg/ha with a mean of 295 kg/ha and a variation of 37.4% under the flat bed system. The seasonal rainfall ranged between 226.4 to 515.2 mm. The runoff ranged between 4.2 to 91.8 mm, while MSI ranged from 0.196 to 0.616 under the ridge and furrow system. Similarly, the runoff was between 12.7 and 129.8 mm under skip row with furrow and 14.8 to 153 mm under the flat bed system, while the corresponding MSI were 0.196 to 0.626 and 0.224 to 0.628 under SMW 30.

When sowing was done during SMW 32, the seed yield of sunflower ranged from 93 to 653 kg/ha with a mean of 351 kg/ha and a variation of 48.4% under the ridge and furrow system. It ranged from 87 to 601 kg/ha with a mean of 300 kg/ha and a variation of 60% under skip row with furrow method for moisture conservation. Similarly, the yield ranged from 93 to 711 kg/ha with a mean of 305 kg/ha and a variation of 70.7% under the flat bed system. The seasonal rainfall ranged between 173.1 and 429.2 mm. The runoff ranged between 5.7 and 88.6 mm, while MSI ranged from 0.32 to 0.644 under the ridge and furrow system. Similarly, the runoff was between 14.7 and 122.1 mm under skip row with furrow and 27.7 to 136.5 mm under the flat bed system, while the corresponding MSI were 0.32 to 0.658 and 0.323 to 0.679 under SMW 32.

When sowing was done during SMW 34, the seed yield of sunflower ranged from 67 to 785 kg/ha with a mean of 377 kg/ha and a variation of 47.4 % under the ridge and furrow system. It ranged from 129 to 531 kg/ha with a mean of 303 kg/ha and a variation of 38.2 % under skip row with furrow method for moisture conservation. Similarly, the yield ranged from 126 to 607 kg/ha with a mean of 322 kg/ha and a variation of 50.1% under the flat bed system. During this period, the seasonal rainfall ranged between 85.1 and 501.7 mm. The runoff ranged between 0.3 and 98.7 mm, while MSI ranged from 0.471 to 0.698 under the ridge and furrow system. Similarly, the runoff was between 2.4 and 138.5 mm under skip row with furrow and from 10.7 to 181.2 mm under the flat bed system, while the corresponding MSI were 0.471 to 0.707 and 0.471 to 0.727 under SMW 34.

The descriptive statistics of range, mean, standard deviation, standard error of mean and coefficient of variation of seed yield, seasonal rainfall, runoff and crop season soil moisture stress index under the 12 combinations of sowing dates and moisture conservation methods are given in Table 2. A graphic plot of mean against coefficient of variation is given in Figure 2 (a - for soil moisture stress index, b - for seasonal rainfall, c - for runoff and d - for sunflower seed yield under different combinations of dates of sowing and moisture conservation methods). It was observed that higher soil moisture stress, seasonal rainfall, runoff and seed yield occurred

with lower variation and vice versa during different seasons. Out of the 12 combinations of dates of sowing and moisture conservation methods, there were no situations of high mean with high variation in moisture stress index, seasonal rainfall and seed yield in either year, except for one case in runoff as indicated in Figure 2 (c). In fact, about 6 cases existed under low mean with high variation for moisture stress index, 2 out of 4 cases under high mean with high variation for rainfall, 4 cases each under low mean with either low or high variation for runoff, and about 7 cases under low mean with low variation for seed yield for different combinations of dates of sowing and moisture conservation methods, as given in Figure 2 for different parameters.

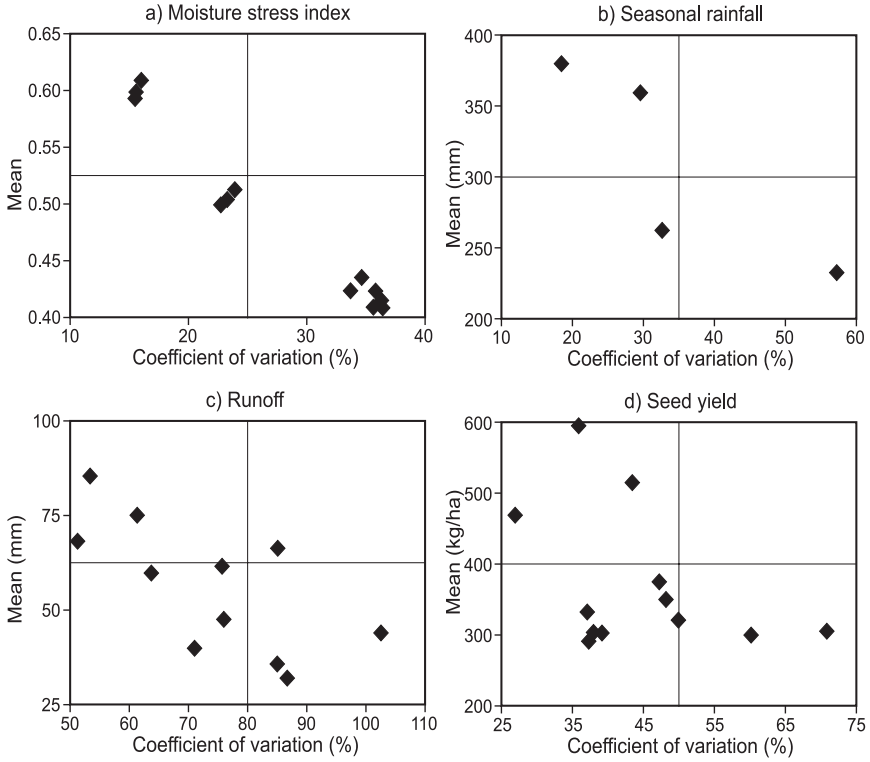

Figure 2: Mean and variation moisture stress index, rainfall, runoff and sunflower seed yield at Solapur

RESULTS AND DISCUSSION

Analysis of variance of seed yield and sustainability of treatments

Based on the analysis of variance (ANOVA) of seed yield attained under different treatments in different years, it was shown that the sowing dates differed significantly in each season. Significantly high seed yields were obtained when sowing on

Table 2: Descriptive statistics of seed yield and other variables in sunflower at Solapur

Treatment	Variable	Minimum	Maximum	Mean	Sem	CV
D1 M1	SY	247	993	599	50.6	35.9
	RF	248.8	470.3	379.4	16.4	18.4
	RO	2.8	94.7	36.1	7.2	84.9
	MSI	0.231	0.693	0.415	0.036	36.3
D1 M2	SY	224	1067	516	52.9	43.4
	RF	248.8	470.3	379.4	16.4	18.4
	RO	7.4	131.7	61.9	11.1	75.8
	MSI	0.233	0.700	0.424	0.036	36.0
D1 M3	SY	285	697	468	29.9	27.1
	RF	248.8	470.3	379.4	16.4	18.4
	RO	9.5	146.2	75.4	10.9	61.3
	MSI	0.246	0.703	0.435	0.036	34.7
D2 M1	SY	167	643	334	29.2	37.2
	RF	226.4	515.2	358.5	24.9	29.5
	RO	4.2	91.8	40.4	6.8	71.1
	MSI	0.196	0.616	0.409	0.035	36.0
D2 M2	SY	155	512	304	28.2	39.3
	RF	226.4	515.2	358.5	24.9	29.5
	RO	12.7	129.8	60.3	9.1	63.9
	MSI	0.196	0.626	0.411	0.035	36.4
D2 M3	SY	141	486	295	26.0	37.4
	RF	226.4	515.2	358.5	24.9	29.5
	RO	14.8	153.0	85.9	10.8	53.3
	MSI	0.224	0.628	0.424	0.034	33.8
D3 M1	SY	93	653	351	40.1	48.4
	RF	173.1	429.2	262.5	20.2	32.6
	RO	5.7	88.6	32.5	6.6	86.6
	MSI	0.320	0.644	0.499	0.027	22.9
D3 M2	SY	87	601	300	42.3	60.0
	RF	173.1	429.2	262.5	20.2	32.6
	RO	14.7	122.1	48.0	8.6	75.9
	MSI	0.320	0.658	0.503	0.028	23.3
D3 M3	SY	93	711	305	50.8	70.7
	RF	173.1	429.2	262.5	20.2	32.6
	RO	27.7	136.5	68.6	8.3	51.2
	MSI	0.323	0.679	0.512	0.029	23.9
D4 M1	SY	67	785	377	42.1	47.4
	RF	85.1	501.7	232.6	31.3	57.1
	RO	0.3	98.7	30.3	7.8	108.7
	MSI	0.471	0.698	0.593	0.021	15.4
D4 M2	SY	129	531	303	27.3	38.2
	RF	85.1	501.7	232.6	31.3	57.1
	RO	2.4	138.5	44.3	10.7	102.4
	MSI	0.471	0.707	0.597	0.022	15.5
D4 M3	SY	126	607	322	38.0	50.1
	RF	85.1	501.7	232.6	31.3	57.1
	RO	10.7	181.2	66.6	13.3	85.0
	MSI	0.471	0.727	0.608	0.023	15.9

MSI: Soil moisture stress index
SY: Seed yield (kg/ha)
RF: Rainfall (mm)
D1: SMW 28 (9-15 July)
D3: SMW 32 (6-12 August)
RO: Runoff (mm)
D2: SMW 30 (23-29 July)
D4: SMW 34 (21–26 August
M1: Ridge & Furrow
M2: Skip row with furrow
Sem: Standard error of mean
CV: Coefficient of variation (%)
M3: Flat bed

9th July in all the 6 seasons, with a mean yield of 528 kg/ha. The other 3 dates of sowing were on a par with each other based on the pooled analysis. However, in individual seasons, 1st DOS was followed by 2nd DOS in 2002 and 4th DOS in 1999. Further, 3rd DOS was found to be superior in 2001, 2003 and 2004. The moisture conservation methods were found to be significantly different only in 2000 and 2002 seasons, while they were on a par in the other 4 seasons of study. The 3 combinations of N and P fertilizers were significantly different only in 2000, 2001 and 2002 seasons, while they were found to be on a par in the remaining 3 seasons. The results of ANOVA for seed yield are given in Table 3.

Table 3: Analysis of variance of sunflower seed yield during 1999 - 2004 at Solapur

Treatment	Seed yield (kg/ha)						Mean	SYI
Sowing date	1999	2000	2001	2002	2003	2004		
SMW 28 (9-15 July)	495	699	346	632	298	696	528	0.75
SMW 30 (23-29 July)	201	209	296	489	261	410	311	0.40
SMW 32 (6 –12 August)	220	229	513	100	279	571	319	0.28
SMW 34 (21-26 August)	402	271	465	239	147	479	334	0.37
Mean	329	352	405	365	246	539	373	0.45
S.Em.	44	23	16	6	21	36	25	
C.D.(0.05)	140	74	54	20	70	118	81	
Moisture conservation								
Ridges & furrows	378	449	454	405	250	555	371	0.52
Skip row with furrow	268	350	379	355	247	553	305	0.43
Flat bed	334	256	381	334	250	528	294	0.41
Mean	329	352	405	365	246	539	373	0.45
S.Em.	34	10	22	10	15	17	18	
C.D.(0.05)	NS	32	NS	33	NS	NS	60	
Fertilizer N & P doses (kg/ha)								
40:20	296	318	329	317	248	506	295	0.41
50:25	334	351	411	366	265	539	329	0.46
60:30	351	387	474	412	234	572	346	0.48
Mean	329	352	405	365	246	539	373	0.45
S.Em.	18	5	11	7	14	20	13	
C.D.(0.05)	NS	15	32	19	NS	NS	45	

Sustainability index of a treatment or a rainfed practice can be derived based on the relations of seasonal rainfall and crop yields achieved in different seasons (Vittal *et al.,* 2003). Based on the estimates of sustainability yield index (SYI) derived for different treatments, it was observed that sunflower sowing in SMW-28 has a maximum sustainability of 0.75 during the 6 seasons, followed by SMW-30, SMW-34 and SMW-32 with 0.40, 0.37 and 0.28, respectively. Among the three moisture conservation treatments, ridges and furrows had high sustainability of 0.52, followed by skip row with furrow with a SYI of 0.43 and the flat bed method

with 0.41 during the 6 seasons. Among the three levels of N and P combinations tested for sunflower, the application of 60 kg N+30 kg P_2O_5/ha had a maximum sustainability of 0.48, while 40 kg N+20 kg P_2O_5/ha had a minimum SYI of 0.41, as given in Table 3.

Relation between seed yield, seasonal rainfall, runoff and soil moisture stress index

Estimates of correlation were derived among seed yield, seasonal rainfall, run-off and crop season soil moisture stress index under each of the 12 combinations of sowing dates and moisture conservation methods and are given in Table 4.

Table 4: Correlation between sunflower seed yield, seasonal rainfall, runoff, soil moisture stress index and fertilizer variables at Solapur

Variable 1	Variable 2	MC	Correlation between variables for different sowing dates			
			D1	D2	D3	D4
		M1	0.47*	0.50*	0.21	0.84**
SY	RF	M2	0.34	0.38	0.61**	0.62**
		M3	0.54*	0.26	0.57*	0.16
		M1	-0.28	0.41	0.21	0.80**
SY	RO	M2	-0.17	0.41	0.64**	0.61**
		M3	-0.17	0.47*	0.69**	0.19
		M1	-0.32	-0.61**	-0.22	-0.41
SY	MSI	M2	-0.49*	-0.60**	-0.62**	-0.47*
		M3	-0.32	-0.60**	-0.69**	-0.08
		M1	0.16	0.20	0.18	0.14
SY	FN	M2	0.24	0.13	0.15	0.26
		M3	0.36	0.22	0.11	0.08
		M1	0.16	0.20	0.18	0.14
SY	FP	M2	0.24	0.13	0.15	0.26
		M3	0.36	0.22	0.11	0.08
		M1	0.47*	0.76**	0.82**	0.90**
RF	RO	M2	0.63**	0.81**	0.84**	0.93**
		M3	0.52*	0.84**	0.84**	0.95**
		M1	-0.33	-0.83**	-0.72**	-0.72**
RF	MSI	M2	-0.30	-0.83**	-0.73**	-0.73**
		M3	-0.35	-0.84**	-0.74**	-0.75**
		M1	-0.39	-0.89**	-0.77**	-0.75**
RO	MSI	M2	-0.47*	-0.92**	-0.79**	-0.76**
		M3	-0.59**	-0.93**	-0.79**	-0.81**

* and ** indicate significance at 5 and 1% levels
SY: Seed yield (kg/ha)
SMI: Soil moisture stress index
RF: Rainfall (mm)
D1: SMW 28 (9-15 July)
D2: SMW 30 (23-29 July)
D3: SMW 32 (6-12 August)
D4: SMW 34 (21–26 August)
M1: Ridge & Furrow
M2: Skip row with furrow
M3: Flat bed
RO: Runoff (mm)
MC: Moisture conservation
FN: Fertilizer N
FP: Fertilizer P

The analysis indicated that seed yield had a positive relation with rainfall in all 4 DOS. The relation was higher for flat bed in 1st DOS, than for ridge & furrow in 2nd DOS and skip row with furrow in 3rd and 4th DOS. Seed yield was negatively related with runoff in 1st DOS, while positively related in the other 3 DOS. The relation was relatively higher under ridge & furrow system in 1st DOS (negative) and 4th DOS (positive) than under flat bed in 2nd and 3rd DOS. Negative relation of moisture stress index was found with seed yield in all 12 combinations of DOS and MC indicating a higher relation under skip row with furrow in 1st, 2nd and 4th DOS, and flat bed in 3rd DOS. The relation between seasonal rainfall and runoff was positive, while moisture stress index had a negative relation with both rainfall and runoff under all the 3 moisture conservation methods in 4 different sowing dates.

These results indicated that in a maximum number out of 12 combinations of dates of sowing and moisture conservation methods, a moderate seed yield of 250 to 500 kg/ha was obtained with a moderate rainfall of 250 to 500 mm, moderate runoff of 30 to 60 mm and moderate moisture stress index of 0.25 to 0.50. In 5 cases of each moderate (0.25 to 0.50) and high moisture stress index (0.50 to 0.75), moderate seed yields were attained, while only in 2 cases of moderate moisture stress index, high yields of more than 500 kg/ha were attained.

Table 5: Grouping of seed yield of sunflower at different quantities of rainfall, runoff and moisture stress at Solapur

Parameter	Seed yield (kg/ha)			
Rainfall (mm)	Low (< 250)	Moderate (250-500)	High (> 500)	Total
Low (< 250)		D4 M1, D4 M2, D4 M3		3
Medium (250-500)		D1 M3 D2 M1, D2 M2, D2 M3 D3 M1, D3 M2, D3 M3	D1 M1, D1 M2	9
High (> 500)				
Total		10	2	12
Runoff (mm)				
Low (< 30)				
Medium (30-60)		D2 M1 D3 M1, D3 M2 D4 M1, D4 M2	D1 M1	6
High (> 60)		D1 M3 D2 M2, D2 M3 D3 M3 D4 M3	D1 M2	6
Total		10	2	12
Moisture stress index				
Low (< 0.25)				
Medium (0.25-0.50)		D1 M3 D2 M1, D2 M2, D2 M3 D3 M1	D1 M1, D1 M2	7
High (> 0.50)		D3 M2, D3 M3 D4 M1, D4 M2, D4 M3		5
Total		10	2	12

D1: SMW 28 (9-15 July) D2: SMW 30 (23-29 July)
D3: SMW 32 (6-12 August) D4: SMW 34 (21–26 August)
M1: Ridge & Furrow M2: Skip row with furrow M3: Flat bed

Seed yield was moderate in 3 cases of low rainfall of less than 250 mm, 7 cases of medium rainfall of 250 to 500 mm, while high yield of more than 500 kg/ha was obtained under medium rainfall situations. When the runoff was medium, from 30 to 60 mm, moderate seed yield was obtained in 5 cases and high yield in one case. Similar numbers of cases were obtained in moderate and high categories, when the runoff was above 60 mm. Table 5 shows the grouping of seed yields in low, moderate and high categories at low, medium and high rainfall, runoff and moisture stress index.

Regression models of seed yield via seasonal rainfall, runoff, soil moisture stress index and fertilizer variables

Multiple regression models of sunflower seed yield via seasonal rainfall, runoff, crop season soil moisture stress index, linear and quadratic terms of fertilizer N and P, along with interaction of fertilizer and soil moisture stress index were calibrated for each of the 12 combinations of sowing dates and moisture conservation methods. The estimates of regression coefficients (β), coefficient of predictability (R^2) and model based prediction error (δ) are given in Table 6. Rainfall and runoff were found to significantly influence seed yield under all the 3 methods of moisture conservation tested when crop was sown on the 1st date of sowing, *i.e.*, under SMW 28. Seasonal rainfall was found to be significant when sowing under SMW 30 and adopting the flat bed method for moisture conservation. The predictability ranged from a low of 0.12 for predicting seed yield based on sowing done during SMW 32 and using the ridge and furrow method for moisture conservation to a maximum of 0.91 for predicting seed yield based on sowing done during SMW 28 and adopting the flat bed method for moisture conservation. Based on the above range of predictability of seed yield, the model based prediction error was found to be in the range of 198.7 kg/ha (SMW 32 with ridges and furrows) to 47.3 kg/ha (SMW 28 with flat bed).

The seasonal rainfall had a positive influence on seed yield when sowing during SMW 28, 30, 32 and 34 and adopting the ridge and furrow method. Under the skip row with furrow system, it had a positive influence on seed yield under all sowing dates except SMW 30. Under the flat bed method, it had a negative influence on seed yield under all sowing dates except SMW 28.

Runoff has a negative influence on seed yield when sown during SMW 28 and 30 and positive influence when sown during SMW 32 under all the 3 methods of moisture conservation. However, when sown during SMW 34, runoff has a negative influence on seed yield under the ridge and furrow method, and positive influence under the skip row with furrow and flat bed methods.

The soil moisture stress index was found to have a negative influence on seed yield when sowing during SMW 30 and positive influence when sowing during SMW 34 and adopting any of the 3 methods of moisture conservation. However, the relation was positive under skip row with furrow and negative under the ridge and fur-

row and flat bed methods when sowing during SMW 28. Similarly, it was positive under the ridge and furrow and skip row with furrow methods and negative under the flat bed method when sowing during SMW 32.

Except for under the ridge and furrow method (when sowing during SMW 30), the skip row with furrow method (when sowing during SMW 28) and the flat bed method (when sowing during SMW 30, 32 and 34), the N and P nutrients were found to have the +/- response type, a positive sign indicating an increasing linear response (positive influence on yield), a negative sign indicating a decreasing quadratic response (negative influence on yield). Out of 8 response types, the occurrence of the +/- response type is essential for optimizing fertilizer doses at varying soil moisture stress index values (Maruthi Sankar, 1986).

Table 6: Multiple regression models of sunflower seed yield via rainfall, runoff, crop season moisture stress index and applied N and P fertilizer at Solapur

DOS	MC	Multiple regression equation	R^2	d
D1	M1	Y=- 2149+2.115 ** (RF)-5.326 ** (RO)-303.12 (MSI)+90.90 (FN)-0.847 (FN^2)+181.81 (FP)-3.387 (FP^2)-5.22 (FN) (MSI)-10.45 (FP) (MSI)	0.75*	140.8
D1	M2	Y=1316+2.354 ** (RF)-4.591 ** (RO)+389.31 (MSI)-59.34 (FN)+0.78 (FN^2)-118.68 (FP)+3.12 (FP^2)-28.68 (FN) (MSI)-57.36 (FP) (MSI)	0.88**	97.5
D1	M3	Y=-80+1.503 ** (RF)-2.538 ** (RO) -329.2 (MSI)+8.44 (FN)-0.018 (FN^2)+16.88 (FP)-0.07 (FP^2)-2.98 (FN) (MSI)-5.96 (FP) (MSI)	0.91**	47.3
D2	M1	Y=559+0.045 (RF) –2.871 (RO) -653.1 (MSI)+5.40 (FN)+0.033 (FN^2)+10.80 (FP)+0.013 (FP^2)-6.69 (FN) (MSI)-13.38 (FP) (MSI)	0.51	107.7
D2	M2	Y=-129 –0.314 (RF)-2.505 (RO)-44.27 (MSI)+37.36 (FN)-0.255 (FN^2)+74.72 (FP)-1.02 (FP^2)-24.21 (FN) (MSI)-48.42 (FP) (MSI)	0.60	93.8
D2	M3	Y=981-0.815 * (RF)-0.896 (RO) -778.6 (MSI)+1.34 (FN)+0.054 (FN^2)+2.68 (FP)+0.217 (FP^2)-9.13 (FN) (MSI)-18.26 (FP) (MSI)	0.65	81.6
D3	M1	Y=- 688+0.13 (RF)+0.378 (RO)+1432.7 (MSI)+23.81 (FN)-0.042 (FN^2)+47.62 (FP)-0.167 (FP^2)-32.27 (FN) (MSI)-64.53 (FP) (MSI)	0.12	198.7
D3	M2	Y=-1070+0.415 (RF)+1.217 (RO)+821.99 (MSI)+41.75 (FN)-0.26 (FN^2)+83.50 (FP)-1.04 (FP^2)-25.12 (FN) (MSI)-50.23 (FP) (MSI)	0.50	158.1
D3	M3	Y=1542-0.405 (RF)+3.131 (RO) -602.73 (MSI)-44.37 (FN)+0.482 (FN^2)-88.74 (FP)+1.927 (FP^2)-2.15 (FN) (MSI)-4.29 (FP) (MSI)	0.56	177.0
D4	M1	Y=-1621+2.627 (RF)-4.858 (RO)+1821.7 (MSI)+29.80 (FN)-0.127 (FN^2)+59.60 (FP)-0.507 (FP^2)-23.99 (FN) (MSI)-47.98 (FP) (MSI)	0.81*	97.2
D4	M2	Y=-2283+0.344 (RF)+0.577 (RO)+2015.1 (MSI)+72.71 (FN)-0.45 (FN^2)+145.42 (FP)-1.81 (FP^2)-40.10 (FN) (MSI)-80.21 (FP) (MSI)	0.55	96.6
D4	M3	Y=-395-5.989 (RF)+16.625 (RO)+1664.1 (MSI)-0.62 (FN)+0.036 (FN^2)-1.24 (FP)+0.143 (FP^2)-2.28 (FN) (MSI)-4.56 (FP) (MSI)	0.25	173.7

* and ** indicate significance at 5 and 1% levels

DOS: Date of sowing — MC: Moisture conservation
FN: Fertilizer N — FP: Fertilizer P
MSI: Soil moisture stress index — RF: Rainfall (mm)
RO: Runoff (mm) — D1: SMW 28 (9-15 July)
D2: SMW 30 (23-29 July) — D3: SMW 32 (6-12 August)
D4: SMW 34 (21-26 August) — M1: Ridge & Furrow
M2: Skip row with furrow — M3: Flat bed
R^2: Coefficient of determination — δ: Estimate of error (kg/ha)

Optimal fertilizer doses for varying levels of available soil moisture

Based on multiple regression models, fertilizer adjustment equations of N and P as a function of available soil moisture stress index were derived and are given in Table 7. The fertilizer adjustment equations of N and P were derived under each model having a positive linear coefficient, a negative quadratic coefficient for a fertilizer variable along with a negative interaction coefficient for fertilizer X soil moisture stress index. This indicates an increasing response at the initial level and diminishing returns at higher levels of fertilizer application. The negative interaction would indicate a higher fertilizer dose at low soil moisture stress index and vice versa for better response of the crop.

Table 7: Fertilizer adjustment equations via crop season moisture stress index for sunflower at Solapur

DOS	Nutrient	Ridge & furrow	Skip row with furrow	Flat bed
D1	N	FN=53.7-3.08 MSI	#	FN=211.0–74.50 MSI
	P	FP=26.8-1.54 MSI	#	FP=105.0– 37.20 MSI
D2	N	#	FN=73.3-47.47 MSI	#
	P	#	FP=36.6-23.74 MSI	#
D3	N	FN=198.0– 268.90 MSI	FN=80.3-48.31 MSI	#
	P	FP=99.0-134.40 MSI	FP=40.1-24.15 MSI	#
D4	N	FN=117.3-94.45 MSI	FN=80.8-44.56 MSI	#
	P	FP=58.6- 47.22 MSI	FP=40.4-22.28 MSI	#

# indicates calibration not possible due to non-diminishing response of a nutrient
DOS: Date of sowing MSI: Crop season water stress index
D1: SMW 28 (9-15 July) D2: SMW 30 (23-29 July)
D3: SMW 32 (6-12 August) D4: SMW 34 (21-26 August)
FN: Fertilizer nitrogen FP: Fertilizer phosphorus

Using the fertilizer adjustment equations, a ready reckon of optimal N and P fertilizer doses at varying levels of soil moisture stress index was worked out and given in Table 8. The analysis indicated that the optimal N fertilizer ranged from 53 to 51 kg/ha and P fertilizer from 27 to 26 kg/ha when the soil moisture stress index ranged from 0.15 to 0.75 and when sowing was performed during SMW 28 (1st DOS) while adopting the ridge and furrow method. Under the skip row with furrow method, the optimal N dose ranged from 66 to 38 kg/ha and P dose from 33 to 19 kg/ha when sowing during SMW 30 (2nd DOS) and adopting the skip row with furrow method. Similarly, the optimal fertilizer N has ranged from 73 to 44 kg/ha and 36 to 22 kg/ha when the crop was sown during SMW 32 (3rd DOS) or SMW 34 (4th DOS) when the soil moisture stress index ranged from 0.15 to 0.75. The corresponding P fertilizer dose ranged from 36 to 22 kg/ha under 3rd DOS and 37 to 24 kg/ha under 4th DOS. The optimal fertilizer doses under the flat bed method for the crop sown during SMW 28 (1st DOS) and the ridge and furrow method when the crop was sown during SMW 32 (3rd DOS) at varying soil moisture stress indices were found to be extrapolable. Thus the study indicated that ridges and furrows is the best method for moisture conservation for sowing during SMW 28, while skip

row with furrows is the best method for sowing during SMW 30, or 32 or 34 for attaining maximum productivity on semi-arid vertisols.

Table 8: Ready reckon of optimum fertilizer N and P doses at varying levels of soil moisture stress index for sunflower at Solapur

MSI	D1			D2			D3			D4		
	M1	M2	M3	M1	M2	M3	M1	M2	M3	M1	M2	M3
						Optimum fertilizer N (kg/ha)						
0.15	53	#	200	#	66	#	158	73	#	103	74	#
0.20	53	#	196	#	64	#	144	71	#	98	72	#
0.25	53	#	192	#	61	#	131	68	#	94	70	#
0.30	53	#	189	#	59	#	117	66	#	89	67	#
0.35	53	#	185	#	57	#	104	63	#	84	65	#
0.40	52	#	181	#	54	#	90	61	#	80	63	#
0.45	52	#	177	#	52	#	77	59	#	75	61	#
0.50	52	#	174	#	50	#	64	56	#	70	59	#
0.55	52	#	170	#	47	#	50	54	#	65	56	#
0.60	52	#	166	#	45	#	37	51	#	61	54	#
0.65	52	#	163	#	42	#	23	49	#	56	52	#
0.70	52	#	159	#	40	#	10	46	#	51	50	#
0.75	51	#	155	#	38	#	0	44	#	46	47	#
						Optimum fertilizer P (kg/ha)						
0.15	27	#	99	#	33	#	79	36	#	52	37	#
0.20	26	#	98	#	32	#	72	35	#	49	36	#
0.25	26	#	96	#	31	#	65	34	#	47	35	#
0.30	26	#	94	#	29	#	59	33	#	45	34	#
0.35	26	#	92	#	28	#	52	32	#	42	32	#
0.40	26	#	90	#	27	#	45	30	#	40	31	#
0.45	26	#	88	#	26	#	39	29	#	38	30	#
0.50	26	#	86	#	25	#	32	28	#	35	29	#
0.55	26	#	85	#	24	#	25	27	#	33	28	#
0.60	26	#	83	#	22	#	18	26	#	30	27	#
0.65	26	#	81	#	21	#	12	24	#	28	26	#
0.70	26	#	79	#	20	#	5	23	#	26	25	#
0.75	26	#	77	#	19	#	0	22	#	23	24	#

# indicates calibration not possible due to non-diminishing response of a nutrient

WSI: Crop season water stress index
D1: SMW 28 (9-15 July)
D2: SMW 30 (23-29 July)
D3: SMW 32 (6-12 August)
D4: SMW 34 (21-26 August)
M1: Ridge & Furrow
M2: Skip row with furrow
M3: Flat bed

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REQUERIMIENTOS PARA OPTIMIZAR LA FERTILIZACIÓN EN GIRASOL DE SECANO BASADOS EN ÍNDICES DE ESTRÉS HÍDRICO DE SUELOS VARIABLES EN VERTISOLES SEMIÁRIDOS DE INDIA

RESUMEN

Se condujeron seis experimentos a campo cuyos tratamientos comprendían cuatro fechas de siembra (siembra durante diferentes semanas meteorológicas estándar: 28 (9-15 de julio), 30 (23-29 de julio), 32 (6-12 de agosto) y 34 (21-26 de agosto), tres métodos de conservación de humedad (camellón y surco, surco salteando una hilera y cama de siembra plana) y tres niveles de fertilizante NP (4-20, 50-25 y 60-30 kg/ha) durante la estación *kharif* de 1999 a 2004 en Solapur en vertisoles semiáridos. Se midieron los índices de estrés hídrico de suelo (MSI) para cada combinación de fecha de siembra (DOS) y método de conservación de suelo (MC) en cada estación sobre la base de lluvia diaria (RF), escurrimiento diario (RO) y estación de cultivo.

Análisis de correlación indicaron una relación positiva entre el rendimiento de semilla y la lluvia en las cuatro DOS. La relación fue relativamente mayor para cama de siembra plana en la 1er DOS, camellón y surco en la 2da DOS y para surco salteando una hilera en la 3ra y 4ta DOS. El rendimiento se relacionó negativamente con RO en la 1er DOS y positivamente en las otras 3 DOS. Esta relación fue mayor bajo el sistema de camellón y surco en la 1er DOS (negativa) y 4ta DOS (positiva) y bajo el sistema de cama de siembra plana en la 2da y 3er DOS. Se encontró una relación negativa entre MSI y rendimiento majo las 12 combinaciones de DOS y MC, indicando una mayor correlación bajo surco salteando una hilera en la 1er, 2da y 4ta DOS y con cama de siembra plana en la 3er DOS. La relación entre RF y RO fue positiva, mientras que MSI tuvo una relación negativa con RF y RO.

Se calibraron modelos de regresión del rendimiento de semilla con RF, RO, SMI, fertilización con N y P e interacción MSI × fertilización. El rango de predecibilidad varió de 0,12 (camellón y surco en la 3er DOS) a 0,91 (cama de siembra plana en la 1er DOS). Un cálculo de las dosis óptimas de N y P al variar los niveles de MSI (0,15 a 0,75) indicó que el método de camellón y surco es eficiente en la 1er DOS con un óptimo de N y P entre 51 y 53 kg/ha y 26 a 27 kg/ha, respectivamente. El método de surco salteando una hilera fue eficiente con el cultivo sembrado en cualquiera de las otras DOS, con un óptimo de N entre 38 y 66 kg/ha (2da DOS), 44 a 73 kg/ha (3ra DOS) y 47 a 74 kg/ha (4ta DOS). La aplicación óptima de P varió de 19 a 33 kg/ha (2da DOS), 22 a 36 kg/ha (3ra DOS) y 24 a 37 kg/ha (4ta DOS) para alcanzar la máxima productividad de girasol en vertisoles semiáridos.

APPORT OPTIMAL NÉCESSAIRE DE FERTILISANTS POUR LE TOURNESOL EN FONCTION DE LA VARIATION DE L'INDICE D'HUMIDITÉ DES SOLS DANS DES CONDITIONS SEMI-ARIDES (VERTISOLS) D'INDE

RÉSUMÉ

Six expériences sur le terrain ont été faites sur le tournesol au moyen des traitements suivants : quatre dates de semis (pendant différentes semaines météorologiques standard, c'est-à-dire 28 (9-15 juillet), 30 (23-29 juillet), 32 (6-12 août) et 34 (21-26 août); trois méthodes de conservation de l'humidité du sol (labour en billons, semis en sillon avec rangs d'espacement intermédiaires et semis en sol plat) et trois niveaux de fertilisants NP (40-20, 50-25 et 60-30 kg/ha) pendant les saisons de *kharif* de 1999 ñ 2004 à Solapur dans des conditions semi-arides (vertisols). Les indices de stress dû au degré d'humidité du sol (MSI) ont été mesurés sur la base des précipitations quotidiennes (RF), de la perte quotidienne d'eau (RO) et de la saison de la récolte pour toutes les dates de semis (DOS) combinées à la méthode de conservation de l'humidité (MC) à chaque saison.

L'analyse corrélative a montré une corrélation positive entre le rendement et les précipitations pour les quatre dates de semis. La relation a été relativement plus élevée pour le semis en sol plat pour la première date de semis, pour le labour en billons pour la deuxième date et pour le semis en sillon avec rangs d'espacement intermédiaires pour les troisième et quatrième dates. On a constaté une relation négative entre le rendement et la perte quotidienne d'eau pour la première date de semis, mais une relation positive pour les trois autres

dates de semis. La relation était élevée pour le labour en billons pour la première date de semis (négative) et pour la quatrième date (positive), et pour le semis en sol plat pour la deuxième et la troisième date. Une relation négative de l'indice d'humidité du sol (MSI) et du rendement a été constatée pour les 12 dates de semis combinées è l'humidité du sol avec une relation élevée pour le semis en sillon avec rangs d'espacement intermédiaires pour la première, la deuxième et la quatrième date de semis et pour le semis en sol plat è la troisième date de semis. La relation entre les précipitations quotidiennes et la perte quotidienne d'eau a été positive tandis que l'indice d'humidité du sol a été en corrélation négative autant pour les précipitations quotidiennes que pour la perte quotidienne d'eau.

Les modèles de régression du rendement en graines en rapport avec les précipitations quotidiennes, la perte quotidienne d'eau, l'indice d'humidité du sol, les fertilisants N et P ainsi qu'en rapport è l'interaction fertilisant × indice d'humidité du sol ont été calculés. Les valeurs prévues s'échelonnaient entre 0,12 (pour le labour en billons pour la troisième date de semis) à 0,91 (pour le semis en sol plat pour la première date de semis). Un barème des doses N et P optimales à différents niveaux de stress dè au degré d'humidité du sol (0,15 à 0,75) a montré que la méthode de labour en billons est efficace pour la première date de semis avec des doses N et P optimales qui s'échelonnent de 51 à 53 kg/ha (N) et de 26 à 27 kg/ha (P) respectivement. La méthode de semis en sillon avec rangs d'espacement intermédiaires a été efficace pour les autres dates de semis avec des valeurs N optimales qui s'échelonnaient de 38 à 66kg/ha (deuxième date de semis), de 44 à 73 kg/ha (troisième date de semis) et de 47 à 74 kg/ha (quatrième date de semis). La valeur optimale P s'échelonnait de 19 à 33 kg/ha (deuxième date de semis), de 22 à 36 kg/ha (troisième date de semis) et de 24 à 37 kg/ha (quatrième date de semis) pour l'obtention d'une productivité maximale du tournesol dans des conditions semi-arides (vertisols).