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EFFECT OF NITROGEN AND IRRIGATION LEVEL ON YIELD OF SAFFLOWER

by

JAMES PRESTON JONES

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GRADUATE COLLEGE

I hereby recommend that this dissertation prepared under my direction by James Preston Jones entitled Effect of Nitrogen and Irrigation Level on Yield of Safflower be accepted as fulfilling the dissertation requirement of the degree of Doctor of Philosophy

Thomas C. Tucker — May 3, 1966
Dissertation Director — Date

After inspection of the dissertation, the following members of the Final Examination Committee concur in its approval and recommend its acceptance:*

Wallace H. Fuller — May 3, 1966
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Jack L. Stroehlein — May 4, 1966

*This approval and acceptance is contingent on the candidate's adequate performance and defense of this dissertation at the final oral examination. The inclusion of this sheet bound into the library copy of the dissertation is evidence of satisfactory performance at the final examination.

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SIGNED: James Preston Jones

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ABSTRACT

Safflower showed little response to added nitrogen in field experiments where appreciable N carryover occurred from preceding crops. Maximum yield was obtained with 240 pounds of nitrogen per acre.

There was a response to added nitrogen up to 120 pounds per acre on nitrogen deficient soil, with wet irrigation treatment. However, there was no response to nitrogen fertilizer on the dry treatment.

Nitrogen fertilizer increased the yield of safflower by increasing seed size in the secondary heads, heads per plant, and number seeds per head in the tertiary heads. Primary heads were not affected by nitrogen fertilizer.

Safflower stem tissue from high nitrogen plots contained 6,000 ppm nitrate-nitrogen early in the season, but had declined to about 100 ppm by first bloom. The unfertilized plots were low in nitrate throughout the period. Plants continued to accumulate considerable total nitrogen after the nitrate level had become very low. Total nitrogen on the mature plant varied from 1.00 percent for the control to 1.30 percent for the high rate of nitrogen. Recovery of fertilizer nitrogen by

safflower was highest for the low fertilizer rate.

Safflower grown in pots accumulated extremely high amounts of nitrate-nitrogen, and was adversely affected by moderate application rates.

INTRODUCTION

Safflower has been recognized as a plant of economic importance since the dawn of recorded history. Until recent years, it was confined to the arid and semi-arid areas around the margins of the Mediterranean Sea and eastward into India. Within the past 30 years determined efforts have been made to establish safflower as an oil crop in many parts of the world. It became a commercially important crop in the United States a little more than a decade ago, and in the arid southwest even more recently.

A survey of the literature discloses a scarcity of information on the fertilizer requirements of safflower. The few studies that have been reported were conducted under dry land conditions or limited irrigation. Results from these studies are not directly applicable to the low desert areas where complete irrigation is necessary for optimum yields. Much the same situation exists with regard to irrigation. The bulk of irrigation information was developed in areas where a limited number of irrigations are necessary to mature a satisfactory crop. In some cases, a thorough pre-irrigation may be adequate, and, at most, only one or two irrigations applied to the crop. Such information does not appear to apply to the low desert area, where rooting depth may be restricted by salt or compacted layers, and where daily transpiration losses can be high.

One of the objectives of this study was to investigate the fertilizer requirements of safflower grown under complete irrigation in the Imperial Valley of California. A wide variety of crop plants are commercially grown in this area. Mainly nitrogen and phosphorus deficiencies have been observed, with phosphorus deficiencies occurring infrequently. Therefore, nitrogen and phosphorus were the only fertilizer nutrients considered in the study. Nitrogen received major consideration.

A second objective of the study was to investigate the irrigation requirements of safflower in the Imperial Valley. Since no work had been published for the area which could serve as a basis for establishing water management, irrigation schedules were chosen to cover a wide range of moisture tensions.

A third objective was to investigate the possibility of using nitrate-tissue analysis for evaluating the nitrogen status of the crop. This technique has been used successfully on certain other crops, and is valuable to predict nitrogen deficiencies before crop productivity is reduced.

A fourth objective was to investigate the effect of applied nitrogen rate on the components of yield. It is desirable to know what yield component is changed when yield is increased, since this information may be helpful in selecting or breeding higher yielding varieties.

LITERATURE REVIEW

Carthamus tinctorius, safflower, belongs to the order *Compositae* and to the tribe of plants commonly known as thistles. It has been an economically important plant throughout recorded history (3,12,18). However, until recent years, safflower was confined to regions of Asia, Africa and Europe where it had been grown for centuries. These include areas around the margins of the Mediterranean Sea and eastward into India. Determined efforts have been made within the past 30 years to establish safflower as a commercial crop in many parts of the world (12).

History and Distribution

The cultivated forms of safflower are supposed to have originated from *Carthamus lanatus* (3), saffron thistle, or from *Carthamus oxacanthus* (3), wild safflower, both of which are closely related to the cultivated form of safflower. *Carthamus oxacanthus*, wild safflower, which is found in India, Pakistan and westward into Turkey, is the most closely related species. Its true relationship to safflower has not been established. It may be a progenitor of *C. tinctorius* or possibly a segregate from a cross between C. *tinctorius* and some other species.

Safflower is reported to have had at least two centers of origin, the mountainous region of Abyssinia and Afghanistan. According to Chavan (3), De Candolle postulated that C. *tinctorius* probably occurred in the wild somewhere in between these regions. However, since no wild plants or plant records have been found in the area, this claim remains only as speculation. The cultivation of safflower is thought to have spread first into India, where it has been cultivated at least as long as the recorded history of the area. Another possible place of origin is believed to be the table-land of Iran (18). From there it is thought to have spread eastward into Kashmir and westward into Syria, Asia Minor, Greece and Italy. Reference to safflower has been found in Sumerian and Akkadian writings dating back to 4,000 B.C. Cloth dyed with the pigment from safflower, as well as plant parts, have been found in Egyptian tombs as early as 1,500 B.C.

The genus *Carthamus*, which contains about 36 species, is confined to the area around the Mediterranean Sea and eastward into India (3,18). Species are particularly abundant in North Africa. Although *Carthamus* is not native to the western hemisphere, two species have become established as weeds. They are *C. lanatus*, "distaff" thistle, and *C. baeticus*, smooth "distaff" thistle (1). Their presence has been reported in the Central Valley of California, in the foothills of the Sierra Nevadas, and in the State of Nevada.

Safflower has not been found growing wild except as strays from cultivated fields (3). Some workers have speculated that through the centuries of cultivation, it has lost the ability to persist without man's intervention.

Safflower is grown commercially in India, Turkey, Israel, France, Russia and Egypt (3,11). India is by far the largest safflower seed producer. The exact acreage is difficult to determine, because safflower is often skip planted and used as field borders. Nevertheless, the annual planting of the crop in India easily exceeds one million acres. Russia grows a considerable acreage, whereas the production in the other countries is small. Recently, it has become important in Australia and the United States. It was introduced into the United States in the 1930s by Rabak (12,16), however it did not become commercially important until the early 1950s.

Before the introduction of the synthetic aniline dyes around the turn of the century, safflower culture was reported to be much more widespread in Europe and the Middle East than at the present time (12).

Production of safflower in the United States is restricted to the Western Great Plains, that part of the Pacific Northwest located between the Cascade and Rocky Mountains, and some areas of the southwest (4,5,11,14). California's Central Valley is by far the most important safflower growing region in the United States. In recent years, acreage in Arizona and the desert areas of California has been increasing (7,13).

Fertilization

A thorough review of the literature was published by Knowles (12). He called attention to the scarcity of information on the fertilizer requirements of safflower. Kellenbarger et al. (10) found that nitrogen gave a response two out of three years under rainfall conditions in Washington. Knowles (12) suggested, based on observation in California, that safflower would require at least as much nitrogen as small grain, and perhaps more. Superphosphate was found to improve yields of safflower grown in Australia (12). Greenhouse studies of nitrogen, phosphorus and potassium response levels were cited by Knowles (12). Nitrogen gave the greatest response. Sailsbery[1] reporting on fertility studies conducted at

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[1]Sailsbery, R. L. A Progress report on safflower fertilization. Unpublished. Address presented before 10th Annual California Fertilizer Conference.

various points in the San Joaquin Valley of California, showed response to nitrogen in some areas up to 150 pounds, whereas others showed no significant increase, with rates over 60-80 pounds. No response to phosphorus fertilizer was noted. Knowles and Miller (14) suggest rates of 75 to 125 pounds of nitrogen for irrigated safflower. They point out that on some soils where cereal crops respond to phosphorus, safflower yields have sometimes been economically benefited by phosphorus fertilizers. Jackson and Kreizinger[2] reported a crop response to added nitrogen in only one of four trials conducted in Arizona. They speculated that carryover from previous crops resulted in the lack of response. No benefit from phosphorus was observed. Significant yield increase was observed by Gilbert[3] up to 150 pounds of nitrogen, which was the highest rate studied. Yield differences were related to the degree of branching

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[2]Jackson, E. B. and Kreizinger, H. F. 1962. Effect of nitrogen and phosphorus fertilization, cultural methods and rates of seeding on yield and oil content of Gila safflower. Unpublished. Progress report. Fifth Annual Report on Soil Fertility and Fertilizer Research, Ariz. Agr. Exp. Sta. and Ext. Ser. Report No. 4: 129-137.

[3]Gilbert, N. W. 1965. Safflower fertilizer trial. Unpublished. Progress report. Eighth Annual Report on Soil Fertility and Fertilizer Research. Ariz. Agr. Exp. Sta. and Ext. Ser. Report No. 7: 17-18.

and the number of heads produced. Oil content was not affected by nitrogen fertilization, according to Gilbert, Jackson and Kreizinger. However, Yermanos et al. (21) reported a slight decrease in oil content with high rate of nitrogen application, but the increase in yield of seed more than offset the lower oil content. Claassen et al. (6) found a significant negative correlation between nitrogen and oil content. They indicated exceptions to the trend and suggested high nitrogen can be combined with high oil by breeding for a low hull content of the seed.

Irrigation

Safflower is a native of arid and semi-arid climatic regions (3,12). It requires a dry atmospheric condition from the time of bud formation until maturity. Low humidity is essential for good seed set and high oil content (4). Humid conditions are conducive to the development of Botrytis, which causes seed rot, and a rust disease of the foliage.

Safflower has been shown to be a very drought tolerant plant. Some seeds will be produced with no water applied after planting, even in the hot, dry Colorado desert of Southern California and Arizona. This ability to survive under adverse conditions is related to its extensive root system, enabling it to obtain soil moisture from a considerable depth. In deep permeable soils, safflower has been reported to extract moisture from below 10 feet[4], and appears to have a deeper rooting depth on heavy clay soils than alfalfa. Safflower has the ability to utilize water from a free water table if it occurs within eight to ten feet of the soil surface. This has been suggested as the reason for the highly successful plantings in the Sacramento Delta of California.

Although safflower has been shown to be a drought tolerant plant, if economic yields are expected in the low desert area, adequate moisture must be available. When grown under irrigation, a total of three to three and a half acre feet of water must be added to satisfy the crop's moisture requirement (7,15).

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[4] Henderson, D. W. et al. 1961. Safflower production. Unpublished. Progress report. Safflower field day. University of California, Davis.

MATERIALS AND METHODS

After safflower seedlings emerge, they remain close to the ground, producing numerous leaves, but no long stems. This semi-dormant stage is commonly called rosette. The main stem begins to grow when temperatures warm and branching occurs from the main stem when the plant is 8 to 15 inches tall. The main stem apex terminates with a flower head. Axillary branches below the main apex produce secondary branches terminating in a flower head. Tertiary branches arise from secondary branches and produce the tertiary head. Each head consists of numerous flowers and each flower potentially produces a single fruit. This fruit is commonly called "seed" and will be so used in this paper.

Nitrogen and Phosphorus Fertilizer Study in 1962

A field study was initiated in California's Imperial Valley in January of 1962 to study the fertilizer requirements of safflower grown under irrigation. The soil on which the trial was conducted was classified as a Rositas fine sandy loam. Five fertilizer variables were studied. They were control, which received no fertilizer, 60, 120, and 240 pounds of nitrogen per acre, and 120 pounds of nitrogen plus 39 pounds of phosphorus per acre. Ammonium nitrate was used as a source of nitrogen. The phosphorus source was treble superphosphate. Fertilizer materials were spread on the surface of the ground prior to listing the beds. Each plot consisted of four double row lettuce beds spaced 42 inches on center by 50 feet in length. The experimental design was a randomized block with four replications. Gila (17) variety of safflower was used. The previous crop on the land was cotton. Cultural practices, irrigation and cultivation were performed by the farmer. Two beds, 40 feet long, were harvested by hand for yield. Wiedeman and Leininger (19) showed that a plot size of five by 20 feet was adequate for safflower yield studies. Seed was separated, using a small stationary thrasher, and weighed. Seed samples were taken for determination of nitrogen, oil percentage, and iodine number.

Fertilizer and Irrigation Study in 1963

An experiment was initiated in January of 1963 at the University of California-Imperial Valley Field Station to study the effect of various levels of fertilizer and irrigation on the yield of safflower. The soil on the experimental site was classified as

Imperial silty clay. Three irrigation treatments - wet, medium and dry - were used. The wet treatment was irrigated when the average tensiometer reading reached 0.30 bars. The medium treatment was irrigated at two times the number of days between the wet treatment. The dry treatment was irrigated at four times the number of days between the wet treatment. The experimental design was a split plot with the main plot (irrigation) replicated six times and with fertilizer plots superimposed upon them. The irrigation plots were four beds (42 inches) 250 feet long. One buffer bed was maintained between the irrigation plots. The fertilizer plots were four beds 50 feet long. Five fertilizer levels were studied. They were, no fertilizer, 60, 120, 240 pounds of nitrogen, and 120 pounds of nitrogen plus 69.5 pounds of phosphorus per acre. Ammonium nitrate was used as a source of nitrogen. The phosphorus source was treble superphosphate. All fertilizer was spread uniformly on the surface by hand before bedding. Gila variety of safflower was planted in dry soil on double row lettuce beds. The field was irrigated to germinate the seeds, followed by two uniform irrigations to insure stand establishment. Subsequently, irrigation treatments were imposed. Water applied to the plots following the establishment of irrigation treatments was measured into each furrow using a container of known volume and a stop watch. Sixty-eight, 37, and 19 inches of water were applied to the wet, medium and dry treatments, respectively. No attempt was made to measure surface runoff. Samples, consisting of ten average size plants selected at random, from each of two fertilizer levels (0 and 120 # N/A), and each irrigation level were taken at maturity. The samples were to be used to determine the variation in the components of yield which were expected from the treatments. The seed heads were removed from the plants and separated into primary, secondary and tertiary heads. The primary head was located at the apex of the main stem. Secondary heads were those on the first branches from the main stem. Tertiary heads were those on branches which originated from the first branches. This classification was described by Francois et al. (8), and Yermanos et al. (20). Heads were thrashed by hand and the seed weighed. One hundred seeds were counted from each head type, and weighed to determine the seed weight. These two factors, plus head count, could be used to calculate the number of seeds per head, seeds per plant, seed weight per head, and the relative contribution of primary, secondary and tertiary heads to yield variation.

Plot yields were measured by harvesting two rows, 46 feet long, with a self-propelled combine, and weighing the seed.

Fertilizer and Irrigation Study in 1964

A third field study was initiated in January of 1964 on a plot adjacent to the site of the 1963 experiment. The area had been uniformly cropped to sudan grass to lower the nitrogen fertility level prior to the establishment of the trial. The design and treatments were similar to those of the 1963 experiment. Certain desirable changes, however, were made as follows: main plots were replicated only four times, the plots were increased to eight rows to minimize border effect, and the 120 pounds of nitrogen plus phosphorus treatment was deleted. The irrigation treatments and the remaining fertilizer treatments were the same as those employed in the 1963 trial. Fertilizer was applied by band injection on either side of the beds using ammonium nitrate. Water, applied to the plots, was measured as described in the previous experiment. In addition, a Parshall flume and stage recorder were installed to measure surface runoff. Each irrigation treatment received water on different days to keep runoff separate. Forty-two, 24 and 17 net inches of water were applied to the wet, medium and dry treatments, respectively. Samples were taken for yield component evaluation as previously described. Plant tissue samples consisting of four inch sections of stem tissue from directly below the apex were taken for nitrate-nitrogen analysis. Sampling started soon after the end of the rosette stage and continued at two-week intervals up to the full-bloom stage. Whole plant samples were taken at the beginning of flower-bud stage, and again at full maturity, by harvesting the total above ground portion of the plants for total nitrogen determination. Plot yields were measured by harvesting two center rows, 44 feet long, with a self-propelled combine, and weighing the seed. Nitrate nitrogen was determined on the stem samples by the method of Johnson and Ulrich (9). Total nitrogen was determined by Kjeldahl method.

Fertilizer Study in the Greenhouse for Tissue-Nitrogen Evaluation

A pot experiment was conducted in the spring of 1965 to study the effect of various application rates of nitrogen fertilizer on the yield and nitrogen content in the tissue of safflower grown in pots. This investigation was conducted in the greenhouse at the University of Arizona on a virgin Mohave sandy loam soil which had been dried, screened and mixed. Seven kilograms of the soil were placed in each of 80 surplus army packing cans, which had been painted inside with asphalt paint.

Each pot of soil was treated with ammonium nitrate at the rates of 0, 0.25, 0.50, 0.75, 1.00, 1.50, 2.00, and 3.00 grams of nitrogen per pot. Each treatment was replicated 10 times.

The pots were supplied with polyethylene watering tubes, but no drain holes were installed. Spot weighings were made to help determine when irrigation was needed. Watering tubes showed the accumulation of water in the bottom of the pots when excess was applied.

Six to eight Gila safflower seeds were planted in each pot and watered. After seedlings were well established, they were thinned to three plants per pot.

The first samples were taken when the plants were six to eight inches high. Each plant was divided into leaf portion and stem portion. The second sampling was made one week later, when the plants were ten to 14 inches tall. The third sampling was made one week after the second sampling when the plants were in the flower-bud stage. The fourth sampling was made two weeks after the third, when the plants were blooming.

All samples were dried and ground for analysis. Nitrate-nitrogen was determined by method of Johnson and Ulrich (9).

The remaining plants were harvested for yield. Total heads were thrashed by hand for seed yield. The seed and straw were ground together for total nitrogen analysis. The micro-Kjeldahl method of Bremner (2) was used to determine total nitrogen.

RESULTS AND DISCUSSION

Nitrogen and Phosphorus Fertilizer Study in 1962

Data for yield, nitrogen content of the seed, oil percentage and iodine number are present in Table 1. Yield was not significantly affected by the nitrogen fertilizer. Residual fertilizer nitrogen from the previous crop appears to have been adequate for the crop needs. Cotton, the crop preceding safflower, generally receives high rates of nitrogen; on the average between 400 and 450 pounds of actual nitrogen per acre. This could have provided a considerable carryover.

Observations of the plots were made throughout the growing season. Visual nitrogen deficiency symptoms were noted in the check plots only after the plants were in full bloom, and apparently this was too late to adversely affect the yield. No other plots showed any deficiency symptoms.

Even though there was no yield difference due to fertilizer treatment, seed samples were drawn from each plot to evaluate the effect of different nitrogen rates on oil percentage, nitrogen percentage, and iodine number of the oil. Yermanos et al. (21) reported that high rates of nitrogen cause a slight depression in

Table 1. The Effect of Fertilizer Treatment on Yield, Nitrogen Content, Oil Content and Iodine Number of Safflower Seed - 1962.

Fertilizer Treatment	Yield	N	Oil	Iodine No.
lbs/A	lbs/plot	%	%	
Check	24.8a*	2.38ab	39.15ab	147.0a
60N	24.9a	2.33a	39.47b	146.6a
120N	25.6a	2.48ab	38.75a	147.0a
240N	23.5a	2.52b	38.65a	147.0a
120+39P	25.3a	2.52b	39.02ab	147.5a
$s\bar{x}$(d.f.=12)	0.648	0.049	0.159	0.206

*All values within a column, followed by the same letter, are not significantly different at 0.05 level.

oil content and iodine number. The analysis of variance for nitrogen content of seed showed a significant effect at the five percent level. Separation of the means by Duncan's Multiple Range Test disclosed that the 60 pound nitrogen treatment was significantly lower than the 240 pound nitrogen and the 120 pound nitrogen plus phosphorus treatments. The control and the 120 pound nitrogen treatment could not be distinquished from either of those populations. The analysis of variance was barely significant at the five percent level, and the difference observed may not be real.

The analysis of variance for the oil content data showed significance at the five percent level. The oil content of the 60 pound nitrogen treatment was significantly higher than the 120 pound nitrogen and 240 pound nitrogen treatments. However, the control and the 120 pound nitrogen plus 39 pound phosphorus treatments were not significantly different from either of the groups.

Iodine number was not significantly affected by fertilizer treatments in this study, Table 1.

Fertilizer and Irrigation Study in 1963

The yield data from the 1963 trial are presented in Table 2 and Figure 1. Statistical analysis of these data showed significant irrigation and fertilizer effects. The wet irrigation treatment produced the highest yield.

Table 2. The Effect of Nitrogen Fertilizer and Irrigation on the Seed Production of Safflower - 1963

Fertilizer Treatment	Seed Weight			
	Irrigation Treatment			
	Wet	Medium	Dry	Average
lbs/A	lbs/plot			
Check	29.80	27.00	24.06	27.51
60N	28.83	27.77	24.20	26.93
120N	29.95	29.08	24.83	27.96
240N	31.77	29.61	25.66	29.02
120N+70P	31.05	27.11	25.25	27.80
Average	30.28	28.12	25.14	

$s\bar{x}$ for irrigation (d.f.=10) = 0.665.

$s\bar{x}$ for fertilizer (d.f.=60) = 0.353.

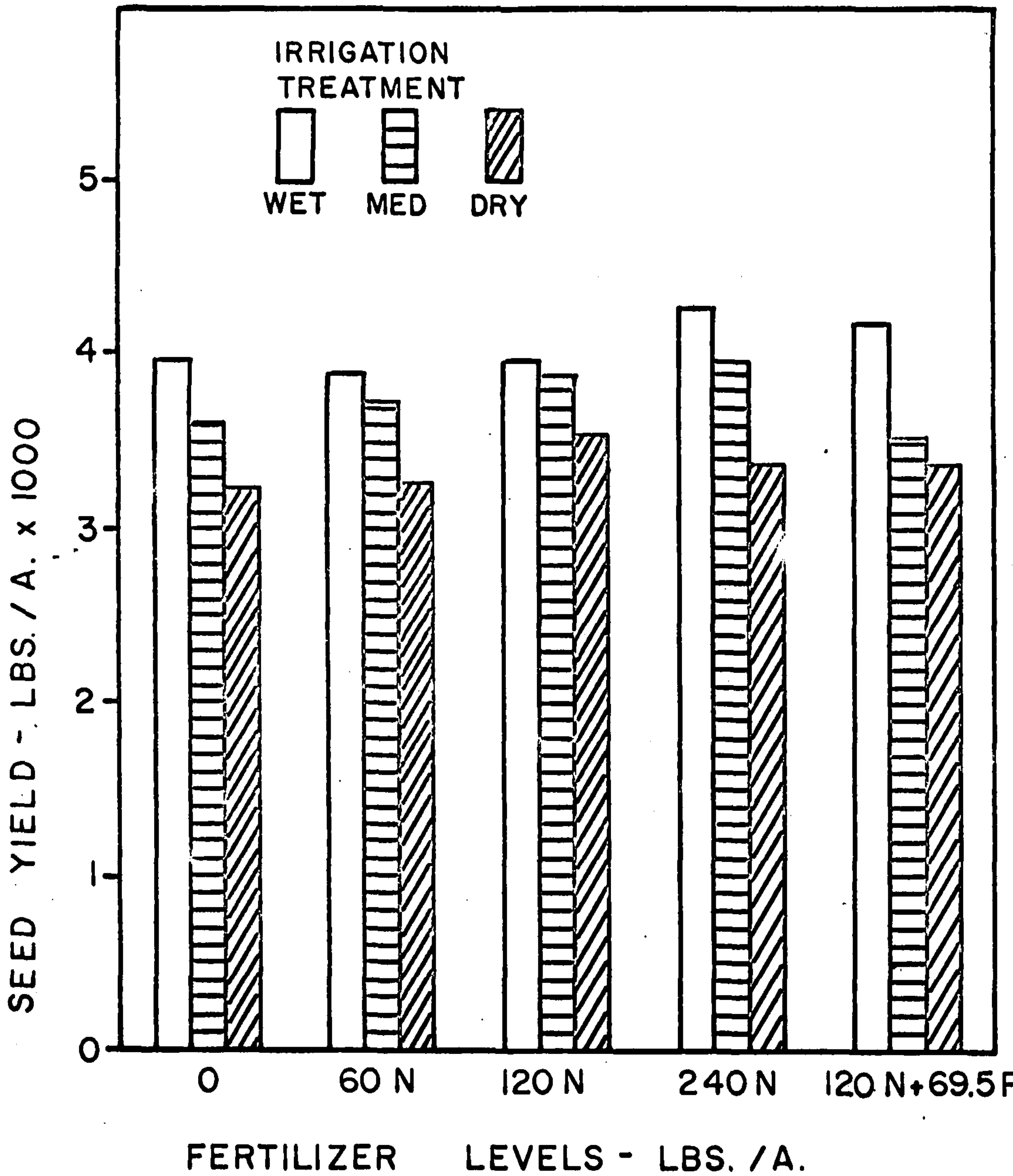

Figure 1. The Effect of Fertilizer and Irrigation on seed production of safflower - 1963.

with each fertilizer treatment. The dry irrigation treatment was the lowest, and the medium was intermediate in all cases as shown in Figure 1. Since there was no significant interaction, the fertilizer means across all irrigation treatments can be compared. Yield resulting from the 240 pound rate of nitrogen was significantly higher than all other fertilizer treatments. The remaining treatments all belonged to the same population. Thus, there was no difference between the phosphorus treatment and the same rate of nitrogen without phosphorus. The increase in yield with the 240 pound rate of nitrogen over the 120 is noted to be quite small. The lack of response at lower rates of nitrogen, and the small increase with the high rate, is probably the result of high residual nitrogen content of the soil. Soil samples taken prior to fertilizer application contained an average nitrate content of more than 16 ppm nitrogen in the upper three feet of the root zone.

This could amount to more than 160 pounds of residual nitrate-nitrogen in the soil; enough to supply much of the plants' needs.

The wet irrigation treatment yielded significantly more seed than the medium treatment, which was significantly better than the dry treatment.

Due to a lack of yield difference between fertilizer treatments, the whole plant sample which was taken before harvest, was not processed. Samples taken from irrigation plots did not correlate with yield from those plots. Therefore, the effect of these two variables upon the components of yield could not be evaluated.

Fertilizer and Irrigation Study in 1964

Growing and removing an unfertilized crop of sudan hay was effective in reducing nitrate-nitrogen content of the soil. Nitrogen deficiency symptoms developed very early in the check plots. The 60 pound per acre nitrogen rate had nitrogen deficiency symptoms before blooming. Yield results are shown in Figure 2 and Table 3. Statistical analysis of the data showed a highly significant over-all fertilizer effect. However, the over-all irrigation effect was not significant. There was a highly significant interaction between fertilizer and irrigation, indicating that the nitrogen response was different with different rates of irrigation. Nitrogen fertilizer did not significantly increase yield of safflower in dry treatments, although there was a tendency toward higher yields with higher nitrogen rates, which approached significance with 120 pounds of nitrogen. It appears that water was limiting yield to such an extent that nitrogen utilization was greatly reduced.

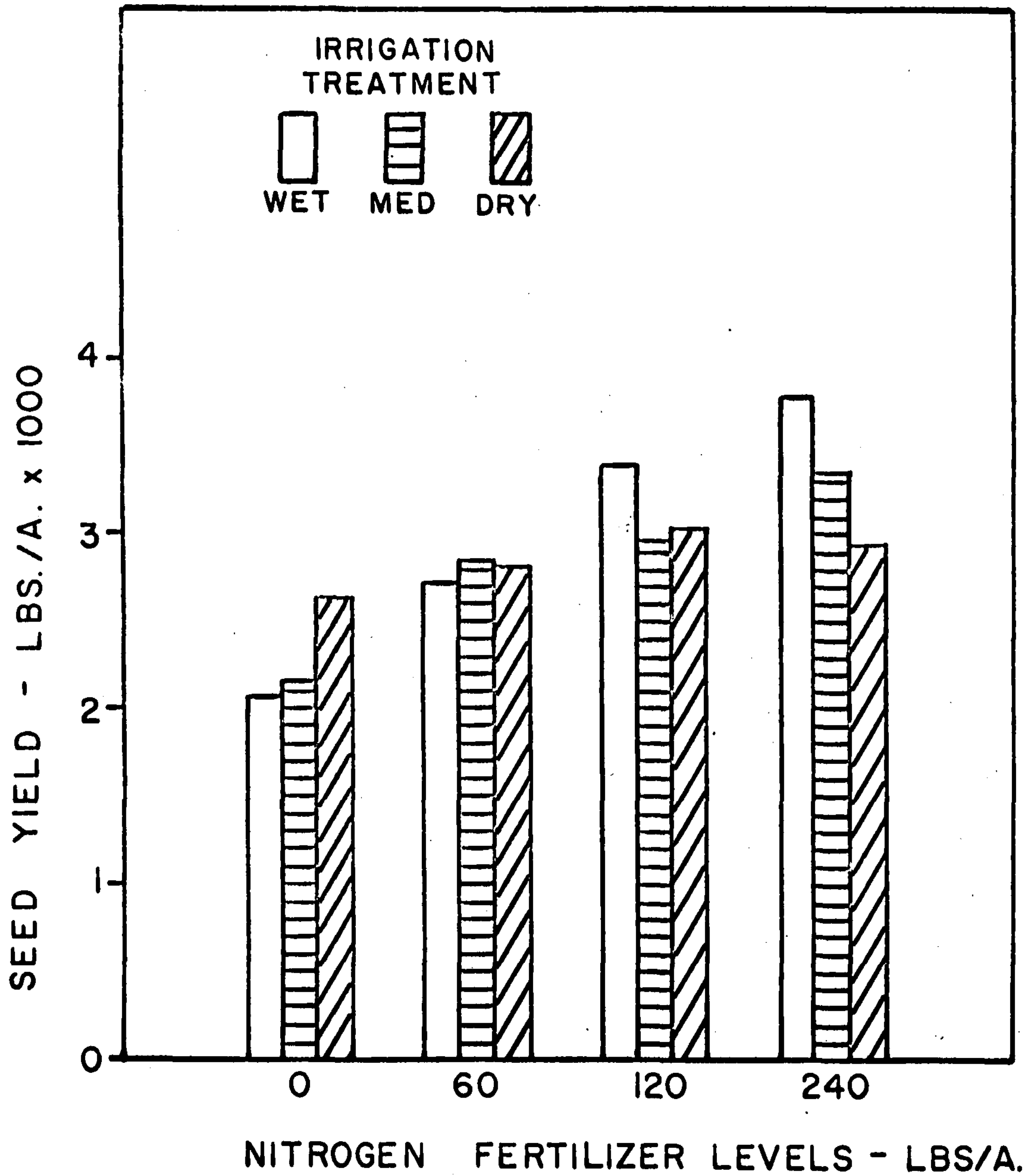

Figure 2. The Effect of Fertilizer and Irrigation on Seed Yield of Safflower - 1964

Table 3. The Effect of Nitrogen Fertilizer and Irrigation on the Seed Production of Safflower - 1964

Fertilizer Treatment	Seed Weight			
	Irrigation Treatment			
	Wet	Medium	Dry	Average
lbs/A	lbs/plot			
Check	14.83	15.22	18.75	16.27
60N	19.27	20.40	19.97	19.98
120N	24.07	21.00	21.62	22.23
240N	26.77	23.65	20.92	23.78

$s\bar{x}$ for fertilizer (d.f.=27) =0.583.

$s\bar{x}$ for fertilizer at one level of irrigation (d.f.=27) =1.015

$s\bar{x}$ for irrigation at one level of fertilizer (d.f.=16) =1.375.

With the medium irrigation rate, 60 pounds of nitrogen significantly increased yield over the check. The 240 pound treatment was significantly higher than the 60 pound rate. However, the 120 pound treatment could not be distinguished from either of these populations.

Each increment of nitrogen produced a significant yield increase up to the 120 pound rate with the wet irrigation treatment. The 240 pound rate was not significantly better than the 120 pound rate, however, it approached significance.

A comparison of yield among different irrigation treatments at the 0 rate of nitrogen shows that the wet irrigation treatment yielded significantly less than the dry treatment. However, when the same comparison is made at the 240 pound nitrogen rate, it is noted that the wet treatment yielded significantly more than either of the other treatments. This suggests that leaching may be removing part of the nitrogen with high rate of irrigation, thus aggravating the nitrogen deficiency at low nitrogen rates. However, the soil, Imperial silty clay, takes water very slowly, thus making it difficult to move enough water through the profile to accomplish much leaching. It seems more probable that high rates of irrigation stimulated early vegetative growth, thereby using up the available nitrogen supply before fruiting. It also suggests that a high rate of nitrogen fertilizer and irrigation are needed in combination to produce maximum yields.

The components of seed yield for safflower may be subdivided as shown in Figure 3. All plots in this study were planted at the same rate and the stand was assumed to be constant. Therefore, yield per acre should be directly related to yield per plant. This relationship was taken into account in sampling for components of yield. Ten average plants were taken from each plot. Harvest yield and sample yield were highly correlated. The correlation coefficient of 0.875 indicated that ten average plants was a reliable sample of yield.

Yield per acre may be expressed as a product of the number of heads per acre times the weight per head. Heads per acre can be expressed as the product of the number of heads per plant times the number of plants. Weight of seed per head may be subdivided into number of seeds per head times the weight per seed. All of these factors can be evaluated for primary, secondary and tertiary heads.

Data presented in Table 4 shows the effect of nitrogen fertilizer on the components of yield. Since the plant population was constant, the number of heads

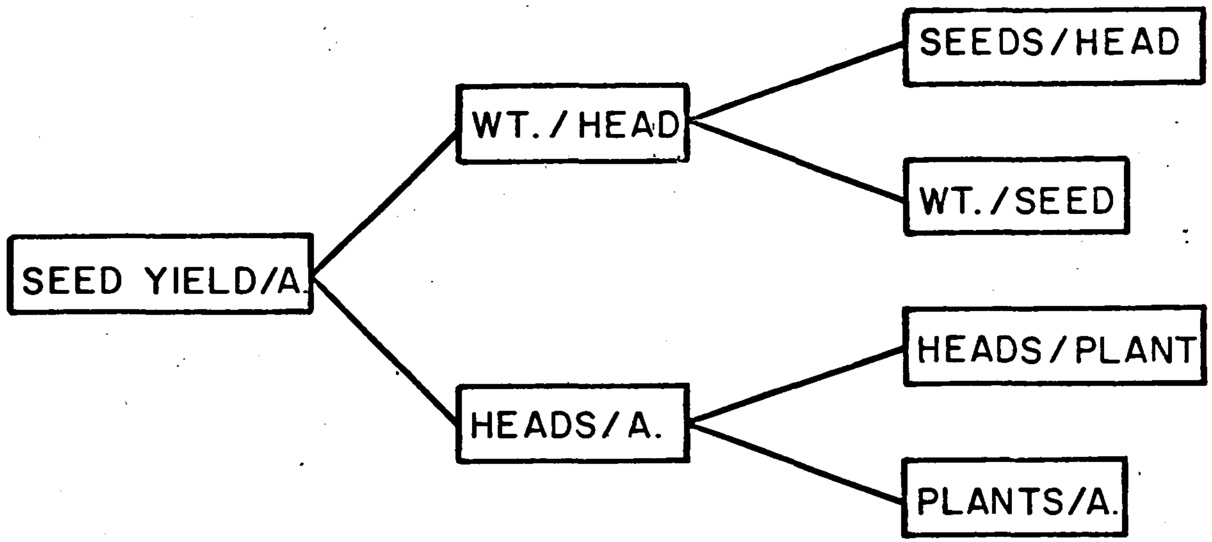

Figure 3. Components of Seed Yield in Safflower

Table 4. The Effect of Nitrogen Fertilizer on the Components of Yield

Nitrogen Applied	Head Position			
	Primary	Secondary	Tertiary	Plant Average
lbs/A	Heads per Plant			
Check	1.0	5.4	5.2	11.6
240	1.0	6.1	8.1	15.2
LSD.05	2.42	2.42	2.42	1.78
	Weight of Seed per Head* - gm.			
Check	1.99	1.43	0.81	1.41
240	2.17	1.98	1.32	1.80
LSD.05	0.26	0.26	0.26	0.19
	Seeds per Head			
Check	41.25	36.00	22.75	33.33
240	44.75	43.25	35.25	41.08
LSD.05	7.70	7.70	7.70	5.71
	Weight of 100 Seeds* - gm.			
Check	4.81	3.97	3.50	4.09
240	4.80	4.41	3.68	4.30
LSD.05	0.38	0.38	0.38	0.35

*Weight expressed as grams of air dry material.

per acre was directly related to the number of heads per plant. Nitrogen at the 240 pound rate resulted in a significantly greater over-all number of heads per plant over the check, Table 4. Further, nitrogen fertilizer resulted in a significantly greater number of tertiary heads, but produced no significant increase in the number of primary or secondary heads. Therefore, it may be concluded that one way in which nitrogen fertilizer increases yield is by increasing the number of tertiary heads.

Yield of seed per head was also affected by nitrogen fertilizer. Data in Table 4 show a significant increase in the average weight of seed per head for plants receiving a high rate of nitrogen over the control treatments. This effect was not significant for primary heads, but was significant for both secondary and tertiary heads. Thus another way in which nitrogen fertilizer affected yield was by increasing the weight of seeds per head in the secondary and tertiary heads.

Yield per head, Figure 3, can be expressed as a product of the number of seeds per head times the weight per seed. Nitrogen fertilizer increased the average number of seeds per plant over the check treatment. This effect was found in the tertiary heads. The primary and secondary heads from nitrogen treated plots were not significantly different from the check, although the secondary head stage approached significance and probably would show significance with more replications.

The over-all average seed weight for nitrogen treated plants was not significantly different from the untreated. However, seeds from the secondary heads of the nitrogen treated plots were significantly larger than those of the check.

Nitrogen fertilizer had no effect on the number of primary heads of safflower. This was expected since by definition there can be only one primary head, the number cannot be influenced by fertilizer treatment. Seeds per head and weight per seed are not affected, probably because the primary head is the first one formed, and has greater access to the nutrients within the plant than later produced heads. Therefore, even in nitrogen deficient plants, the primary heads have a better opportunity to develop normally. Nitrogen fertilizer influenced yield by increasing the number of tertiary heads produced, by increasing the number of seeds per head in the tertiary heads, and by increasing weight per seed in the secondary heads.

The nitrate level in safflower stem tissue was influenced greatly by nitrogen fertilizer treatment. Figure 4 shows the effect of the different treatments

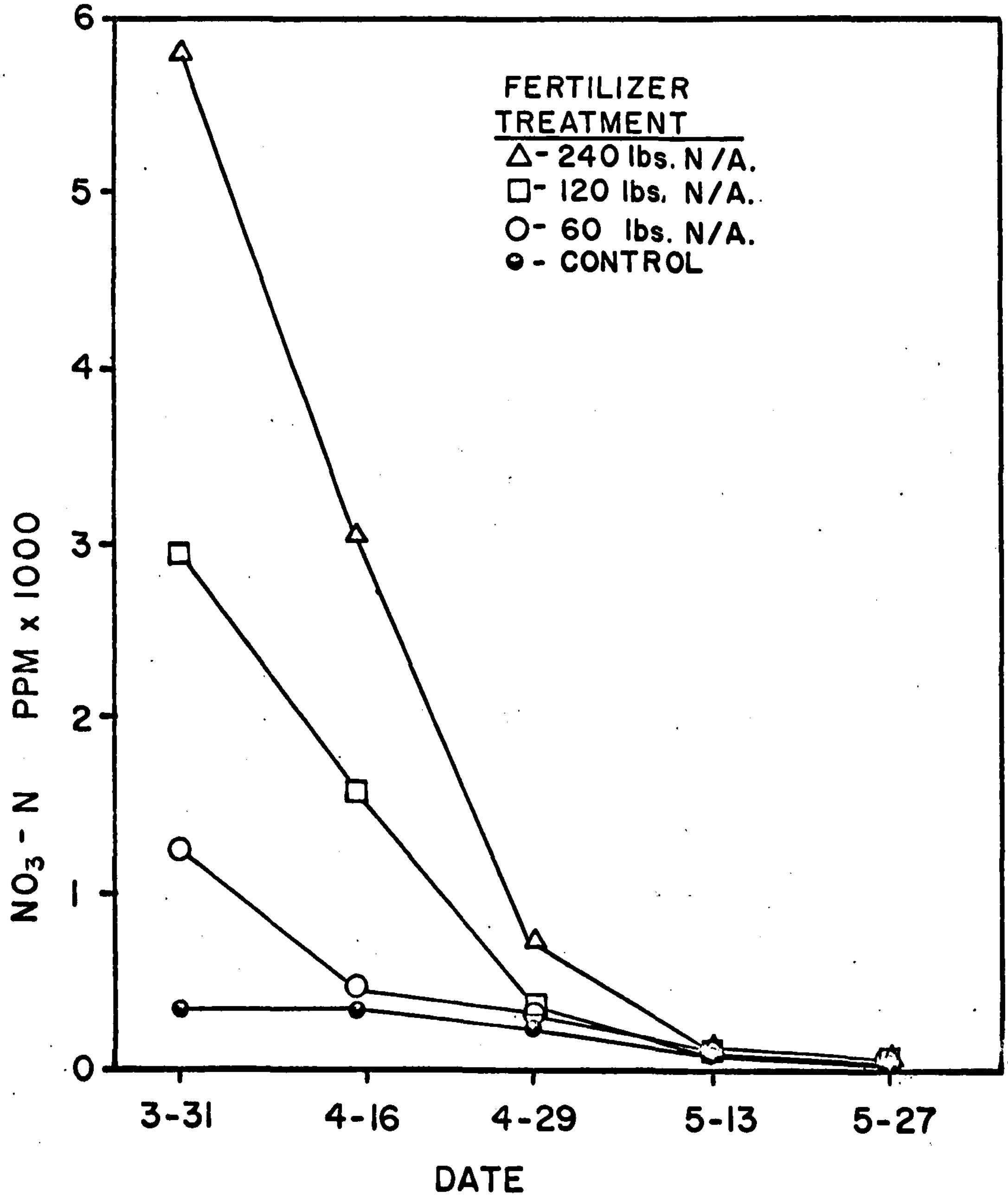

Figure 4. Nitrate-Nitrogen Content of Safflower Stem Tissue

at five sampling dates. The plants from the untreated plots had a very low level of nitrate, less than 1,000 ppm, and were obviously short of nitrogen, since visual nitrogen deficiency symptoms appeared very early. There was a slight decline at later samplings.

The 240 pound nitorgen treatment resulted in concentrate of almost 6,000 ppm nitrate-nitrogen in the stem tissue at the first sampling date. The 120 and 60 pound nitrogen treatments resulted in proportionately less nitrate in the stem tissue. There was a sharp decline with later samplings until all treated plots had a concentration of less than 1,000 ppm nitrate-nitrogen. This corresponded to the flower-bud initiation stage of plant development. Later samplings showed a nitrate level in the tissue from treated plots that was no higher than the check, about 100 ppm.

Table 5 shows the nitrate content of the stem tissue for the various fertilizer treatments. Also included are the seed yields for those treatments. This shows a large difference in nitrate level for the various treatments at the early stage of development. The difference had become considerably smaller by the next sampling date two weeks later, and had largely disappeared by the third sampling date.

Table 5. Nitrate Content of Safflower Stem Tissue And Seed Yields in 1964

Date	Fertilizer Treatment, lbs. N/A			
	Check	60	120	240
	ppm NO_3-N			
3/3	375	1250	2975	5825
4/16	475	537	1637	3050
4/29	250	350	325	712
	Yield of Safflower Seed lbs/A			
	2,153	2,885	2,970	3,345

Table 6. Total Nitrogen in Whole Plant Samples in 1964

Date	Fertilizer Treatment, lbs. N/A			
	Check	60	120	240
	% N			
4/23	1.39	1.55	1.77	2.36*
6/23	0.99	1.18	1.21	1.29**

*Average of two replications.

**Average of four replications.

Since maximum yield was obtained with the high rate of nitrogen, it seems probable that nitrate concentration in the stem tissue of this treatment at the various stages would be the minimum needed to assure maximum yield.

The rapid decline in nitrate concentration makes the use of this technique as a dianogistic tool more difficult, since the stage of plant development must be carefully defined. The decline can be explained in part by the rapid growth resulting in a dilution of the absorbed nitrate, and a change in the physiological age of sampled material. Since safflower exhibits a determinate growth pattern, tissue samples taken near the growing tip during the later growth stages are more mature and contain less parenchyma tissue which can serve as reservoirs for nitrate. However, these factors seem inadequate to explain all of the reduction in level of nitrate-nitrogen. It seems probable that some physiological factors, such as more rapid utilization of the nitrate, or reduction of nitrate to amino nitrogen, occurs before it is translocated to the top of the plant.

Total nitrogen in the whole plant tissue, Table 7, indicates that accumulation of nitrogen continues in the above ground portion long after the nitrate concentration in the stem has declined to a very low level. From the first flower-bud stage until maturity, the safflower plants accumulated as much nitrogen as had accumulated up to that point. This occurred even though the level of nitrate-nitrogen in the stem tissue was less than 1,000 ppm throughout the period.

The percent nitrogen in the above ground portion of the plant did show a marked decrease from first flower-bud to maturity, as would be expected with the maturation of tissue, Table 6.

The rate of nitrogen fertilizer application had an inverse effect on the percentage of the fertilizer nitrogen recovered by the above ground portion of the plants. After subtracting the amount of nitrogen accumulated by the check as an estimate of the amount supplied by the soil, the lowest rate of fertilizer nitrogen, 60 pounds per acre, produced the highest percent recovery, 82.5 percent. Each of the higher rates produced successively lower recovery percentages, Table 8. The date suggests that each increment of fertilizer is less effective than the increment preceding it in affecting additional nitrogen uptake. The same relationship exists between fertilizer rate and yield.

Table 7. Total Nitrogen Accumulation in Above Ground Portion of Safflower in 1964.

Date	Fertilizer Treatments, lbs. N/A			
	Check	60	120	240
	N, lbs/A			
4/23	30.4	46.1	53.7	76.3*
6/23	63.7	113.2	110.0	134.2**

*Average of 2 replications.

**Average of 4 replications.

Table 8. Recovery of Fertilizer Nitrogen by Safflower At Maturity.

Fertilizer Treatment, lbs. N/A			
Check	60	120	240
percent recovery			
0	82.5	37.7	29.3

Fertilizer Study in the Greenhouse for Tissue-Nitrogen Evaluation

Safflower plants grown in pots in the greenhouse were affected adversely by high rates of nitrogen fertilizer, Figure 5. Yield of the total above ground portion of the plant and seed yield followed the same pattern. Both were highest where 0.50 grams of nitrogen fertilizer per pot was used. Total plant yield declined slightly as the fertilizer rate was increased up to 1.00 gram per pot, followed by a sharp decrease to 2.00 grams per pot. Seed yields showed a small decrease with each increasing increment of fertilizer above 0.5 grams per pot up to the highest rate. The 0.50 grams nitrogen per pot rate, which resulted in the maximum yield of both seed and plant material, represents only 145 pounds of nitrogen per acre furrow slice, and is less than the rate necessary for maximum yield in the field studies. Simularly, nitrate concentrations, Figure 6, in safflower stem tissue were considerably higher when grown in pots than at the same fertilizer rate in the field studies. The nitrate concentration in leaf tissue, Figure 7, was somewhat lower than in stems, but were higher than stem tissue from field studies. The leaf and stem nitrate levels generally followed the same pattern. Figure 8 shows the relationship of applied nitrogen to nitrogen

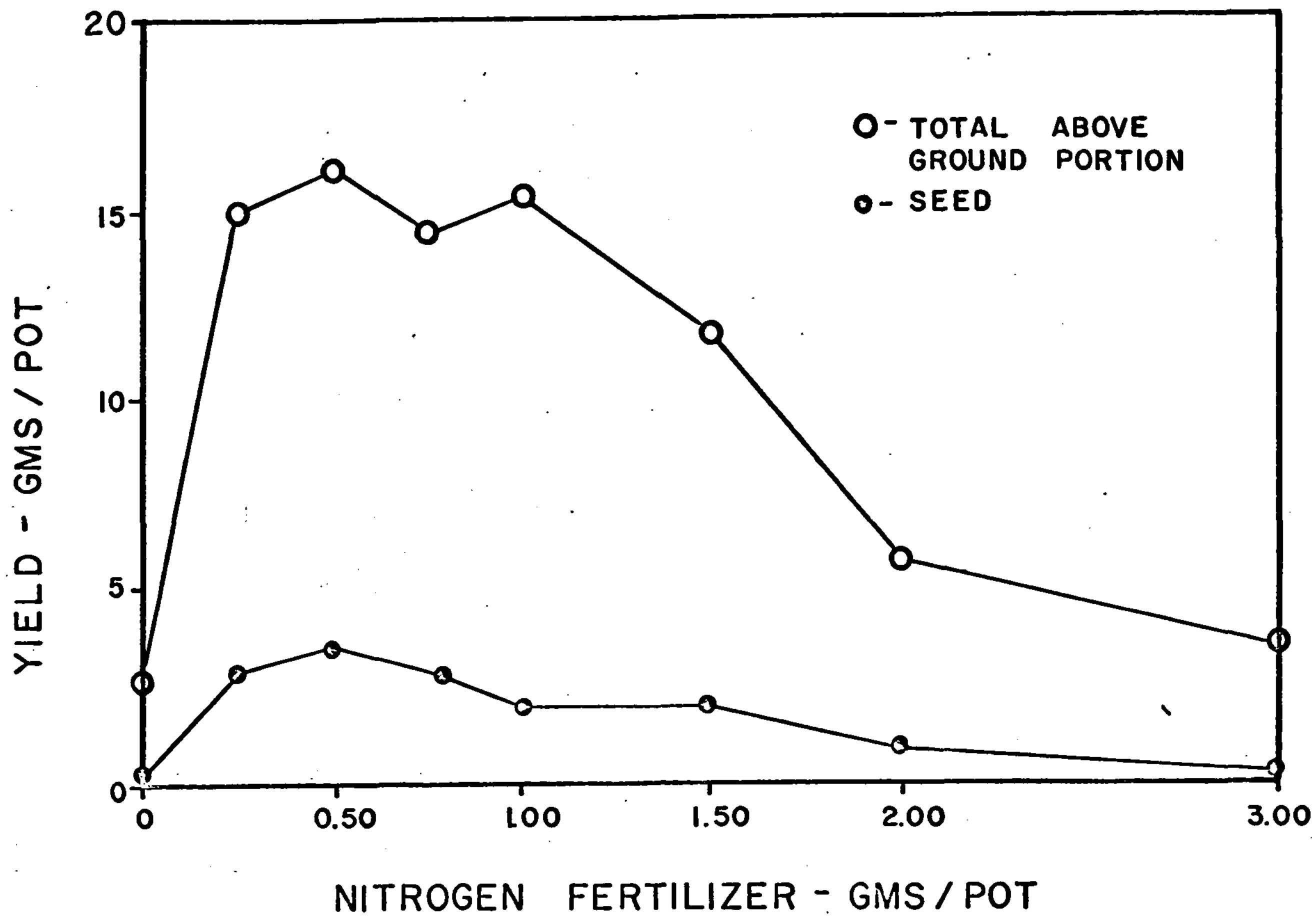

Figure 5. The Effect of Added Nitrogen on Yield of Safflower in Pots

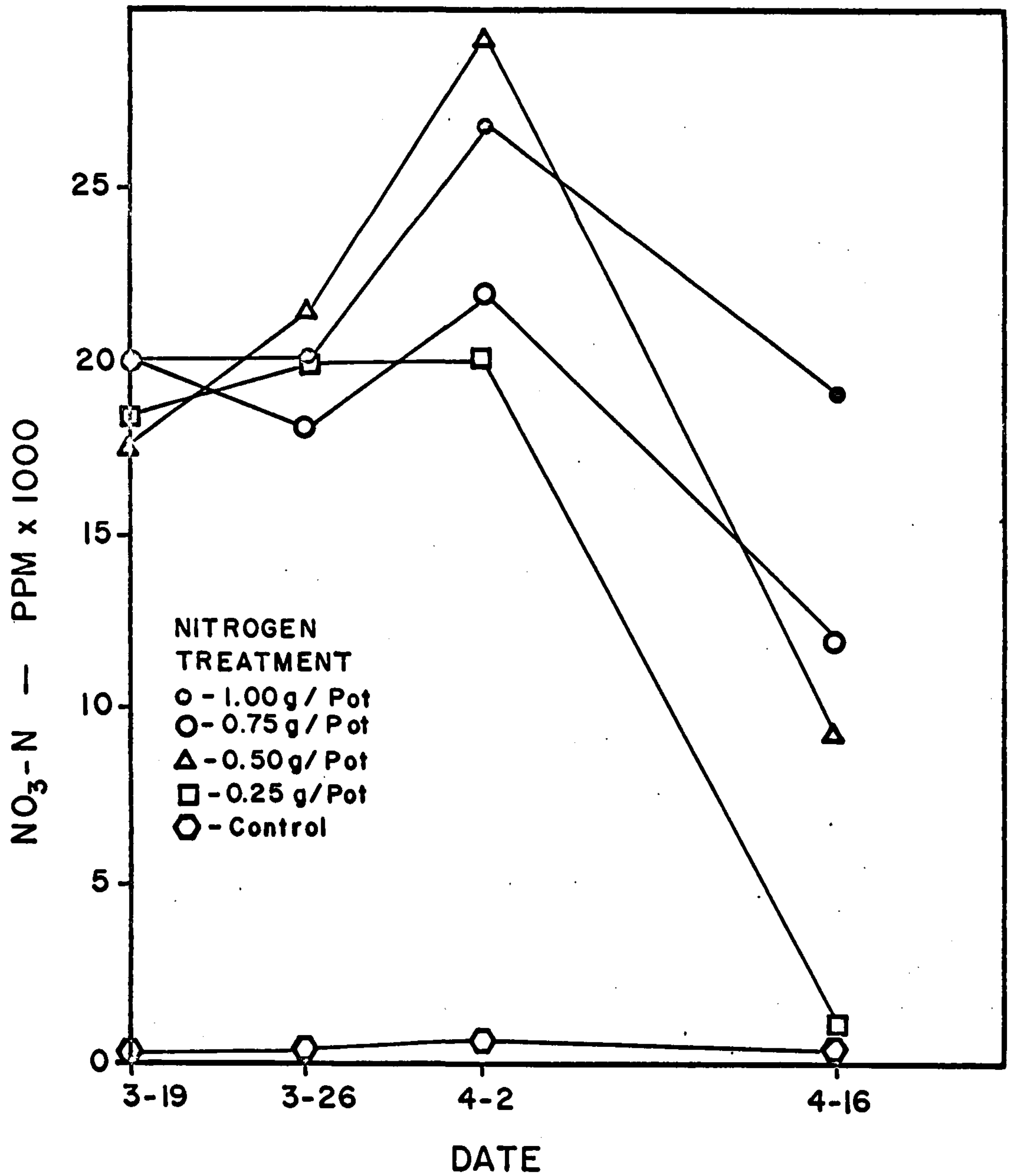

Figure 6. The Effect of Added Nitrogen on the Nitrate-Nitrogen Content of Safflower Stem Tissue

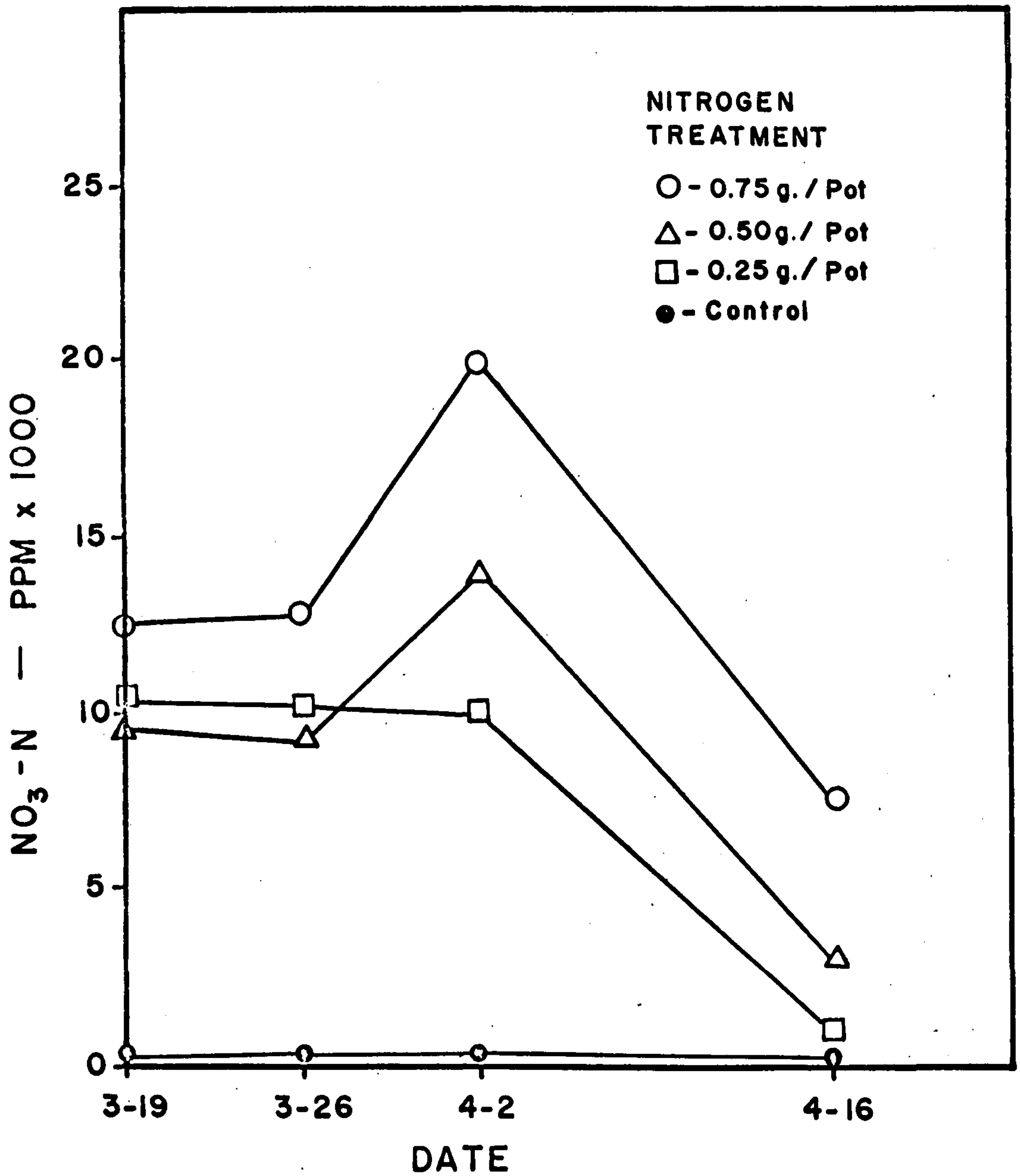

Figure 7. The Effect of Added Nitrogen on the Nitrate-Nitrogen Content of Safflower Leaf Tissue

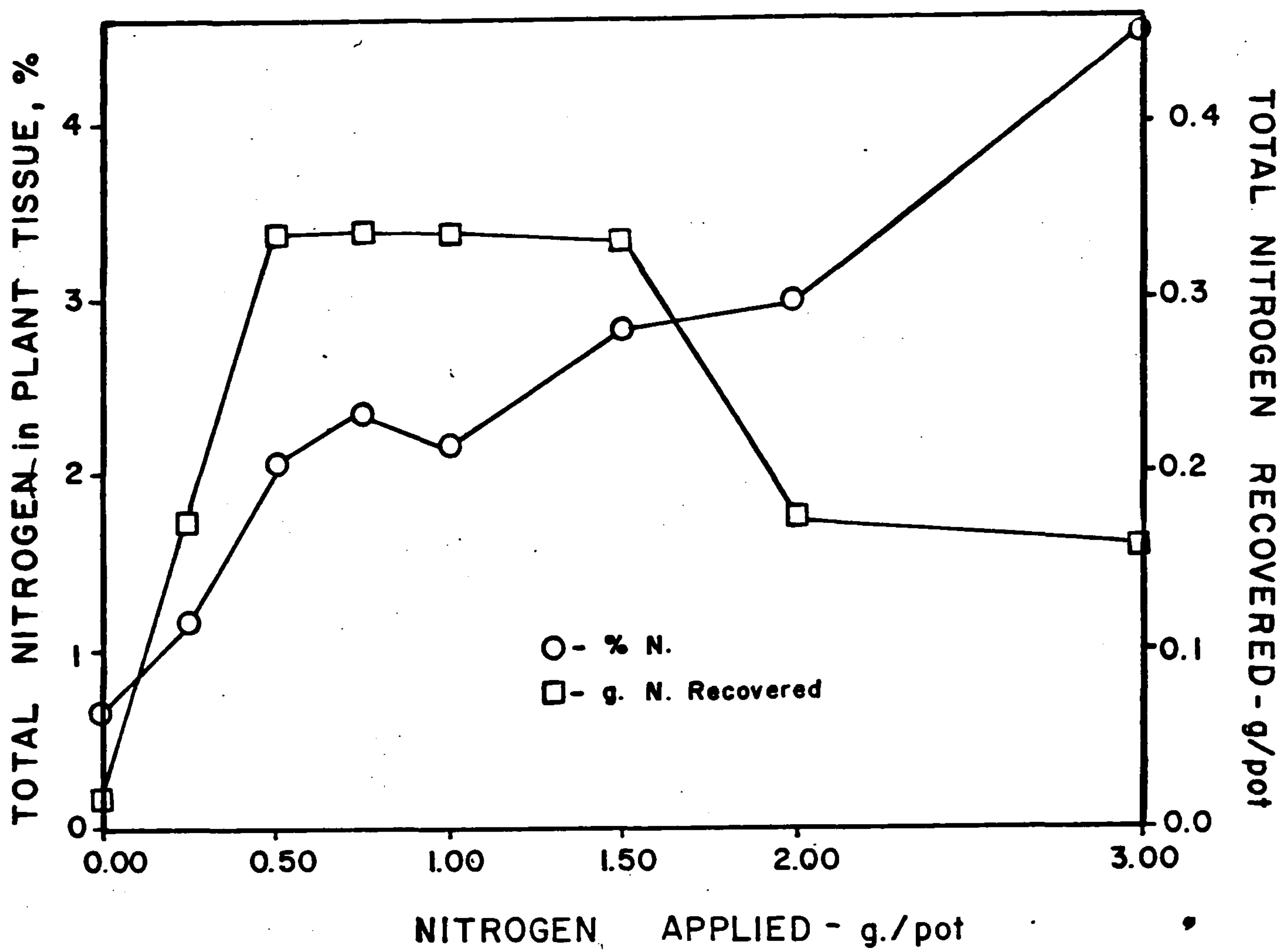

Figure 8. The Effect of Added Nitrogen on Nitrogen Content of Safflower and Nitrogen Recovery

content of plant tissue and total nitrogen recovered. The nitrogen content in the tissue increased with each increasing increment of added nitrogen, from less than 0.7 percent with no nitrogen added, to 4.5 percent with 3.0 grams of nitrogen per pot added. This relationship was nearly linear. Total nitrogen accumulated by the plants increased from 0.02 grams for the check, up to 0.34 grams for the 0.50 gram per pot treatment. It remained constant with higher fertilizer rates up to 1.50 grams per pot. Thus, a threefold increase in applied nitrogen resulted in no change in total nitrogen uptake. Rates higher than 1.50 grams per pot reduced sharply the amount accumulated. The increase in total nitrogen concentration with higher rates of nitrogen application was more than offset at the highest rates by the reduction in growth. These data suggest that under the conditions of this test, when the total nitrogen concentration at maturity exceeded 2.0 percent, growth had been detrimentally affected.

It appears that confining the roots to the relatively small volume of soil in the pot resulted in reduced top growth. However, the plants continued to absorb nitrogen. Thus, concentrations, which were injurious to the plant, resulted, even at application rates that would not be harmful in the field.

SUMMARY

Safflower can be expected to show little response to nitrogen fertilizer in the low desert area of California when grown on land following highly fertilized crops such as cotton or vegetables. An experiment conducted on land following cotton showed no yield increase due to the addition of nitrogen or phosphorus fertilizer. A slight effect on nitrogen content and oil percent was noted. However, it was barely significant and probably does not represent a real difference. Nitrogen fertilizer treatment did not effect the iodine number of oil from safflower grown in this test.

A second experiment was conducted on the University of California's Imperial Valley Field Station. The site of this trial also had a high residual nitrogen level in the soil; an average of more than 16 ppm in the surface three feet of soil. Therefore, little response to added nitrogen fertilizers was noted. The 240 pound of nitrogen per acre was significantly better than all other treatments. Other treatments were not significantly different from one another. Phosphorus fertilizer did not increase yield. The level of

irrigation had a marked effect on safflower yield. The wet treatment, which was irrigated often, gave the highest yield. The medium irrigation was next, and the dry treatment yielded the least. There was no interaction between irrigation and fertilization in this study.

A third experiment was conducted at the University of California's Imperial Valley Field Station on a site which had been cropped to sudan hay to lower the residual nitrogen level of the soil. A highly significant interaction between levels of irrigation and nitrogen was shown. Nitrogen fertilizer did not increase yield with the dry irrigation treatment. Sixty pounds of nitrogen per acre produced significantly more safflower than the control at the medium irrigation level. The 240 pound of nitrogen per acre yielded more than the 60 and 120 pound treatments. With a high rate of irrigation, both 60 and 120 pounds of nitrogen per acre gave a significant yield increase. The 240 pound rate was not significantly higher than the 120 pound rate.

Nitrogen fertilizer increased the yield of safflower by increasing the number of tertiary heads per plant, and by increasing the number of seeds per head in the tertiary heads. The total weight of seed per head in secondary and tertiary heads, and seed weight in the secondary, were increased by nitrogen fertilizer. Thus, yield increases resulted in the secondary and tertiary heads.

Nitrate-nitrogen content of stem tissue was relatively high for the treated plots early in the season; 6,000 ppm for 240 pounds nitrogen rate. Other treatments were correspondingly less. The level declined sharply, and all treatments had 100 ppm nitrate-nitrogen, or less, by first bloom. The plants continued to accumulate nitrogen even after the plant tissue level of nitrate-nitrogen had become very low. Total nitrogen percent of mature safflower varied from 1.00 in the control to 1.30 for the highest nitrogen rate. Nitrogen recovery varied from a high 82 percent for the low rate of nitrogen, to a low of 30 percent for the highest rate.

A fourth experiment was conducted in the greenhouse at the University of Arizona. Safflower grown in pots was adversely affected by high rates of nitrogen. Nitrate-nitrogen in leaf and stem tissue was extremely high for even moderate rates of application. Total nitrogen content greater than 2.0 percent appears to be injurious to safflower grown in pots.

APPENDIX

Table A. Analysis of Variance for Safflower Data, 1962

Source	d.f.	M.S.	F.
		Seed Yield Data	
Replication	3	12.720	
Treatment	4	2.625	1.57 N.S.
Error	12	1.674	
Total	19		
		% N in Seed	
Replication	3	0.09282	
Treatment	4	0.03777	3.91*
Error	12	0.00967	
Total	19		
		% Oil in Seed	
Replication	3	0.2000	
Treatment	4	0.5767	5.67*
Error	12	0.1017	
Total	19		
		Iodine No.	
Replication	3	0.31	
Treatment	4	0.20	1.17 N.S.
Error	12	0.17	
Total	19		

*Significant at the 0.05 level.

Table B. Analysis of Variance for Safflower Yield Data, 1963

Source	d.f.	M.S.	F.
Replications	5	6.80	
Irrigation	2	200.07	15.07**
Error A	10	13.27	
Fertilizer	4	10.48	4.68**
I X F	8	4.07	1.82 N.S.
Error	60	2.24	
Total	89		

Table C. Analysis of Variance for Safflower Yield Data, 1964

Source	d.f.	M.S.	F.
Replications	3	6.60	
Irrigation	2	6.06	1.27**
Error A	6	4.77	
Fertilizer	3	128.32	31.15**
I X F	6	25.58	6.21 N.S.
Error B	27	4.12	
Total	47		

**Significant at the 0.01 level.

Table D. Analysis of Safflower Components of Yield Data

Source	d.f.	M.S.	F.
Heads per Plant			
Replications	3	5.787	
Fertilizer	1	8.882	4.70 N.S.
Error A	3	1.881	
Head Stage	2	74.071	48.80**
F X HS	2	4.425	2.90 N.S.
Error B	12	1.517	
Total	23		
Weight per Head			
Replications	3	0.081	
Fertilizer	1	0.924	4.50**
Error A	3	0.021	
Head Stage	2	2.075	123.00**
F X HS	2	0.068	4.00*
Error B	12	0.017	
Total	23		
Seeds per Head			
Replications	3	67.153	
Fertilizer	1	360.375	15.5*
Error A	3	19.375	
Head Stage	2	427.042	27.5**
F X HS	2	40.875	2.60 N.S.
Error B	12	15.513	
Total	23		

Table D.-Continued.

Source	d.f.	M.S.	F.
	Weight of 100 Seeds		
Replications	3	0.127	
Fertilizer	1	0.250	35 N.S.
Error A	3	0.007	
Head Stage	2	2.941	107.7**
F X HS	2	0.107	3.9*
Error B	12	0.027	
Total	23		

*Significant at the 0.05 level.

**Significant at the 0.01 level.

Literature Cited

1. Abrams, L. and R. S. Ferris. 1960. Illustrated Flora of the Pacific States. Vol. IV. Stanford University Press, Stanford, California.

2. Bremner, J. M. 1965. Methods of Soil Analysis, Part 2. American Society of Agronomy, Madison, Wisc.

3. Chavan, V. M. 1961. Niger and Safflower. Published by Dr. R. Sankaran, London.

4. Claassen, C. E. 1948. Safflower, a potential oil seed crop in the western U. S. Chemurg. Dig. 7:11-14.

5. Claassen, C. E. 1949. Safflower, a potential oil seed crop in the western states. Econ. Bot. 3:143-149.

6. Claassen, C. E., G. W. Ekdahl and G. M. Stevenson. 1950. The estimation of oil percentage in safflower seed and the association of oil percentage with hull and nitrogen percentage, seed size and degree spininess of the plant. Agron. J. 42:478-482.

7. Erie, L. J., O. F. French and K. Harris. 1965. Consumptive use of water by crops in Arizona. Ariz. Expt. Stat. Tech. Bull. 169.

8. Francois, L. E., D. M. Yermanos and L. Bernstein. 1964. Salt tolerance of safflower. Calif. Agri. 18 (9): 12-14.

9. Johnson, C. M. and A. Ulrich. 1959. Analytical Methods for use in plant analysis. Calif. Agri. Expt. Stat. Bull. 766.

10. Kellenbarger, S., R. L. Albrock and A. H. Harrington. 1951. Safflower, agronomic, processing and economic data. Wash. Expt. Stat. Bull. 521.

11. Knowles, P. F. and L. I. Davis. 1951. Safflower, an oil crop. Univ. of Calif. Agri. Ext. Serv.

12. Knowles, P. F. 1955. Safflower production, processing and utilization. Econ. Bot. 9:273-299.

13. Knowles, P. F., M. D. Miller and W. H. Isom. 1963. Safflower, an established crop in California. Calif. Agri. Expt. Stat. Leaflet. 162.

14. Knowles, P. F. and M. D. Miller. 1965. Safflower. Univ. of Calif. Agri. Ext. Serv. Circ. 532.

15. Luebs, R. E., D. M. Yermanos, A. E. Laag and W. D. Burge. 1965. Effect of planting date on seed yield, oil content and water requirements of safflower. Agron. J. 57:162-164.

16. Rabak, F. 1935. Safflower, a possible new oil seed crop for the northern Great Plains and the far western U. S. U. S. Dept. Agri. Circ. 366.

17. Rubis, D. D., and D. S. Black. 1958. Gila, a new safflower variety. Ariz. Agri. Expt. Stat. Bull. 301.

18. Tackholm, V. and M. Drar. 1954. Flora of Egypt. Vol. VII. Cairo Univ. Press.

19. Wiedemann, A. M. and L. N. Leininger. 1963. Optimum plot size and shape for safflower yield trials. Agron. J. 55:222-225.

20. Yermanos, D. M., L. E. Francois and L. Bernstein. 1963. Soil salinity effects on the chemical composition of oil and oil content of safflower seed. Agron. J. 56: 35-37.

21. Yermanos, D. M., B. J. Hall and W. Berge. 1964. Effect of iron chelates and nitrogen on safflower and flax seed production and oil content and quality. Agron. J. 56: 582-585.