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Response of rainfed safflower to nitrogen fertilization under Mediterranean conditions

Sui-Kwong Yau [a,*], John Ryan [b]

[a] Faculty of Agricultural and Food Sciences, American University of Beirut, Bliss Street, P.O. Box 11-236, Beirut, Lebanon
[b] International Center for Agricultural Research in the Dry Areas (ICARDA), P.O. Box 5466, Aleppo, Syria

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ABSTRACT

The deep root system of safflower (*Carthamus tinctorius* L.) may be able to take up moisture and nutrients, especially nitrogen (N) that has been leached below the rooting zone of most other crops. The objective of the present study was to test the hypothesis that safflower would not respond to N fertilizer when grown after crops fertilized at economic levels. Field experiments were conducted for 5 years under Mediterranean rainfed conditions at a site with moderate soil mineral N levels in Lebanon's Bekaa Valley (513 mm long-term, annual precipitation). In the first series of experiments, there were four N application rates: 0, 40, 80 and 120 kg ha^{-1}, with three or six replicates. Seed and straw yield, leaf chlorophyll, shoot and seed N content and other agronomic characters were measured. In the second experiment, there were two N application rates: 0 and 40 kg ha^{-1}. No significant response to N application was detected, except for N concentration in the lower part of the shoot at maturity in 2001–2002; in that season, a total of 125 kg ha^{-1} N was removed by the crop from the control which had no added N, suggesting that safflower is an efficient user of carryover N from prior cropping. Growing safflower after a fertilized crop may remove N from the lower part of the soil profile and thus reduce the possibility of this accumulated N eventually reaching the ground water. Cropping with safflower in rotation with other crops may have environmental benefits as well as saving on the costs of N fertilizers. The study supports the wider adoption of safflower in Mediterranean dryland cropping systems.

1. Introduction

Safflower is an underutilized multi-purpose crop belonging to the family *Compositae* or *Asteraceae* (Li and Mundel, 1996). Historically, it was used to extract dyes for use to color cloth and in the carpet-weaving industry. Its oil was also used in the paint industry. Currently, it is mainly used to extract edible oil, which is high in either linoleic or oleic fatty acids. Other common uses of safflower include medicinal and herbal tea, cosmetics, spice, vegetable, forage, cut flowers, and bird seed. After oil extraction, the safflower meal is used for ruminant feed, and can be used for poultry feed if safflower seed is de-hulled before pressing (Farran et al., 2009). Although safflower is used mainly for edible oil production, it has a high potential for industrial use in the near future. As biodiesel fuel is gaining more and more importance due to the depletion of fossil fuel resources, research on using safflower oil and its derivatives as an alternative for diesel fuel has been initiated. Safflower oil, which contains 75–80% of linoleic acid, has good properties in low-temperature environments (Meka et al., 2007).

Safflower originated from the eastern Mediterranean region (Knowles, 1976) and can be a suitable rainfed oil-seed crop in semi-arid countries in West Asia and North Africa, including Lebanon. In the Bekaa Valley of Lebanon, safflower was shown to produce as much grain as barley, the highest yielding crop in the area (Yau, 2004). Coupled with the relatively higher price of safflower seed in the world market, growing safflower is expected to give much higher economic returns than barley (Yau, 2004).

Nitrogen fertilization is a key component in any viable economic crop production enterprise (Scheppers and Raun, 2008), and one that globally has increasing implications for the environment (Ladha et al., 2005), thus making N-use efficiency a fundamental concern (Fageria and Baligar, 2005). In areas of the world with intensive fertilizer use, excessive use of nitrogen (N) has led to pollution of our ground water with nitrate, the most mobile form of N in any ecosystem. Though the era of commercial fertilization is relatively recent in the Middle East, many field studies from the region sought to establish appropriate fertilizer N recommendations for economic crop yields (Ryan et al., 2009). Since safflower is an under-researched crop, the relationship between safflower and N is poorly understood, with even contrasting reports on the optimal rate of N fertilization (Knowles and Miller, 1960). Application rates of 20–50 kg N ha^{-1} in semi-arid rainfed agriculture

* Corresponding author. Tel.: +961 1 350000x4501; fax: +961 1 744460.
E-mail address: sy00@aub.edu.lb (S.-K. Yau).

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and 50–80 kg N ha^{-1} for irrigated systems were recommended in California (Knowles and Miller, 1960). For dryland conditions in southern Italy, an application rate of 75 kg N ha^{-1} was identified as being optimum (Cazzato et al., 1997). However, much higher rates had been recommended by other studies, especially under irrigated conditions (Cazzato et al., 1997; Dordas and Sioulas, 2008).

The perception on N fertilization of safflower may need to be changed since more is known about safflower in non-irrigated semi-arid areas. Safflower is generally known to have deeper roots than wheat or other small grains; thus it may potentially use nutrients and moisture in the deeper soil layers that are unavailable to the cereals (Weiss, 1983). Research in the USA has shown that safflower can effectively use carryover N from prior cropping to depths of 2 m (Tanaka and Merrill, 1998; Bassil et al., 2002; Eckhoff et al., 2008). A study on use of residual N by safflower after cotton (*Gossypium hirsutum*) recommended that N fertilizer applied to safflower could be reduced or even eliminated following crops previously fertilized at economic levels (Bassil et al., 2002). Accordingly, no N fertilizer is now applied to the safflower trials in experimental stations in Montana and North Dakota since safflower did not show any response to N fertilization (J.W. Bergman, personal communication).

As little research on N fertilization of safflower has been conducted in the Mediterranean region, the objective of the study was to test the hypothesis that safflower would not respond to N fertilizer when grown after crops previously fertilized with N at economic application rates.

2. Materials and methods

2.1. Location and climatic conditions

The experiments were conducted under rainfed field conditions at the Agricultural Research and Educational Centre (AREC) of the American University of Beirut. The Centre (33°56′N, 36°05′E) is located at 995 m above sea level in the semi-arid northern Bekaa Valley. The soil is an alkaline (pH 8.0), clayey, Vertic Xerochrept formed from fine-textured alluvium derived from limestone (Ryan et al., 1980).

The area has a Mediterranean-type of climate. The average long-term annual precipitation is 513 mm, 58% of which falls in December, January and February. The long-term mean annual temperature is 13.9 °C. The climatic conditions of the trial are depicted in Fig. 1, indicating mean monthly rainfall and temperatures for the individual years. There were large differences in temperature between the five production years. In 1998–1999, the winter was warmer than usual with only five below-freezing nights, but autumn was mildest in 2005–2006. In contrast, there were 51 below-freezing nights in 1999–2000. In 2000–2001, May was cooler than average. Rainfall of each of the five production years was below average (383, 366, 424, 441, and 480 mm in 1998–1999, 1999–2000, 2000–2001, 2001–2002 and 2005–2006, respectively). In 2001–2002, 172 mm of rain, which was above-average for the period, was received in March and April.

2.2. Experiment on seasonal response to nitrogen fertilization

Two sets of experiments, one on seasonal N response and one on tillage-by-N interaction, were conducted. The first research experiment on seasonal N response was carried out in conventionally tilled fields over four cropping seasons (1998–1999, 1999–2000, 2000–2001 and 2001–2002) with four N application rates, i.e., 0, 40, 80 and 120 kg ha^{-1} (only 0, 40, and 80 kg ha^{-1} in 2001–2002 to allow more replications to increase accuracy of measurement). After sowing in November (on 7th in 1998, 17th in 1999, 9th in

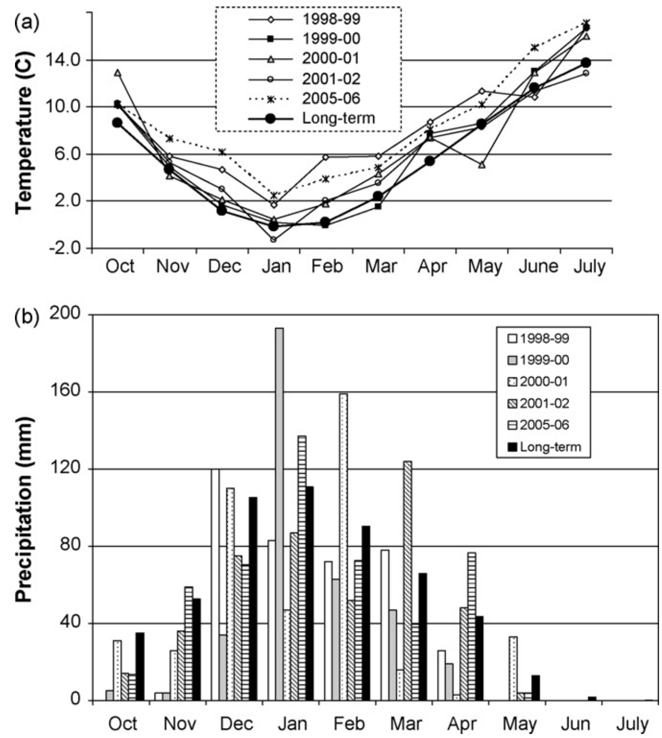

Fig. 1. (a) Average monthly minimum temperatures and (b) monthly precipitation for the five seasons in comparison to the long-term average of 50 years (1957–2006) at the Agricultural Research and Educational Centre in Central Bekaa, Lebanon.

2000, 15th in 2001, and 23rd in 2005), 40 kg N ha^{-1}as ammonium sulfate was broadcast by hand, except on the unfertilized control. The remaining N (for the 80 and 120 kg N ha^{-1}) was broadcast as ammonium nitrate in early spring. A randomized complete block design with three replicates (six replicates in 2001/2002) was used; the plot size was 5.4, 7.2, 14.4 and 7.2 m^2 in 1998–1999, 1999–2000, 2000–2001 and 2001–2002, respectively. A high yielding safflower accession, PI301055, was sown at a seeding rate of 30 kg ha^{-1} using a small-plot seed drill with 30 cm spacing between rows; no significant yield difference exist among seed rates of 6, 12, 24, and 48 kg ha^{-1} in rainfed trials at the same site (Yau, 2009).

The experiments were conducted after fertilized (105 kg N ha^{-1}) crops, i.e., barley (*Hordeum vulgare*), oat (*Avena sativa*), or summer corn (*Zea mays*)), in different fields to avoid growing safflower after safflower. The mean soil nitrate concentration was 19.1 mg kg^{-1} (0–20 cm) in 2000–2001, and 20.3 mg kg^{-1} (0–15 cm) and 19.6 mg kg^{-1} (15–30 cm) in 2001–02. Soil mineral N (NH_4 plus NO_3) concentration was 21.8 mg kg^{-1} in 2000–2001, and 36.7 mg kg^{-1} (0–15 cm) and 38.7 mg kg^{-1} (15–30 cm) in 2001–2002. These concentrations were equivalent to 49.7 kg ha^{-1} nitrate (NO_3) and 56.7 kg ha^{-1} mineral N in the top 20 cm in 2000–2001 and 78 kg ha^{-1} nitrate and 147 kg ha^{-1} mineral N in the top 30 cm in 2001–2002. Soil NO_3 and mineral N were not measured in the first 2 years (1998–1999 and 1999–2000), but were expected to be within the same range as in 2000–2001 and 2001–2002. Since the soil had Olsen-P > 20 g kg^{-1}, no phosphate fertilizer was applied. Similarly, no other fertilizer was applied as levels of potassium, magnesium, calcium, and micronutrients were adequate. Weeds were controlled by hand weeding in spring. *"Boss-tox"* (a.i., mevinphos) at a rate of 500 g ha^{-1} was sprayed to control aphids in June.

Safflower plant stand, dry weight N concentration at stem elongation, bud initiation, and flowering, leaf area index, leaf chlorophyll, days to flowering, and seed and straw yield were recorded. The number of emerged seedlings was counted in two random 1-m rows in each treatment of each replicate. For dry weight measurement at stem elongation, bud initiation, and flowering, plants from one random row 1, 1, 3, and 2 m in length were hand-harvested by cutting at ground level in 1998–1999, 1999–2000, 2000–2001, and 2001–2002, respectively. Harvested plant material was dried for 48 h at 90 °C before weight was recorded. Flowering date was considered when about 50% of the plants had opened flowers. Shoot-area index was measured before bud initiation in 1999–2000 and 2000–2001, but before flowering in 2001–2002, by a LAI-2000 (LI-COR Inc., Lincoln, NE, USA) plant canopy analyzer following the procedure on the manual for the instrument by LI-COR. Readings were taken before sunset using a 45° restriction cover on the fisheye lens above ground surface at four random spots in each plot. Leaf chlorophyll was measured with a Minolta SPAD 502 chlorophyll meter around flowering time on 10 random leaf samples (one each from the top half of 10 random plants).

Date of maturity was recorded in the last 3 years: July 18–27 in 2000, July 17–23 in 2001, and July 29 to August 1 in 2002. A week to 10 days after maturity, plants from the middle section of the plots (1.2, 1.8, 5.4 and 2.7 m^2 in 1998–1999, 1999–2000, 2000–2001 and 2001–2002, respectively) were cut at ground level by hand, put into cloth bags, and left in the field for further drying before being collected for weighing. A small-plot thresher was used for threshing. Straw yield was calculated by subtracting seed yield from dry matter yield. Harvest index was calculated as a percentage of seed over dry matter yield. In 2001–2002, plant N concentration measurement was carried out on the harvested plants at stem elongation, bud initiation, and maturity. The harvested plants at maturity were divided into three portions: head, upper half, and lower half. Both leaves and stems were ground together and a sub-sample around 1.5 g of the ground material was analyzed using the Kjeldahl method. The General Analysis of Variance option under the ANOVA directive of the GENSTAT package (Version 6.1) was used to handle the unequal replication across years.

2.3. *Experiment on tillage-by-nitrogen*

The second research experiment was conducted in 2005–2006 on a field having low mineral N content (5.1 mg kg^{-1} or 31.2 kg ha^{-1} in the 0–40 cm soil layer) after a previous conventionally tilled and fertilized crop of oats was harvested. In this trial, there were two factors with four replications. The first factor was tillage with three treatments: *conventional*, *minimum*, and *no-tillage*. Conventional tillage consisted of one ploughing in early October with a mouldboard plough, followed by one tandem disc-cultivation in late October. With minimum tillage, there was one tandem disc-cultivation in late October. The no-tillage plots were left uncultivated.

The second factor was N, which was applied by broadcasting 0 or 40 kg N ha^{-1} as ammonium sulphate on December 16. The experiment was laid out in a split-plot design with sub-plots of N randomly assigned within the main plots of tillage. Plot size was 14 m × 6 m for main plots and 14 m × 3 m for sub-plots.

A new safflower accession, PI603207 (bred at Lethbridge, Alberta, Canada by Dr. H. Muedal), which was the highest yielding entry in yield trials conducted at the Centre in the Bekaa for several years, was used in this experiment. Seeds were sown with an experimental no-till drill in mid-November at a seeding rate of 30 kg ha^{-1}. Glyphosate "N-(phosphonomethyl)glycine" (Roundup) was sprayed on all plots a few days after sowing to kill the volunteer oats and weeds that had germinated. An aphidcide *"Boss-tox"* (a.i. mevinphos) at a rate of 500 g ha^{-1} was sprayed in May/June to control aphids.

Safflower variables that were measured included: dates of flowering, plant height at maturity, shoot dry weight at flowering and at maturity, and seed yield. For dry weight measurement, plants from three 0.25 m^2 random quadrates were cut at ground level, dried at 80 °C for 24 h, and the dry weight measured. A small-plot thresher was used for threshing. Straw yield and harvest index were calculated as indicated earlier. Data were analyzed using the split-plot option under the ANOVA directive of the GENSTAT package (Version 6.1).

3. Results

3.1. *Seasonal nitrogen responses*

There was no significant N rate-by-year interaction in all the measured variables. Nitrogen application had no significant effect on seedlings m^{-2}, plant height, seed and straw yields, or harvest index (Table 1). Relative to the 40 kg N ha^{-1} rate, flowering was delayed by 1 day compared to the control. There were significant differences in the plant traits among the 4 years. In 1999–2000, seedlings m^{-2} was lower, as many seedlings were killed by frost, and harvest index was higher than the other years. Seed yield in 1999–2000 was higher than 1998–1999 and 2000–2001. The higher rainfall in March and April of 2001–2002 could have caused plants to flower later, grow much taller, and produce much more straw yield than the other years.

Table 1
Safflower mean seedling number, days to flowering, plant height, seed and straw yield, and harvest index for different N rates (means over 4 years) and years.

N rate (kg ha^{-1})	Seedlings (m^{-2})	Days to flowering from May 31	Plant height (cm)	Seed yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Harvest index (%)
0	69	8.4	104	1890	6440	22
40	63	7.3	105	1630	6290	20
80	69	7.9	108	1860	6700	22
120	66	7.9	104	1770	6200	23
L.S.D.	ns		ns	ns	ns	ns
(5%)				428	1355	3.2
	7.9	1.02	6.5	(383)	(1212)	(2.8)
	(7.3)[a]	(0.91)	(5.8)			
Year						
1998–1999	73	0.8	97	1390	5610	19
1999–2000	30	10.2	91	2440	5460	31
2000–2001	76	1.3	93	1450	5030	22
2001–2002	86	15.4	130	1840	8560	17
L.S.D.	8.3	2.79	11.7	893	1927	5.1
(5%)	(7.6)[a]	(2.55)	(10.7)	(816)	(1759)	(4.6)

[a] Value within parenthesis is for comparison between treatments with unequal numbers of replicates.

Table 2
Dry matter weight at different stages, leaf area index, and leaf chlorophyll reading on 10 random samples under the different N rates (means over 3 years) and years.

N rate ($kg\,ha^{-1}$)	Dry matter weight ($kg\,ha^{-1}$)				Leaf area index	Leaf chlorophyll reading
	Safflower plant development stage					
	Stem elongation	Bud initiation	Flowering	Maturity		
0	2650	4910	7810	9090	20.7	65
40	2750	4560	8310	8570	19.4	66
80	2630	5290	8500	8910	19.4	67
L.S.D. (5%)	ns	ns	ns	ns	ns	ns
	951	1391	1251	1555	4.02	3.7
Year						
1999–2000	2220	5050	10040	8010	12.6	65
2000–2001	3630	4600	7370	6610	18.9	71
2001–2002	2430	5010	7710	10400	24.0	64
L.S.D.	ns	ns	ns			
(5%)	1996 (1729)[a]	2369	3316	2716	10.17	5.2
		(2051)	(2872)	(2352)	(8.81)	(4.5)

[a] Value within parenthesis is for comparison between treatments with unequal numbers of replicates.

Table 3
Safflower N concentration by growth stages for three N fertilizer rates in 2001–2002.

N rate ($kg\,ha^{-1}$)	N concentration ($mg\,g^{-1}$)				
	Safflower plant development stage				
	Stem elongation	Bud initiation	Maturity		
			Seed	Upper shoot	Lower shoot
0	31.4	23.2	22.4	14.5	2.6
40	32.1	21.7	23.3	14.7	3.4
80	33.7	23.6	23.2	14.5	3.9
L.S.D.	ns	ns	ns	ns	
(5%)	3.49	2.62	1.81	1.82	0.50

Similarly, N application rates did not affect plant growth at different stages from stem elongation up to maturity, leaf area index, and leaf chlorophyll reading (Table 2). There were significant differences among years with respect to dry weight at maturity, leaf area index, and leaf chlorophyll, but not in dry weight at stem elongation, at bud initiation and at flowering among the 3 years (1999–2000, 2000–2001, and 2001–2002).

At maturity in 2001–2002, the lower half of the shoots under the zero N treatment had a lower N tissue concentration than the 40 $kg\,N\,ha^{-1}$ rate, which, in turn, was lower than the 80 $kg\,N\,ha^{-1}$ rate (Table 3). The N concentrations of the upper half of the shoot and seed at maturity, at stem elongation, and at bud initiation were similar under the three N application rates. Nitrogen application did not have an effect on N yield in 2001–2002 (Table 4). An N uptake of 125 $kg\,ha^{-1}$ was obtained from the control at maturity.

3.2. Tillage-by-N experiment

There was no significant tillage × N interaction in grain and straw yield, harvest index, days to flowering and plant height at maturity, but the interaction was significant for dry weight at flowering. With application of 40 $kg\,N\,ha^{-1}$, dry weight at flowering was higher under no-tillage than both conventional and minimum tillage, but there was no significant difference among tillage practices when no N was applied (Fig. 2). Under no-tillage and minimum tillage, dry weight at flowering increased with N fertilization, but there was no response under conventional tillage.

Across tillage practices, N application had no significant effect on grain and straw yields (Table 5). However, application of N reduced the harvest index, led to earlier flowering, and increased dry weight at flowering and plant height at maturity.

Table 4
Safflower N uptake by growth stages for three N fertilizer rates in 2001–2002.

N rate ($kg\,ha^{-1}$)	N uptake ($kg\,ha^{-1}$)				
	Safflower plant development stage				
	Stem elongation	Bud initiation	Maturity		
			Whole plant	Seed	Straw
0	79	114	125	43	83
40	63	107	116	42	74
80	88	137	125	42	83
L.S.D.	ns	ns	ns	ns	ns
(5%)	53.4	66.1	38.2	17.9	28.3

Table 5
Safflower seed yield and five other agronomic characters under the two N fertilizer rates in 2005–2006.

N rate ($kg ha^{-1}$)	Grain yield ($kg ha^{-1}$)	Straw yield ($kg ha^{-1}$)	Harvest index (%)	Days to flowering (from April 1)	Dry wt. at flowering ($kg ha^{-1}$)	Plant ht. at maturity (cm)
0	3070	9650	24	67	7780	83
40	2820	10970	20	65	11600	91
Mean	2950	10310	22	66	9690	87
L.S.D. (5%)	ns 587	ns 1469	2.6	1.1	1251	5.0

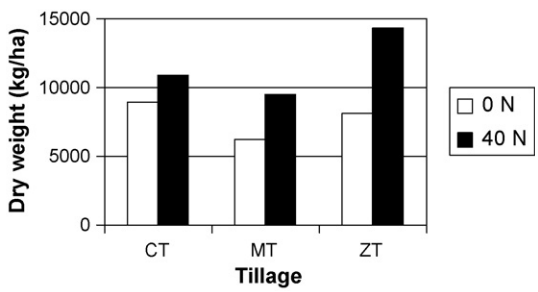

Fig. 2. Dry matter weight at flowering under the three tillage practices (CT, MT, and NT stands for conventional, minimum, and no-tillage, respectively) and the two N fertilization rates (L.S.D. 5% = 2529; 2166 in same tillage).

4. Discussion

In our study, the lack of response to N fertilization was not likely to have resulted from too much residual N in the 0–30 cm soil depth since the soil NO_3 level was only 20 mg kg^{-1} at the 0–30 cm depth in our first experiment. A study in California, which also has Mediterranean-type climate, clearly showed that safflower seed yield reached the maximum when soil residual NO_3 reached 40 mg kg^{-1} (Bassil et al., 2002). In another study under rainfed conditions in Mediterranean conditions, N fertilization of 100 and 200 kg ha^{-1} increased seed yield of safflower even though the soil NO_3 levels were 27–29 mg kg^{-1} (Dordas and Sioulas, 2008). More importantly, it is difficult to argue that the soil mineral N level of 5.1 mg kg^{-1} at the 0–40 cm depth in the second experiment was high.

The most plausible explanation for the absence of a seed yield response to N application is that safflower has deep roots that can take up nutrients and water that leached down and accumulated deeper in the soil profile. Nutrients are unavailable to the cereals and other crops that are shallow-rooted. This was illustrated by the fact that as much as 125 kg N ha^{-1} was taken up by the crop from the unfertilized control at maturity. This finding was not surprising as safflower was shown to use residual N at 2 m depth (Tanaka and Merrill, 1998). After studying the effects of residual N on safflower yields, Bassil et al. (2002) had concluded that N application to safflower could be reduced or eliminated if previous crops were fertilized at normal application rates.

Another reason for the non-response to N application was probably the poor rainfall distribution leading to terminal drought, especially in 2000–2001, 1999–2000, and 1998–1999. However, even when the quantity and distribution of rainfall are good, as in 2005–2006, N application may not lead to seed yield response in Mediterranean areas if N fertilization leads to greater crop vegetative growth, which, in turn, contributes to earlier depletion of soil moisture and consequently reduced harvest index. One of the reasons why farmers in drier areas of West Asia and North Africa allow green-stage grazing by sheep on barley is to avoid earlier depletion of soil moisture leading to lower grain yield (Yau, 2003).

The absence of a seed yield response to N is in contrast to that obtained by Dordas and Sioulas (2008), although both studies were conducted under rainfed conditions in Mediterranean conditions. In their study (Dordas and Sioulas, 2008), N fertilizer rates of 100 and 200 kg ha^{-1} increased seed yield of safflower even though their soil NO_3 levels were higher than those of our soils. A review of the rainfall distribution at Thessaloniki, Greece, where their study was carried out, shows that rainfall distribution contrasts sharply with that of our site in the Bekaa Valley of Lebanon. Thessaloniki receives rainfall every month, but the Bekaa usually receives no rainfall from May to September. We contend that this difference in rainfall distribution contributed to the difference in results between the two studies. The rainfall in the summer at Thessaloniki is equivalent to applying irrigation to safflower under our conditions to make it respond to N fertilizer. An earlier study on irrigated safflower at the same site in the Bekaa showed that safflower responded to 70 kg N ha^{-1} (Nasr et al., 1978).

The absence of tillage × N interaction on grain yield suggests that N fertilizer recommendation for safflower obtained under conventional tillage is applicable in no-till as well. No-tillage or other conservation tillage is increasingly being accepted by farmers throughout in the world (Derpsch and Friedrich, 2009). This immense change in tillage practices has major implications for nutrient management and suggests the need to evaluate earlier fertilizer recommendation (Kassam and Friedrich, 2009). For cereals, there are reports that in the first few years of using no-tillage, farmers tended to use higher N rates, with some research findings to support this practice (Angas et al., 2006).

There has been no research on the interaction of tillage systems with N with respect to safflower. This is the first study to indicate that safflower did not response to N application even in the first year of practicing no-tillage, thus providing evidence that safflower does not response to N after fertilized crops. It appears that safflower can serve as a “scavenger” of subsoil N. This accumulated N in the lower profile could be due to leaching of excess N in previously irrigated crops or in dryland cropping where unusually high rainfall is able to leach N below the rooting zone.

Thus, having safflower in the prevailing cropping systems can be economical in terms of savings on N fertilizer costs by recovering previously applied N in addition to the normal benefits as a break crop in cereal rotations (Yau, 2005). Furthermore, planting safflower after a heavily fertilized crop is likely to reduce NO_3 leaching to the groundwater, and thus be environment-friendly.

5. Conclusions

This multi-year study from a Mediterranean environment clearly showed that safflower did not respond to N application even in the first year after no-tillage. A plausible reason for the lack of response to N application is that the crop, by virtue of its deep-rooted system, was able to take up N that had accumulated below the normal rooting zone of other crops. It is expected that having this crop in prevailing cropping systems can be economical in terms of saving on N fertilizer costs and will likely be environment-friendly by reducing NO_3 leaching to the groundwater.

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References

Angas, P., Lampurlanes, L., Cantero-Martinez, C., 2006. Tillage and N fertilization effects on N dynamics and barley yield under semiarid Mediterranean conditions. Soil Tillage Res. 87, 59–71.

Bassil, E.S., Kaffka, S.R., Hutmacher, R.A., 2002. Response of safflower (*Carthamus tinctorius* L.) to residual soil N following cotton (*Gossypium* spp.) in rotation in the San Joaquin Valley of California. J. Agric. Sci. (Camb.) 138, 395–402.

Cazzato, E., Ventricelli, P., Corleto, A., 1997. Response of hybrid and open-pollinated safflower to increasing doses of nitrogen fertilizer. In: Proceedings of the IVth International Safflower Conference, Bari, Italy, 2–7 June 1997, pp. 98–102.

Derpsch, R., Friedrich, T., 2009. Global overview of conservation agriculture adoption. In: Innovations for Improving Efficiency, Equity and the Environment: Proceedings of the 4th World Congress on Conservation Agriculture, New Delhi, India, 4–7 February 2009, pp. 429–438.

Dordas, C.A., Sioulas, C., 2008. Safflower yield, chlorophyll content, photosynthesis, and water use efficiency response to nitrogen fertilization under rainfed conditions. Ind. Crops Prod. 27, 75–85.

Eckhoff, J.L.A., Bergman, J.W., Flynn, C.R., 2008. Nitrates in soil and ground water under irrigated safflower, sugarbeet and small grain. In: Proceedings of the 7th International Safflower Conference, Wagga Wagga, Australia, November 3–7, 2008.

Fageria, N.K., Baligar, V.C., 2005. Enhancing nitrogen use efficiency in crop plants. Adv. Agron. 88, 97–185, 1.

Farran, M.T., Barbour, G.W., Usayran, N.N., Yau, S.K., Salem, R., Jabbour, C., 2009. Performance of male broiler chicks fed practical diets containing graded levels of de-hulled extruded safflower meal during the starter period. In: Proceedings of the Second Mediterranean Summit of WPSA, Antalya, Turkey, October 2009, pp. 507–509.

Kassam, A., Friedrich, T., 2009. Perspectives on nutrient management in conservation agriculture. In: Innovations for Improving Efficiency, Equity and the Environment: Proceedings of the 4th World Congress on Conservation Agriculture, New Delhi, India, 4–7 February 2009, pp. 85–92.

Knowles, P.F., 1976. Safflower. In: Simmonds, N.W. (Ed.), Evolution of Crop Plants. Longmans, London, pp. 31–33.

Knowles, P.F., Miller, M.D., 1960. Safflower in California. In: California Agricultural Experiment Station and Extension Service, Manual 27. University of California, Davis.

Ladha, J.K., Pathak, H., Krupnik, T.J., Six, J., Van Kessel, C., 2005. Efficiency of fertilizer nitrogen: retrospects and prospects. Adv. Agron. 87, 85–156.

Li, D.J., Mundel, H.H., 1996. Safflower (*Carthamus tinctortius* L.). International Plant Genetic Resources Institute, Rome, Italy.

Meka, P.V., Tripathi, V., Singh, R.P., 2007. Synthesis of biodiesel fuel from safflower oil using various reaction parameters. J. Oleo Sci. 56, 9–12.

Nasr, H.G., Katkhuda, N., Tannir, L., 1978. Effects of N fertilization and population rate-spacing on safflower yield and other characteristics. Agron. J. 70, 683–684.

Ryan, J., Musharrafieh, G., Barsumian, A., 1980. Soil Fertility Characterization at the Agricultural Research and Educational Center of the American University of Beirut. Publication No. 64. American University of Beirut, Beirut.

Ryan, J., Ibrikci, H., Sommer, R., McNeill, A., 2009. Nitrogen in rainfed cropping systems of the Mediterranean region. Adv. Agron. 104, 53–136.

Scheppers, J.S., Raun, W.R., 2008. Nitrogen in Agricultural Systems. Agronomy Monograph no. 9. ASA/CSSA/SSSA, Madison.

Tanaka, D.L., Merrill, S.D., 1998. Deep-rooted safflower cuts fertilizer losses. http://www.ars.usda.gov/is/AR/archive/apr98/saff0498.htm.

Weiss, E.A., 1983. Oil Seed Crops. Longmans, London, UK.

Yau, S.K., 2003. Yields of early-planted barley after clipping or grazing in a semi-arid area. Agron. J. 95, 821–827.

Yau, S.K., 2004. Yield, agronomic performance, and economics of safflower in comparison with other rainfed crops in a semi-arid, high-elevation Mediterranean environment. Exp. Agric. 40, 453–462.

Yau, S.K., 2005. Yield increase of barley following safflower in a cool, semi-arid Mediterranean area. In: Proceedings of the 6th International Safflower Conference, Istanbul, Turkey, 6–10 June 2005, pp. 92–97.

Yau, S.K., 2009. Seed rate effects on rainfed and irrigated safflower yield in Eastern Mediterranean. Open Agric. J. 3, 32–36.