J. Agr. Sci. Tech. (2018) Vol. 20: 1455-1466

Impact of Split Application of Different N-Fertilizer Sources on Weed Growth, Safflower Yield, and Nitrogen Use Efficiency

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ABSTRACT

A 2-year field experiment was conducted to evaluate the effect of N sources [Ammonium Nitrate (AN), Ammonium Sulfate (AS), Sulfur Coated Urea (SCU), and Urea (U)] and split application (($^1/_4,^3/_4$,0), ($^1/_3,^1/_3,^1/_3$), ($^1/_2,^1/_2$,0), and ($^1/_3,^2/_3$,0)) on weed growth, safflower (*Carthamus tinctorius* L.) yield, and N Use Efficiency (NUE), using a split split-plot design with three replications, at the Experimental Research Station of Shiraz University, in 2015 and 2016. In weedy plots, applying AN-fertilizer in a split pattern of $^1/_2,^1/_2$,0 (applying half of the N at sowing time and the rest at stem elongation) increased weed infestation. This treatment enhanced total weed N Uptake Efficiency (NUpE) up to 5% compared to U-fertilizer and similar split pattern. In weed free plots, the highest seed and oil yields (3303.52 and 753.09 kg ha^{-1}, respectively) were achieved by AN- and U-fertilizers in a split pattern of $^1/_2,^1/_2$,0. Applying AN fertilizer and split patterns of $^1/_3,^2/_3$,0 (one third of N at sowing and two thirds at stem elongation) and $^1/_4,^3/_4$,0 (one quarter of N at sowing and three quarters at stem elongation) maximized safflower *NUpE* (0.78 kg kg^{-1}). Applying U fertilizer and split pattern of $^1/_2,^1/_2$,0 increased safflower ability to compete *vs*. weeds up to 20% compared to AN-fertilizer. Overall, in order to improve safflower yield and NUE and control weed, applying U-fertilizer and split application of $^1/_3,^2/_3$,0 or $^1/_4,^3/_4$,0 can be suggested as a component of integrated weed management programs.

Keywords: Ability to compete index, Fertilizer management, Nitrogen efficiency, Redroot pigweed.

[DOR: 20.1001.1.16807073.2018.20.7.5.9]

INTRODUCTION

Safflower, a member of the asteraceae family, is a multipurpose crop and one of the most ancient among cultivated oilseeds. An important characteristic of this crop is its adaptation to semi-arid growing conditions owing to a deep root system (2–3 m in depth), enabling it to obtain moisture from levels unavailable for most crops (Ashkani *et al*., 2007). Safflower was traditionally cultivated for extraction of a natural dye from its flowers for textiles, food and cosmetics. However, it is cultivated nowadays around the world mainly as an oilseed crop for both edible and industrial purposes (paint, bio-fuel and fuel additives) (Yeilaghi *et al*., 2012). Its production, however, is challenged with a number of factors. For example, low yield is caused by weed infestation, which has been a major constraint for a long time. Concerning this issue, despite several decades of modern weed control practices, weeds still continue to be a constant threat to agricultural productivity leading to diminished crop productivity and raising agricultural production costs (Naderi and Ghadiri, 2011). Reduction in crop yield results from weeds different ways of interfering with crop growth and cultivation because they compete with crops for one or more plant growth factors such as mineral nutrients, water, solar energy, and space and

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also hinder crop cultivation operations (Monsefi *et al*., 2016).

The importance of inorganic fertilizers in crop productivity is well recognized, of which nitrogen is the major nutrient added to increase crop yield (Ryan, 2008). However, soil N will likely be depleted more rapidly in the presence of weeds, causing additional losses in crop yield (Liebman and Davis, 2000). On the other hand, studies have indicated that increase in N application increases the competitiveness of weed with crop (Naderi and Ghadiri, 2011). An approach employed to improve yield and decrease weed-crop competition is the manipulation of crop fertilization, particularly N application (Jalali *et al*., 2012; Sheibani and Ghadiri, 2012). Therefore, selection and use of the correct dose, source, and splitting application of N are important aspects in fine-tuning N management under weed-crop interference (Rathke *et al*., 2005; Hosseiny and Maftoun, 2008). Muharnmad *et al*. (2007) reported that the highest seed protein was obtained when oilseed rape (*Brassica napus* L.) was treated by Calcium Ammonium Nitrate (CAN). Similarly, Ozturk (2010) found that Ammonium Sulfate (AS) and Urea (U) fertilizers gave higher crop yield than Ammonium Nitrate (AN) fertilizer while Osman *et al*. (2014) showed that AN increased growth and yield parameters of oilseed rape compared to other N fertilizer sources. On the contrary, AN fertilizer stimulated emergence of sown redroot pigweed (*Amaranthus retroflexus* L.) and velvetleaf (*Abutilon theophrasti* Medic.) (Teyker *et al*., 1991), whereas U fertilizer, and to some extent ammonium, reduced weed infestations by inhibiting germination and radicle elongation (Sweeney *et al*., 2008). Thus, adding different N fertilizer sources to cropping systems can potentially have the unintended consequence of increasing the growth and competitive ability of weeds more than crop.

Because N availability is an important factor that determines crop productivity, split fertilization can be a suitable strategy to ensure nutrient availability when crops need it or when water is available to enhance nutrient uptake and to improve crop growth and yield (Barlog and Grzebisz, 2004). Mossedaq and Smith (1994) suggested that N should be immediately applied before the period of peak N demand i.e. the onset of stem elongation, and speculated that this will result in minimizing N leaching. Emam and Borjian (2000) reported that the highest yield of wheat (*Triticum aestivum* L.) was obtained when crop was nourished with U fertilizer at pre-anthesis phase as compared with later applications. Likewise, several lines of research suggested that low early-season N levels could result in selective weed suppression (Liebman and Davis, 2000). Davis and Liebman (2001) indicated that, for certain crop-weed combinations, delaying soil N availability can shift the competitive balance to favor crop growth. In other words, splitting patterns of N fertilizer that minimize N availability early in the growing season should reduce weed infestation. Ivy-leaf speedwell (*Veronica hederifolia* L.) competitive ability was greater when N was applied at tillering than at stem elongation stage of winter wheat (Angonin *et al*., 1996).

Thus, optimum N fertilizer management not only has potential to protect crop yield but also could contribute to long-term reductions in weed populations. Therefore, manipulation of crop fertilization in competition with weeds requires an understanding of the fertilization strategies to reduce weed competitiveness. In order to achieve the maximum potential of the safflower yield and weeds control, this study was conducted to determine the combined effects of N sources and splitting N fertilization on weed growth, safflower yield, and changes in N use efficiency of plants under safflower-weed competition.

MATERIALS AND METHODS

Plant Materials and Growth Conditions

A 2-year field experiment was conducted at the Experimental Research Station (Badjgah), Shiraz University (52° 46' E, 29° 50' N, at 1810 m), Iran, in 2015 and 2016. The soil was silty clay loam with a pH of

[DOR: 20.1001.1.16807073.2018.20.7.5.9]

7.25 and an EC of 0.475 dS m^{-1}. The site was under fallow before cultivation. Total N, mean Phosphorus (P) and mean potassium (K) were 0.07%, 12 and 250 mg kg^{-1}, respectively. Monthly 30-year average temperature, rainfall, and relative humidity including the years 2015 and 2016 are shown in Table 1.

The experiment was laid out as split-split-plot based on randomized complete block design in three replications. The treatments consisted of two levels of weed control (weedy and weed free) as main plot, N fertilizer sources in four levels: Ammonium Nitrate (AN; 25% N), Ammonium Sulfate (AS; 21% N), Sulfur Coated Urea (SCU; 34% N), and Urea (U; 46% N) as sub plot, and split application of N were top-dressed (broadcast method) in four levels (($^1/_4$,$^3/_4$,0), ($^1/_3$,$^1/_3$,$^1/_3$), ($^1/_2$,$^1/_2$,0), and ($^1/_3$,$^2/_3$,0)) as sub-sub plot. Nitrogen fertilization was carried out at three stages of safflower growing season including sowing time, stem elongation, and flowering (Flemmer *et al*., 2015). Safflower N requirement (at a rate of 100 kg pure N ha^{-1} during growing season) was determined according to the soil test analysis. The numbers in each treatment represent the amount of N fertilizer applied at each stage. For example treatment of $^1/_4$,$^3/_4$,0 indicates that one quarter of the N (25 kg N ha^{-1}) at sowing, three quarters (75 kg N ha^{-1}) at stem elongation, and no-N application at flowering stage. Land preparation practices included plowing, disking, and ridging plots (sized 3 by 3 m). Each plot was separated by two ridges to avoid cross contamination among plots. The seeds of safflower (Zendehrood cultivar) were sown two cm deep in rows spaced 15 cm apart (30 plants m^{-2}) on March 25th in both years. Triple super phosphate fertilizer was applied at the sowing time at a rate of 50 kg ha^{-1} according to the soil test analysis. Other management practices, such as pest control, were conducted according to local agronomic practices unless otherwise indicated. In weed free plots, weeds were controlled by hand hoeing throughout the growing season. The irrigation schedule was set at 10-day intervals for all treatments. Soil samples were taken at three depths (30, 60, and 90 cm) at the time of irrigation using gravimetric method, and moisture content of soil was measured each time before irrigation and each plot was uniformly irrigated by siphon.

Trait Measurements

At the end of the growth period (approximately middle of July in both years), weeds and safflower samples were randomly hand harvested from the middle 1 m^2 of each plot at maturity, and partitioned into stems, leaves, and capitulums. Predominant weed species were redroot pigweed, common lambsquarters (*Chenopodium album* L.), field bindweed (*Convolvulus arvensis* L.), and wild safflower (*Carthamus oxycanthus* L.). Weed species were separated, oven dried at 76°C for 48 hours and weighed. Ability to Compete (AC) index was determined as follows (Szumigalski and Van Acker, 2005):

$$(AC) = 100 - [(\frac{\mathrm{bw}}{\mathrm{bt}}) \times 100] \qquad (1)$$

Equation (1) was used to quantify the changes weed biomass in competitive ability

Table 1. Some 30-year (1986-2016) mean monthly weather parameters of the study site (2015 and 2016 are presented separately).

Months	Average temperatures (°C)			Precipitation (mm month^{-1})			Average relative humidity (%)		
	2015	2016	30-Year	2015	2016	30-Year	2015	2016	30-Year
April	13.90	10.20	11.23	39.50	33.50	45.82	43.10	43.16	51.85
May	17.60	17.30	16.15	10.00	0.50	11.70	34.56	33.81	48.41
June	23.00	20.30	20.49	0.00	0.00	0.76	24.65	27.29	39.47
July	26.00	25.29	25.43	0.00	0.00	0.30	24.48	25.31	37.49
August	24.00	25.04	24.23	0.00	0.00	0.27	26.37	27.05	37.96

[DOR: 20.1001.1.16807073.2018.20.7.5.9]

between safflower and weed, where *bw* and *bt* indicate weed biomass and total plant biomass (crop and weed), respectively. Additionally, safflower seed yield, oil yield (soxhelt method according to Jensen, 2007), protein yield (semi micro-Kjeldahl digestion according to Bremner and Mulvaney, 1982), biological yield (total plant dry weight), and Harvest Index $(HI) = \frac{\text{Seed yield}}{\text{Biological yield}}$ were calculated. Moreover, N Uptake Efficiency $(NUpE) = \frac{\text{Total N uptake}}{\text{Pure N requirment of crop}}$ and N Utilization Efficiency $(NUtE) = \frac{\text{Seed yield}}{\text{Total N uptake}}$ were estimated according to Rathke *et al*. (2006). Uptake efficiency is the ability of the plant to remove N from the soil as nitrate and ammonium ions, while the utilization efficiency is the ability to use N to produce grain yield.

Statistical Analysis

Differences between means were tested using the statistical program SAS 9.1 software (SAS Institute, 2003). Statistical tests included one-way analysis of variance (GLM) followed by Least Significant Difference (LSD) test at 5% probability level (Petersen, 1994), assuming a normal distribution of the dependent variable data and homogeneity of variances. The effect of year and interaction between year and all treatments were not significant, so, the combined data were reported.

RESULTS

Weed Growth and Safflower Yield Response

The results showed that the highest biomass and density of redroot pigweed (3,360.86 g m^{-2} and 10 plants m^{-2}), common lambsquarters (1,541.02 g m^{-2} and 10 plants m^{-2}), field bindweed (593.63 g m^{-2} and 7 plants m^{-2}) and wild safflower (170.36 g m^{-2} and 4 plants m^{-2}) were obtained by AN fertilizer and split pattern of $^{1}/_{2}$,$^{1}/_{2}$,0 (Table 2). Applying U fertilizer and split application of $^{1}/_{3}$,$^{2}/_{3}$,0 decreased total weed biomass and density approximately 33 and 45%, respectively, compared to AN fertilizer and split application of $^{1}/_{2}$,$^{1}/_{2}$,0. However, weed growth increased to a lesser extent by SCU fertilizer and split application of $^{1}/_{3}$,$^{1}/_{3}$,$^{1}/_{3}$ compared to other treatments. It was found that split N fertilization resulted in different *NUpE* responses (Table 2). The results showed that the lowest *NUpE* of redroot pigweed (0.18 kg kg^{-1}) was obtained by applying AS and SCU fertilizers and split application of $^{1}/_{4}$,$^{3}/_{4}$,0, while applying U fertilizer and split application of $^{1}/_{3}$,$^{1}/_{3}$,$^{1}/_{3}$ maximized *NUpE* of redroot pigweed (0.27 kg kg^{-1}) (Table 2). The highest *NUpE* of common lambsquarters and field bindweed (0.25 and 0.20 kg kg^{-1}, respectively) were achieved when AN fertilizer was applied in a split pattern of $^{1}/_{3}$,$^{1}/_{3}$,$^{1}/_{3}$. Likewise, applying AN fertilizer in split application of $^{1}/_{2}$,$^{1}/_{2}$,0 increased *NUpE* of wild safflower by 30% compared to U fertilizer in a similar split pattern (Table 2). The regression results showed that *NUpE* of individual weeds was closely related to weed density. Weeds *NUpE* increased as weed density increased, yet increase rate of *NUpE* was different among weed species. Results showed *NUpE* of common lambsquarters was less than redroot pigweed at similar density. Likewise, wild safflower *NUpE* increased as density increased to more than 3 plants m^{-2} progressively. In contrast, increasing field bindweed density increased *NUpE* gradually (Figure 1).

The results showed that safflower yield and NUE declined in weedy plots compared to weed free. However, yield reduction and NUE response was affected by split N fertilization (Table 3). In weedy plots, the lowest safflower seed, oil, and protein yields (253.65, 51.68 and 16.66 kg ha^{-1},

[DOR: 20.1001.1.16807073.2018.20.7.5.9]

Table 2. Effects of split nitrogen fertilizers application on weed biomass (g m^{-2}), density (plant m^{-2}) and NUpE (kg kg^{-1}).

Treatments									
Nitrogen sources	Split pattern ^{a}			Redroot pigweed			Common lambsquarters		
	ST	SE	F	Biomass	Density	*NUpE*^{b}	Biomass	Density	NUpE
Ammonium Sulfate (AS)	1/4	3/4	0	2044.66	4.66	0.18	995.81	4.16	0.16
	1/3	1/3	1/3	1730.96	3.66	0.21	596.09	2.33	0.19
	1/2	1/2	0	1805.20	5.00	0.20	957.01	3.16	0.20
	1/3	2/3	0	1732.13	3.83	0.26	658.35	2.83	0.20
Urea (U)	1/4	3/4	0	2251.08	4.83	0.23	1038.65	4.00	0.24
	1/3	1/3	1/3	1803.03	4.33	0.27	677.50	4.83	0.22
	1/2	1/2	0	2314.24	8.50	0.25	1255.07	6.50	0.24
	1/3	2/3	0	2236.09	5.00	0.25	1069.96	4.00	0.23
Ammonium Nitrate (AN)	1/4	3/4	0	2779.91	6.66	0.26	1231.81	7.83	0.24
	1/3	1/3	1/3	2411.42	5.66	0.26	1060.94	4.33	0.25
	1/2	1/2	0	3360.86	10.16	0.26	1541.02	10.33	0.22
	1/3	2/3	0	2375.29	7.00	0.27	1352.80	5.50	0.23
Sulfur Coated Urea (SCU)	1/4	3/4	0	1694.65	3.83	0.18	736.20	2.50	0.15
	1/3	1/3	1/3	1637.40	3.16	0.20	600.56	2.16	0.17
	1/2	1/2	0	1655.14	5.16	0.19	998.23	2.66	0.16
	1/3	2/3	0	1596.81	3.83	0.20	646.53	2.50	0.18
LSD (5%)^c				448.1	1.27	0.04	105.1	1.51	0.05
Nitrogen sources	Split pattern			Field bindweed			Wild safflower		
	ST	SE	F	Biomass	Density	*NUpE*	Biomass	Density	NUpE
Ammonium Sulfate (AS)	1/4	3/4	0	296.92	2.83	0.12	58.48	3.00	0.04
	1/3	1/3	1/3	161.96	2.00	0.16	35.25	1.33	0.01
	1/2	1/2	0	259.29	4.00	0.17	74.95	2.16	0.05
	1/3	2/3	0	265.86	2.83	0.18	74.83	2.33	0.06
Urea (U)	1/4	3/4	0	393.74	3.66	0.17	84.17	2.83	0.09
	1/3	1/3	1/3	358.81	3.16	0.18	79.06	3.00	0.06
	1/2	1/2	0	492.53	4.66	0.20	104.24	4.00	0.10
	1/3	2/3	0	403.20	5.33	0.19	82.55	3.50	0.08
Ammonium Nitrate (AN)	1/4	3/4	0	471.90	5.83	0.17	86.19	3.33	0.09
	1/3	1/3	1/3	421.72	2.83	0.20	89.40	2.83	0.08
	1/2	1/2	0	593.63	7.33	0.19	170.36	4.50	0.13
	1/3	2/3	0	440.45	6.00	0.19	126.35	3.83	0.12
Sulfur Coated Urea (SCU)	1/4	3/4	0	222.26	2.66	0.15	64.23	2.16	0.04
	1/3	1/3	1/3	206.38	2.66	0.14	27.55	1.33	0.01
	1/2	1/2	0	319.62	2.5	0.17	79.06	2.83	0.05
	1/3	2/3	0	230.47	3.66	0.17	67.16	2.16	0.04
LSD (5%)				60.94	0.85	0.04	31.14	0.78	0.04

[a] ST: Sowing Time; SE: Stem Elongation stage, F: Flowering stage. [b] Nitrogen Uptake Efficiency. [c] Least Significant Difference at $P< 0.05$.

respectively) were observed when SCU fertilizer in a split pattern of $^{1}/_{3}$,$^{1}/_{3}$,$^{1}/_{3}$ was applied. In addition, applying AN fertilizer and split pattern of $^{1}/_{3}$,$^{2}/_{3}$,0 increased seed yield to 612.19 kg ha^{-1} and oil yield to 153.45 kg ha^{-1}, but the highest protein yield (58.78 and 58.23 kg ha^{-1}) was obtained when AN fertilizer in split application of $^{1}/_{4}$,$^{3}/_{4}$,0 and $^{1}/_{3}$,$^{2}/_{3}$,0 were applied (Table 3). In weed free plots, the highest seed yield (3303.52 kg

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Table 3. Effects of split nitrogen fertilizers application on seed yield (kg ha^{-1}), oil yield (kg ha^{-1}), protein yield (kg ha^{-1}), biological yield (kg ha^{-1}), harvest index (%), *NUpE* and *NUtE* (kg kg^{-1}).

Treatments					Seed yield	Oil yield	Protein yield	Biological yield	Harvest index	*NUpE*[b]	*NUtE*[c]
Weed	Nitrogen sources	Split pattern[a]									
		ST	SE	F							
Weedy	Ammonium Sulfate (AS)	1/4	3/4	0	340.44	73.70	25.69	2498.03	13.62	0.21	16.01
		1/3	1/3	1/3	270.12	56.79	18.38	2214.70	12.03	0.15	17.71
		1/2	1/2	0	376.55	85.68	34.64	2640.23	13.96	0.29	12.61
		1/3	2/3	0	402.90	90.55	33.81	2542.10	15.69	0.22	18.15
	Urea (U)	1/4	3/4	0	572.28	121.17	50.95	2779.54	20.09	0.27	20.39
		1/3	1/3	1/3	392.72	101.54	37.54	2898.45	13.47	0.32	12.02
		1/2	1/2	0	392.21	102.86	23.83	2782.53	13.88	0.30	13.90
		1/3	2/3	0	581.91	144.15	53.74	3149.91	17.80	0.29	20.14
	Ammonium nitrate (AN)	1/4	3/4	0	598.30	147.87	58.78	3348.96	17.84	0.38	15.70
		1/3	1/3	1/3	323.67	76.42	31.10	2772.17	11.69	0.33	9.66
		1/2	1/2	0	580.21	126.16	39.15	3129.38	18.38	0.36	16.03
		1/3	2/3	0	612.19	153.45	58.23	3291.88	18.00	0.39	15.19
	Sulfur Coated Urea (SCU)	1/4	3/4	0	355.98	87.01	19.67	2211.49	15.72	0.15	22.00
		1/3	1/3	1/3	253.65	51.68	16.66	2236.47	11.31	0.16	15.75
		1/2	1/2	0	401.76	72.42	23.19	3022.56	13.27	0.26	16.30
		1/3	2/3	0	425.53	88.88	37.12	2737.41	15.54	0.25	18.70
Weed free	Ammonium Sulfate (AS)	1/4	3/4	0	754.74	171.25	80.71	4195.54	17.95	0.48	15.91
		1/3	1/3	1/3	628.43	143.59	60.22	4199.45	14.82	0.40	15.67
		1/2	1/2	0	713.88	184.24	88.09	4118.49	17.28	0.57	12.31
		1/3	2/3	0	834.42	231.92	81.23	4566.98	17.78	0.51	16.00
	Urea (U)	1/4	3/4	0	1688.06	485.86	249.95	5643.47	29.52	0.70	24.07
		1/3	1/3	1/3	1039.35	393.89	124.86	5042.12	20.45	0.65	15.80
		1/2	1/2	0	2708.77	753.09	425.29	7124.73	37.19	0.73	38.99
		1/3	2/3	0	1664.46	512.04	255.87	5828.38	28.46	0.70	24.07
	Ammonium Nitrate (AN)	1/4	3/4	0	2599.97	720.79	377.51	6799.73	37.55	0.78	33.01
		1/3	1/3	1/3	1685.22	446.03	186.65	5910.33	28.28	0.67	24.69
		1/2	1/2	0	3303.52	715.65	694.95	8443.60	39.14	0.76	43.70
		1/3	2/3	0	2715.58	673.88	508.24	7292.34	37.15	0.78	35.25
	Sulfur Coated Urea (SCU)	1/4	3/4	0	840.49	177.90	90.21	4321.90	19.27	0.47	17.42
		1/3	1/3	1/3	640.37	164.46	76.42	4052.13	15.62	0.44	14.56
		1/2	1/2	0	1134.83	238.31	114.22	4834.63	23.39	0.53	21.31
		1/3	2/3	0	743.26	167.82	98.98	4211.70	17.59	0.53	14.10
LSD (5%)[d]					511.97	156.65	77.95	702.18	6.80	0.10	10.06

[a] ST: Sowing Time; SE: Stem Elongation stage, F: Flowering stage. [b] Nitrogen Uptake Efficiency. [c] Nitrogen Utilization Efficiency. [d] Least Significant Difference at $P< 0.05$.

ha^{-1}), protein yield (694.95 kg ha^{-1}), biological yield (8443.60 kg ha^{-1}) and harvest index (39.14%) were achieved by AN fertilizer and split application of $^1/_2,^1/_2,0$. However, the highest oil yield (753.09 kg ha^{-1}) was observed when U fertilizer was applied in the same split pattern (Table 3). In weedy plots, applying AN fertilizer and split pattern of $^1/_3,^2/_3,0$ increased *NUpE* of safflower (0.39 kg kg^{-1}) approximately by 35% compared to U fertilizer and similar split pattern. Likewise, the highest *NUtE* of safflower (22.00 kg kg^{-1}) was obtained when crop was treated with SCU fertilizer and split pattern of $^1/_4,^3/_4,0$. In weed free plots, AN fertilizer and split patterns of $^1/_4,^3/_4,0$ and $^1/_3,^2/_3,0$ maximized safflower *NUpE* (0.78 kg kg^{-1}), however the highest safflower *NUtE* (43.70 kg kg^{-1}) was obtained when

[DOR: 20.1001.1.16807073.2018.20.7.5.9]

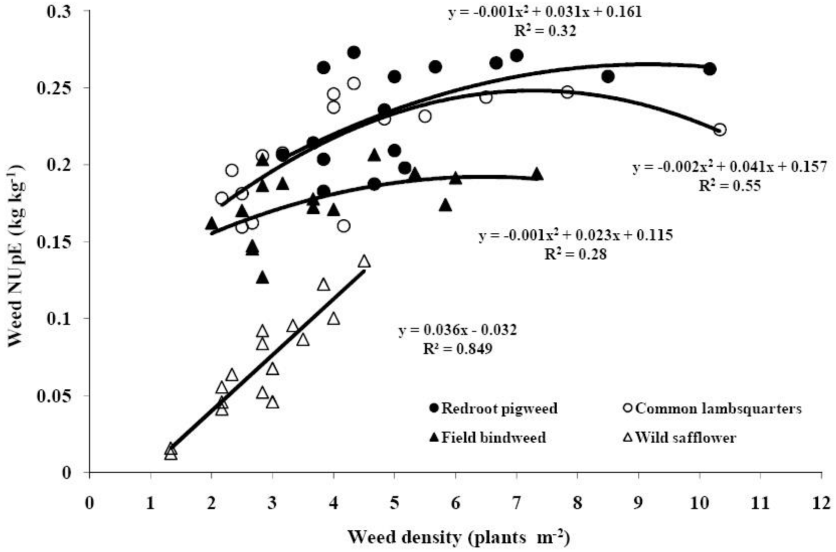

Figure 1. Correlation between weed density with *NUpE* of redroot pigweed (●), common lambsquarters (○), field bindweed (▲) and wild safflower (Δ).

AN fertilizer was applied in split application of $^{1}/_{2}$,$^{1}/_{2}$,0 (Table 3).

Ability to Compete Index

Among weeds, the lowest *AC* index (8.06%) was obtained for safflower-redroot pigweed competition when AN fertilizer was applied in a split pattern of $^{1}/_{2}$,$^{1}/_{2}$,0 (Table 4). It was found that applying AN fertilizer and split pattern of $^{1}/_{2}$,$^{1}/_{2}$,0 decreased safflower *AC* index *vs*. weeds such as redroot pigweed, common lambsquarters, field bindweed and wild safflower approximately by 30, 18, 13, and 16%, respectively. Furthermore, applying U fertilizer and split pattern of $^{1}/_{3}$,$^{2}/_{3}$,0 increased safflower *AC* index *vs*. weeds; however, the increase in safflower *AC* index *vs*. redroot pigweed and field bindweed was approximately 3%. Whereas, safflower *AC* index *vs*. common lambsquarters and wild safflower increased by 17.8 and 10.5%, respectively. Similarly, safflower *AC* index *vs*. redroot pigweed was maximized by SCU fertilizer in a split application of $^{1}/_{2}$,$^{1}/_{2}$,0, while similar N source applied in a split pattern of $^{1}/_{3}$,$^{1}/_{3}$,$^{1}/_{3}$ maximized safflower *AC* *vs*. common lambsquarters and wild safflower. But, safflower *AC* *vs*. field bindweed peaked to its maximum level when AS fertilizer was applied in a split pattern of $^{1}/_{3}$,$^{1}/_{3}$,$^{1}/_{3}$ (Table 4).

DISCUSSION

We found that weeds growth increased when AN fertilizer was applied. This may be due to increasing the ability of weeds to take up N (Adam and Liebman, 2001). Thus, for those species using N as a signal for seed germination, N fertilizer additions could potentially limit seed mortality by increasing germination and may directly affect weed infestation densities (Booth *et al*., 2003). Likewise, our results showed that applying split pattern of $^{1}/_{2}$ at sowing time and $^{1}/_{2}$ at stem elongation could maximize weed growth and density and cause adverse effects on safflower growth and yield. However, other studies have suggested that early-season soil N levels are kept intentionally low in a split application management system because crop demand for N at this time is low and the potential for loss of excess N from the system is high

Table 4. Effects of split nitrogen fertilizers application on ability to compete (%).

Treatments				*AC*[a]			
Nitrogen sources	Split pattern[b]			Safflower *vs* redroot pigweed	Safflower *vs* common lambsquarters	Safflower *vs* field bindweed	Safflower *vs* wild safflower
	ST	SE	F				
Ammonium sulfate (AS)	1/4	3/4	0	11.98	21.71	48.17	82.66
	1/3	1/3	1/3	13.08	30.68	61.57	88.04
	1/2	1/2	0	13.46	22.62	51.94	78.87
	1/3	2/3	0	13.46	28.97	50.28	78.49
Urea (U)	1/4	3/4	0	10.87	20.70	40.78	76.47
	1/3	1/3	1/3	14.21	30.71	45.46	79.31
	1/2	1/2	0	11.45	19.03	37.57	74.09
	1/3	2/3	0	11.41	21.13	41.52	77.64
Ammonium nitrate (AN)	1/4	3/4	0	10.15	20.26	39.92	78.38
	1/3	1/3	1/3	11.33	22.55	42.22	77.69
	1/2	1/2	0	8.06	15.64	32.63	62.62
	1/3	2/3	0	11.11	17.94	40.19	70.24
Sulfur coated urea (SCU)	1/4	3/4	0	12.51	24.76	52.13	79.08
	1/3	1/3	1/3	15.10	31.14	56.77	90.80
	1/2	1/2	0	15.92	23.91	49.50	80.04
	1/3	2/3	0	15.34	30.67	55.36	81.13
LSD (5%)[c]				3.05	3.21	3.53	6.18

[a] Ability to Compete.[b] ST: Sowing Time; SE: Stem Elongation stage, F: Flowering stage. [c] Least Significant Difference at $P< 0.05$.

(Liebman and Davis, 2000). Because weeds often have higher abilities to exploit nutrients than agricultural crops, applying low early-season N levels can reduce weed germination (Sheibani and Ghadiri, 2012). Sweeney *et al*. (2008) found that emergence of sown giant foxtail (*Setaria faberi* L.) increased as N application rate increased, particularly at the early N application date. Furthermore, increasing weeds growth and density by AN fertilizer caused an increase in N uptake (Bonifas and Lindquist, 2006). Among the weeds, the highest *NUpE* was observed in redroot pigweed because most C_4 weed species absorb N more efficiently and rapidly than C_3 weed species (Harbur and Owen, 2004).

It seems that applying AN and U fertilizer sources stimulates plant growth by means of an enlarged leaf canopy and a greater rate of leaf expansion, which increases light interception and enhances photosynthesis (Ozturk, 2010). Tuncturk and Yildirim (2004) reported that the highest yield response of safflower was obtained by AN and U fertilizers application. Osman *et al*. (2014) showed that AN fertilizer increased seed yield of oilseed rape compared to other N fertilizer sources. Furthermore, we found that the highest growth and yield response were obtained when safflower was treated by split application of $^1/_2$ at sowing time, $^1/_2$ at stem elongation. The reason for the high crop growth performance seems to be that the high application rate of N in early growing season is beneficial to plant growth because it helps plants to avoid competition for N (Ribaudo *et al*., 2011; Jaynes, 2013). Additionally, Zong *et al*. (2014) found that the high application rate of N in mid-growing season resulted in relatively higher plant production compared with the early growing season, and this increase was associated with N enrichment during vegetative-reproductive transition. Kaefer *et al*. (2015) reported that oilseed rape growth and yield response were not influenced by N fertilizer sources, but were significantly

[DOR: 20.1001.1.16807073.2018.20.7.5.9]

influenced by split N application of $^1/_3$ at sowing and $^2/_3$ at stem elongation. Meanwhile, results showed that adding AN and U fertilizers can increase NUE due to greater access of safflower root to the mass flow of N, especially NO_3 (Dawson *et al*., 2008). *NUpE* indicates effectiveness of fertilizer N-recovery due to N uptake by the plant (Hirel *et al*., 2007). Furthermore, high *NUtE* results from effective remobilization and translocation of N from vegetative parts (especially stem) of the plant to developing tissues representing strong sinks for N during the seed-filling period (Masclaux-Daubresse *et al*., 2010).

We found that applying AN fertilizer source and split application of $^1/_2$,$^1/_2$,0 increased growth and yield response of safflower; on the other hand, this can potentially cause the unintended increase in the growth and competitive ability of weeds by increasing germination (Benech-Arnold *et al*., 2000), which may directly increase weeds-safflower competition. In our study, applying AN fertilizer reduced safflower *AC* index, especially *vs*. redroot pigweed and common lambsquarters. Because redroot pigweed is a C_4 species while common lambsquarters is a C_3 and, therefore, the former is expected to be more efficient N user and, consequently, more competitive with safflower for light and other resources (Barker *et al*., 2006). Likewise, the competitiveness of wild mustard (*Sinapis arvensis* L.), a winter annual, in sugar beet (*Beta vulgaris* L.) was favored by high rate of fertilizer application at the early growth stage (Paolini *et al*., 1999). Blackshaw and Brandt (2008) reported that the competitive ability of the high N-responsive species such as redroot pigweed progressively improved as N fertilizer was applied. This finding suggests that farming systems that minimize N availability early in the growing season should limit weed growth.

CONCLUSIONS

Further expansion of safflower growing area requires increase in N fertilizer consumption on marginal lands, resulting in increased losses of N fertilizer. More efficient use of N fertilizer is essential for improving the economic output of the farm and reducing the risk of environmental pollution. To enhance the productivity of safflower and suppress weeds infestation, efficient N management practices such as use of different sources and timing of N application adapted to the field conditions could be remarkable growing strategies in safflower production, and weed control. In weed free conditions, to achieve the maximum potential of the safflower yield and NUE, applying AN fertilizer in split pattern of $^1/_2$,$^1/_2$,0, is recommended. On the contrary, in competition with weeds, applying U fertilizer and split pattern of $^1/_3$, $^2/_3$, 0 or $^1/_4$, $^3/_4$, 0 suppressed weed, improved safflower yield, and enhanced the competitive ability of safflower.

ACKNOWLEDGEMENTS

This project was funded by a grant from the Research Council and Graduate Center of Shiraz University, Shiraz, Iran.

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[DOR: 20.1001.1.16807073.2018.20.7.5.9]

اثر تقسیط منابع کود نیتروژن بر رشد علف های هرز، عملکرد گلرنگ و کارآیی مصرف نیتروژن

ر. مرادی طالب بیگی، س. ع. کاظمینی، و ح. غدیری

چکیده

در پژوهشی مزرعه ای در ایستگاه تحقیقات دانشگاه شیراز در سال ۱۳۹۴ و ۱۳۹۵، اثرات منابع نیتروژن (نیترات آمونیوم (AN)، سولفات آمونیوم (AS)، اوره با پوشش گوگردی (SCU) و اوره (U)) و الگوهای تقسیط نیتروژن ((۱/۴، ۰، ۳/۴)، (۱/۳، ۱/۳، ۱/۳)، (۱/۲، ۰، ۱/۲) و (۱/۳، ۰، ۲/۳)) بر رشد علف های هرز، عملکرد گلرنگ (*Carthamus tinctorius* L.) و کارآیی مصرف نیتروژن (NUE) به صورت آزمایش کرت های دوبار خرد شده و در ۳ تکرار اجرا شد. در شرایط حضور علف هرز، کاربرد AN و الگوی تقسیط (۱/۲، ۰، ۱/۲) (کاربرد نیمی از نیتروژن در زمان کاشت و مابقی آن در زمان ساقه رفتن) هجوم علف های هرز را افزایش داد. این تیمار کارآیی جذب نیتروژن (NUpE) کل علف های هرز را در مقایسه با کاربرد U و الگوی تقسیط مشابه بیش از ۵ درصد افزایش داد. در شرایط بدون علف هرز، بیشترین عملکرد دانه (۳۳۰۳/۵۲ کیلوگرم در هکتار) و روغن (۷۵۳/۰۹ کیلوگرم در هکتار) به ترتیب با کاربرد کود AN و U و الگوی تقسیط (۱/۲، ۰، ۱/۲) حاصل شد. کاربرد AN و الگوهای تقسیط (۱/۳، ۰، ۲/۳) (کاربرد یک سوم کود نیتروژن در زمان کاشت و ۲/۳ نیتروژن در زمان ساقه رفتن) و (۱/۴، ۰، ۳/۴) (کاربرد یک چهارم نیتروژن در هکتار در زمان کاشت و ۳/۴ نیتروژن در زمان ساقه رفتن) کارآیی جذب نیتروژن گلرنگ (۰/۷۸ کیلوگرم در کیلوگرم) را افزایش داد. کاربرد U و الگوی تقسیط (۱/۲، ۰، ۱/۲) در مقایسه با AN شاخص توانایی رقابت گلرنگ را در مقابل علف های هرز بیش از ۲۰ درصد افزایش داد. در کل، برای حفظ ثبات عملکرد گلرنگ، بهبود کارآیی مصرف نیتروژن و کنترل علف های هرز، کاربرد U و الگو های تقسیط (۱/۳، ۰، ۲/۳) و یا (۱/۴، ۰، ۳/۴) می تواند به عنوان یکی از اجزاء برنامه های مدیریت تلفیقی علف های هرز توصیه شود.

[DOR: 20.1001.1.16807073.2018.20.7.5.9]