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Effects of Sowing Dates and Seeding Rates on Nitrogen and Water Use Efficiency of Facultative Wheat

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Abstract

In this study, effects of different sowing dates and seeding rates on N uptake efficiency (NUE), N translocation efficiency (NTE), agronomic efficiency (AE), physiological efficiency (PE), water use efficiency for grain yield (WUE_g) and water use efficiency for biomass (WUE_b) of facultative wheat were investigated. As the average of cropping year, sowing dates and seeding rates, N uptake efficiency (NUE), N translocation efficiency (NTE), agronomic efficiency (AE), physiological efficiency (PE), water use efficiency for grain yield (WUE_g) and water use efficiency for biomass (WUE_b) values were respectively obtained as 1.17 kg N_{uptake}/kg $N_{applied}$, 68.5%, 36.9 kg grain/kg $N_{applied}$, 31.2 kg grain/kg N_{uptake}, 5.19 kg ha^{-1} mm^{-1} and 18.04 kg ha^{-1} mm^{-1}.

Nitrogen and water use efficiencies decreased with delayed sowing dates and increased with increasing seeding rates. It is possible to maintain a high wheat yield, nitrogen and water use efficiency by increasing plant density through winter sowing. It was concluded based on present findings that sowing date and seeding rates had significant effects on nitrogen and water use efficiencies and winter sowing should be practiced as not to cause yield losses and high seeding rates (575 seeds m^{-2}) yielded greater nitrogen-water use efficiencies.

Keywords Facultative wheat · Sowing date · Seeding rate · Nitrogen use efficiency (NUE) · Water use efficiency (WUE)

Auswirkungen von Aussaatterminen und Aussaatmengen auf die Stickstoff- und Wassernutzungseffizienz von Wechselweizen

Zusammenfassung

In dieser Studie wurden die Auswirkungen verschiedener Aussaattermine und Aussaatmengen auf die N-Aufnahmeeffizienz (NUE), die N-Umsetzungseffizienz (NTE), die agronomische Effizienz (AE), die physiologische Effizienz (PE), die Wassernutzungseffizienz für den Kornertrag (WUE_g) und die Wassernutzungseffizienz für die Biomasse (WUE_b) von Wechselweizen untersucht. Als Durchschnittswerte für das Anbaujahr, die Aussaattermine und die Aussaatmengen wurden die Werte für die N-Aufnahmeeffizienz (NUE), die N-Translokationseffizienz (NTE), die agronomische Effizienz (AE), die physiologische Effizienz (PE), die Wassernutzungseffizienz für den Kornertrag (WUE_g) und die Wassernutzungseffizienz für die Biomasse (WUE_b) jeweils mit 1,17 kg N_{uptake}/kg $N_{applied}$, 68,5 %, 36,9 kg Korn/kg $N_{applied}$, 31,2 kg Korn/kg N_{uptake}, 5,19 kg ha^{-1} mm^{-1} und 18,04 kg ha^{-1} mm^{-1} angenommen.

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Die Stickstoff- und Wassernutzungseffizienz verringerte sich mit späteren Aussaatterminen und erhöhte sich mit steigenden Aussaatmengen. Es ist möglich, einen hohen Weizenertrag sowie eine hohe Stickstoff- und Wassernutzungseffizienz aufrechtzuerhalten, indem die Pflanzdichte durch Wintersaat erhöht wird. Die vorliegenden Ergebnisse lassen den Schluss zu, dass Aussaattermin und Aussaatstärke signifikante Auswirkungen auf die Stickstoff- und Wassernutzungseffizienz haben und dass die Winteraussaat praktiziert werden sollte, um Ertragseinbußen zu vermeiden, und dass hohe Aussaatstärken (575 Samen m^{-2}) eine höhere Stickstoff- und Wassernutzungseffizienz bewirken.

Schlüsselwörter Wechselweizen · Aussaattermin · Aussaatmenge · Stickstoffnutzungseffizienz (NUE) · Wassernutzungseffizienz (WUE)

Introduction

Cereals have a significant place in nutrition of world population. According to 2020 world data, wheat has the first place worldwide in terms of cultivation area (217 million ha) and the second place after maize in terms of annual production quantity (763 million tons). In 2020, 19 million tons of wheat were produced in Turkey from 6 million 846 thousand ha land area and the average yield per decare was calculated as 277.5 kg. Such a value is 339 kg in the world (FAO 2020; USDA 2021). In Turkey, cereals are cultivated over 49.7% of agricultural lands. Among the cereals, wheat has the first place with 43.8% (6.9 million ha) share in cereals (TUIK 2020). Wheat is the most widely cultivated crop in Turkey. Wheat is quite rich in carbohydrate and minerals; thus, it is the most widely consumed cereal crop. It is the basic foodstuff of Turkish people. Turkey is among the leading wheat consuming countries (225 kg/year/person) and about 30% of daily calorie intake is met by wheat (FAO 2020).

Production quantity and quality should be improved to meet nutritional demands of ever-increasing world population. Greater yield per unit area and better quality are the essential components of proposed solutions. Since the production lands are limited and already reached to ultimate levels, increasing productions will only be possible through efficient use of production inputs like water, nitrogen and through arranging sowing dates and densities.

However, measurement and interpretation of nitrogen uptake efficiency (NUE) and water use efficiency (WUE) in the field are often hampered by high degree of complexity of these systems due to season-to-season variability in rainfall, the variation in crop responses to soil types and to agronomic management (Asseng et al. 2001; Dai et al. 2013). It is evident that cultivars able to use soil nitrogen most efficiently should be selected while developing high-yield and quality cultivars (Barraclough et al. 2010; Baenziger et al. 2011). Wheat yield in inland areas of Erzurum province is largely limited by inadequate storage of winter precipitations within the soil profile and unpredictable and low spring rainfall levels and has been found to be linearly related to the sum of soil water storage in March plus the amount of subsequent spring rain. Optimum yield is usually received when crop phenology and growth matched the soil water availability. In many environments, water supply is a major source of variability in crop yields. The ratio between grain yield and evapotranspiration, generally accepted definition of water-use efficiency (WUE) for grain production, can be an important parameter defining the productivity of crops in water-limited environments.

Apparently, in order to maintain sustainable production of cereals in arid zones, it is urgent to develop water-saving agriculture and improve water use efficiency (WUE). The aim of water-saving cultivation in winter wheat should be to keep high-yield and improve WUE through appropriate agricultural measures. There is abundant growth redundancy in root system, plant height, leaf area, number of tillers (or branches) and the length of growth period of crop, etc, (Sheng 1990) which exerts adverse effects on crop production, since they are major sinks for assimilates, requiring large amounts of photosynthate to produce dry matter. In agricultural practices, sowing date and seeding rates are two important factors affecting the population structure and yield formation of wheat. Appropriate sowing dates could make full use of thermal resources before winter, cultivate strong seedling and improve the population quality as well as grain yield of wheat (Zhang et al. 2016a). Early sowing at an appropriate time is one of the most important conventional measures in increasing grain yield of winter wheat, which often facilitates the fast growth of plant while consumes lots of soil water before winter.

Seeding rate alters the relative importance of intra-plant competition for light, water, and nutrients during crop growth, thereby strongly influences the use of environmental resources (Hiltbrunner et al. 2007). Previous study showed that increased seeding rates consumed more soil water before anthesis, thus decreased grain yield (Fang et al. 2010). In addition, the optimum seeding rate for maximal yield varies with sowing dates (Spink et al. 2000; Anderson et al. 2004). Therefore, optimizing seeding rate and sowing date is a significant management practice to maximize NUE and water use. A study on sowing time and seeding rate can provide another management option for improving WUE of wheat by reducing the growth redun-

dancy of crop and changing water use from the vegetative period to the reproductive period. So far, although there are many studies on the effect of seeding rate and sowing time on the population character and yield of wheat (Dai et al. 2017, 2013; Wang et al. 2011; Zhang et al. 2016b), more knowledge is needed on how different sowing times and seeding rates can affect NUE and WUE of alternative wheat.

Nitrogen use efficiency of cereals was reported to vary with the genotypes (Dai et al. 2013). Raun and Johnson (1999) reported nitrogen use efficiency of cereals as 33%. This ratio is even lower in developing countries (Dobermann and Cassman 2005). Such low ratios for nitrogen use efficiency were mostly attributed to improper dosing and timing of nitrogenous fertilizers. Although avoidance from excessive fertilizer use seems to be the only way to achieve high N efficiency, insufficient fertilization is the primary reason of such low nitrogen use efficiencies in developing countries.

Early seeding may be constrained by the timing of fall rains because soil profiles may be too dry for sowing. In Eastern Anatolia, this is a typical case when sowing into ground that was previously cropped (as opposed to fallowed). For annual cropping systems, rainfall is generally inadequate for seeding until October. In fallowed ground, earlier seeding can be accomplished by using a deep furrow drill to place the seeds into the moist soil. Growers who plant early (i.e., early September) usually use wider row spacing and lower seeding rates than they would for later plantings to take advantage of the high tillering capacity of early sown wheat and to reduce within-row competition.

Wheat production and yield increase are largely associated with the use of improved cultivar and appropriate management practices such as optimum sowing time and seeding rate. Therefore, the objectives of this study were set as to determine the effects of sowing date and seeding rate on nitrogen and water use efficiency of facultative Kirik wheat varieties grown under rainfed conditions of Erzurum Plain.

Materials and Methods

Location, Design and Treatments

Present experiments were conducted on fallow lands of Experimental Farm of Ataturk University in Erzurum (29° 55′ N and 41° 16′ E with an altitude of 1850 m), Turkey in 2002–2003 and 2003–2004 growing seasons. Experimental soils were clay-loam in texture with organic matter contents of between 1.7–1.9% and pH values of between 7.7–7.8. Available P contents were between 15.7–18.8 and K contents between 1790.1–1870.4 kg ha^{-1}.

Three different sowing dates were used as follows: 2nd of September (winter sowing, WS), 28th of October (freezing sowing, FS) and 28th of April (spring sowing, SS) in 2002–03; 1st of September (WS), 26th of October (FS) and 29th of April (SS) in 2003–04 growing season. Seeding rates were experimented as 325, 375, 425, 475, 525, 575 and 625 viable seeds m^{-1}. The experimental design was randomized complete blocks split-plots with four replications. Sowing dates were placed into the main plots and seeding rates were placed into sub-plots.

Crop Management and Measurements

Experimental fields were prepared by ploughing to a depth of 20 cm, which was followed by surface cultivation. The facultative bread wheat cultivar Kirik (awnless, white-grain) was used as the plant material of the experiments. Plots were sown with a six-row planter. Sub-plots consisted of 6 rows spaced 20 cm apart, with a row length of 6.0 m. N in ammonium sulphate form was applied to plots as to have 60 kg ha^{-1} and P in triple super phosphate form as to have 50 kg ha^{-1}. Half of N and all P were applied at sowing; the second half of N was applied at the beginning of stem elongation.

Anthesis was defined as when 50% of spikes had anthers extruding and physiological maturity defined as when 50% of the glumes of the spikes had turned yellow (Gebeyehou et al. 1982). One 30 cm sample from the outer row of each plot was harvested at anthesis stage and leaf area was determined on plants within this 30 cm of row. Green leaf lamina area was measured with a green area meter (CID, Inc. model CI-202). The leaf area index (LAI) was calculated as the sum of the areas of the green leaf laminae (one side) per unit of ground surface area (Yunusa and Sedgley 1992). Leaf area duration (LAD) was computed from LAI × days summed from anthesis to physiological maturity (Borojevic and Williams 1982). Spikes per m^{-1} were determined from a 1 m row sample. Ten spikes were randomly harvested from the plots for kernels per spike determination. At maturity, hand harvested samples of above-ground material from 0.4 m^{-1} were taken. These samples were air dried, weighed and threshed to retrieve the grain. Harvest index was calculated as the ratio of the grain to the total biomass of the sample. Immediately prior to harvest, the plots were trimmed to 4.5 m and 4 inner rows were harvested with a plot combine, and the weight of cleaned grain from each plot was recorded. Plant samples taken were separated into grain and straw, oven-dried for 24 h at 80 °C before %N in the grain and straw were determined by the Kjeldahl method (A.A.C.C. 1983 method 46-12) (Table 1).

N-uptake efficiency (kg total N uptake/kg N applied), N-translocation efficiency (kg grain N / [kg grain N + kg straw N] × 100), N-agronomic efficiency (kg grain/kg N ap-

Table 1 Effects of experimental variables on yield, harvest index and N concentrations

Variable	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Harvest index (%)	Grain N (%)	Straw N (%)	Total N yield (kg ha^{-1})
Years (Y)						
2002–03	2096 b	5354 b	27.9 b	2.24 a	0.41 a	68.5 b
2003–04	2327 a	5536 a	29.3 a	2.18 b	0.39 b	71.9 a
Mean	2212	5445	28.6	2.21	0.40	70.2
Sowing dates (SD)						
Winter	2638 a	5723 a	31.5 a	2.09 c	0.37 c	76.4 a
Freezing	2312 b	5501 b	29.6 b	2.20 b	0.39 b	72.1 b
Spring	1685 c	5112 c	24.8 c	2.33 a	0.45 a	62.1 c
Seeding rates (SR)						
325 seeds m^{-1}	1790 d	4725 f	27.3 b	2.18	0.41	57.8 f
375	1910 d	5005 ef	27.4 b	2.23	0.40	62.3 e
425	2078 c	5210 de	28.3 ab	2.19	0.41	66.4 d
475	2227 b	5441 cd	28.9 ab	2.21	0.41	71.0 c
525	2416 a	5628 bc	29.8 a	2.21	0.40	75.4 b
575	2521 a	5918 ab	29.7 a	2.21	0.39	78.1 ab
625	2539 a	6190 a	28.9 ab	2.24	0.39	80.4 a
F values						
Y	84.1***	10.4**	14.6***	43.6***	14.7**	26.0***
ST	490.3***	39.9***	111.1***	211.5***	76.5***	164.1***
SR	76.7***	30.3***	3.6**	1.4	1.9	81.6***
Y × ST	19.3***	0.1	4.4*	1.6	0.1	12.0***
Y × SR	0.7	1.1	1.6	2.0	0.5	0.4
ST × SR	3.1***	0.9	1.5	0.4	1.2	1.5
Y × ST × SR	0.7	0.3	0.4	1.0	1.3	1.0
CV (%)	7.53	8.39	8.95	4.28	9.03	6.49

The means with the same letter within variable are not significantly different (Duncan's multiple range test $p < 0.05$)
*, ** and *** significant at 0.05, 0.01 and 0.001 levels, respectively

Table 2 The long-term averages (*LTA*) and crop season values for total monthly rainfall, average monthly temperature, minimum air temperature (T_{min}), and maximum air temperature (T_{min}) of Erzurum province

Month	Rainfall (mm)			Temperature (°C)			T_{min} (°C)		T_{max} (°C)	
	2002–03	03–04	LTA	02–03	03–04	LTA	02–03	03–04	02–03	03–04
September	18.1	19.3	19.3	13.6	13.8	14.3	–0.3	–1.0	28.4	32.0
October	42.9	90.9	90.9	8.9	8.8	6.2	–10.8	–14.1	24.0	25.4
November	25.6	35.1	35.1	1.3	–0.7	2.6	–11.8	–11.2	16.2	13.0
December	19.7	16.1	16.1	–12.0	–6.6	–5.1	–37.2	–25.8	6.0	9.0
January	17.7	14.3	14.3	–7.7	–9.0	–16.1	–26.2	–28.0	4.2	3.9
February	30.7	90.0	90.0	–8.2	–8.7	–3.4	–29.2	–28.6	4.1	4.0
March	32.9	33.7	33.7	–6.6	–1.7	–1.0	–28.2	–15.0	4.6	13.5
April	81.4	36.0	36.0	4.4	4.0	4.2	–22.4	–14.7	16.4	20.9
May	29.9	121.7	121.7	11.6	9.7	10.4	–7.1	–2.8	24.4	23.2
June	45.7	40.7	40.7	14.5	14.5	15.3	–1.8	0.2	27.2	27.1
July	18.5	2.4	2.4	18.9	17.9	19.9	4.4	2.8	31.2	30.8
August	5.1	1.3	1.3	20.0	19.6	19.5	5.0	4.6	34.0	32.3
Total	368.2	496.5	368.7	–	–	–	–	–	–	–
Mean	–	–	–	4.9	4.6	5.6	–	–	–	–

LTA from 53 years

Table 3 Total rainfall (*mm*) and growing degree days GDD (*°C days*) from sowing to anthesis, anthesis to maturity and sowing to maturity of three sowing dates

Variables	Winter sowing		Freezing sowing		Spring sowing	
	2002–03	03–04	2002–03	03–04	2002–03	03–04
Rainfall from sowing to anthesis	322.0	460.7	283.7	436.0	77.0	168.2
Rainfall from anthesis to maturity	23.2	32.6	14.3	12.3	17.9	2.6
Rainfall from sowing to maturity	345.2	493.3	298.0	448.3	94.9	170.8
GDD from sowing to anthesis	1466.3	1440.7	978.4	928.6	1003.8	925.0
GDD from anthesis to maturity	591.9	561.9	569.0	528.3	501.6	530.6
GDD from sowing to maturity	2058.2	2002.6	1547.4	1456.9	1505.4	1455.6

Table 4 Effects of experimental variables on N uptake efficiency (*NUE*), N translocation efficiency (*NTE*), N-agronomic efficiency (*AE*), N-physiological efficiency (*PE*), and water use efficiency for grain yield (WUE_g) and biomass (WUE_b)

Variable	NUE (kg N_{uptake}/kg $N_{applied}$)	NTE (%)	AE (kg grain/kg $N_{applied}$)	PE (kg grain/kg N_{uptake})	WUE_g (kg ha^{-1} mm^{-1})	WUE_b (kg ha^{-1} mm^{-1})
Years (Y)						
2002–03	1.14 b	67.5 b	34.9 b	30.3 b	5.69 a	20.23 a
2003–04	1.20 a	69.5 a	38.8 a	32.1 a	4.69 b	15.84 b
Mean	1.17	68.5	36.9	31.2	5.19	18.04
Sowing dates (SD)						
Winter	1.27 a	71.9 a	44.0 a	34.4 a	6.16 a	19.66 a
Freezing	1.20 b	70.5 b	38.5 b	32.0 b	5.44 b	18.42 b
Spring	1.03 c	63.1 c	28.1 c	27.1 c	3.97 c	16.03 c
Seeding rates (SR)						
325 seeds m^{-1}	0.96 f	66.2 c	29.8 d	30.7 bc	4.18 d	15.38 e
375	1.04 e	67.3 bc	31.8 d	30.4 c	4.49 d	16.30 d
425	1.11 d	67.7 abc	34.6 c	31.1 abc	4.87 c	17.19 cd
475	1.18 c	68.5 abc	37.1 b	31.1 abc	5.21 b	18.06 bc
525	1.26 b	69.5 ab	40.3 a	31.6 ab	5.67 a	18.93 b
575	1.30 ab	70.5 a	42.0 a	32.0 a	5.93 a	19.87 a
625	1.34 a	69.8 ab	42.3 a	31.4 abc	5.98 a	20.54 a
F values						
Y	26.0^{***}	14.2^{**}	84.1^{***}	43.0^{***}	299.5^{**}	1334.7^{***}
ST	164.1^{***}	112.6^{***}	490.3^{***}	264.6^{***}	494.3^{***}	313.3^{***}
SR	81.6^{***}	4.5^{***}	76.7^{***}	2.3^{*}	77.4^{***}	77.3^{***}
Y × ST	12.0^{***}	2.3	19.3^{***}	1.4	6.5^{**}	1.7
Y × SR	0.4	0.6	0.7	1.8	3.3^{**}	0.3
ST × SR	1.5	1.6	3.1^{***}	1.0	3.1^{***}	1.0
Y × ST × SR	1.0	0.9	0.7	0.7	0.8	0.5
CV (%)	6.49	5.26	7.53	5.66	7.60	5.81

The means with the same letter within variable are not significantly different (Duncan's multiple range test $p < 0.05$)
*, ** and *** significant at 0.05, 0.01 and 0.001 levels, respectively

plied) and N-physiological efficiency (kg grain/kg N uptake) were calculated as described by Moll et al. (1982), Delogu et al. (1998), Raun and Johnson (1999), Cassman et al. (2002), Roberts (2008), Fageria (2014) (Table 1). Water use efficiency based on biomass (WUEb) was estimated as the ratio of biomass to rainfall between September and August. Water use efficiency based on grain yield (WUEg) was estimated as the ratio of grain yield to rainfall during the same period; after this, they were calculated as described by Gomez-Macpherson and Richards (1995) and Corbeels et al. (1998). Growing degree days were determined using 0 °C as the base temperature (Tables 2, 3 and 4).

Years and sowing dates were considered as random variables, while seeding rates were considered as fixed variables. Analysis of variance was performed with the use of MSTAT-C (1991) software package. When the "year × treatment" interactions were not significant, data

were combined over the years and presented as the average of two years.

Results

Cropping Years and Weather Conditions

Results for N uptake efficiency (NUE), N translocation efficiency (NTE), agronomic efficiency (AE), physiological efficiency (PE), water use efficiency for grain yield (WUE_g) and water use efficiency for biomass (WUE_b) of Kirik wheat genotype under different sowing dates and seeding rates are provided in Table 4. Differences in efficiency parameters of 2002–03 and 2003–04 cropping years were found yo be significant. The cropping year of 2003–04 with greater precipitations had higher N uptake efficiency (NUE), N translocation efficiency (NTE), agronomic efficiency (AE) and physiological efficiency (PE) values. On the other hand, cropping year of 2002–30 with greater temperatures during flowering and grain-fill periods had greater water use efficiency for grain yield (WUE_g) and water use efficiency for biomass (WUE_b) values. As the average of cropping years, N uptake efficiency (NUE), N translocation efficiency (NTE), agronomic efficiency (AE), physiological efficiency (PE), water use efficiency for grain yield (WUE_g) and water use efficiency for biomass (WUE_b) values were respectively calculated as 1.17 kg N_{uptake}/kg $N_{applied}$, 68.5%, 36.9 kg grain/kg $N_{applied}$, 31.2 kg grain/kg N_{uptake}, 5.19 kg ha^{-1} mm^{-1} and 18.04 kg ha^{-1} mm^{-1} (Table 4).

Reflections of Sowing Date and Seeding Rates on N and Water Use Efficiency

As the average of experimental factors, N uptake efficiency (NUE) was calculated as 1.17 kg N_{uptake}/kg $N_{applied}$. Winter, freezing and sipring sowing dates yielded N uptake efficiency of 1.27, 1.20 and 1.03 kg N_{uptake}/kg $N_{applied}$, respectively and decreasing NUE values were seen with delayed sowing dates. N uptake efficiency (NUE) at 325, 375, 425, 475, 525, 575 and 625 seed/m^2 seeding rates were respectively measured as 0.96, 1.04, 1.11, 1.18, 1.26, 1.30 and 1.34 N_{uptake}/kg $N_{applied}$. Increasing NUE values were seen with increasing seeding rates (Table 4).

As the average of entire experimental factors, N translocation efficiency (NTE) was calculated as 68.5%. Winter, freezing and spring sowing dates yielded NTE values of 71.9, 70.5 and 63.1%, respectively. Significant decreases were seen in NTE values with delayed sowing dates. NTE values at 325, 375, 425, 475, 525, 575 and 625 seed/m^{-1} seeding rates were respectively measured as 66.2, 67.3, 67.7, 68.5, 69.5, 70.5 and 69.8%. N translocation efficiencies (NTE) increased until the seeding rate of 575 seed/m^{-1}.

As the average of experimental factors, agronomic efficiency (AE) of wheat genotype was calculated as 36.9 kg grain/kg $N_{applied}$. Winter, freezing and sipring sowing dates yielded agronomic efficiency (AE) values of 44.0, 38.5 and 28.1 kg grain/kg $N_{applied}$, respectively. Significant decreases were seen in agronomic efficiency (AE) values with delayed sowing dates. Agronomic efficiency (AE) values at 325, 375, 425, 475, 525, 575 and 625 seed m^{-1} seeding rates were respectively calculated as 29.8, 31.8, 34.6, 37.1, 40.3, 42.0 and 42.3 kg grain/kg $N_{applied}$. Significant decreases were seen in agronomic efficiency (AE) values with increasing seeding rates.

As the average of entire experimental factors, physiological efficiency (PE) of wheat genotype was calculated as 31.2 kg grain/kg N_{uptake}. Winter, freezing and sipring sowing dates yielded physiological efficiency (PE) values of 34.4, 32.0 and 27.1 grain/kg N_{uptake}, respectively. Significant decreases were observed in physiological efficiency (PE) values with delayed sowing dates. Physiological efficiency (PE) values at 325, 375, 425, 475, 525, 575 and 625 seed m^{-1} seeding rates were respectively measured as 30.7, 30.4, 31.1, 31.1, 31.6, 32.0 and 31.4 grain/kg N_{uptake}. Significant increases were seen in physiological efficiency (PE) values with increasing seeding rates.

As the average of experimental factors, agronomic efficiency (AE) of wheat genotype was calculated as 36.9 kg grain/kg $N_{applied}$. Winter, freezing and sipring sowing dates yielded agronomic efficiency (AE) values of 44.0, 38.5 and 28.1 kg grain/kg $N_{applied}$, respectively. Agronomic efficiency (AE) values significantly decreased with delayed sowing dates. Agronomic efficiency (AE) values at 325, 375, 425, 475, 525, 575 and 625 seed m^{-1} seeding rates were respectively measured as 29.8, 31.8, 34.6, 37.1, 40.3, 42.0 and 42.3 kg grain/kg $N_{applied}$. Significant increases were seen in agronomic efficiency (AE) values with increasing seeding rates.

As the average of entire factors, water use efficiency for grain yield (WUE_g) was calculated as 5.19 kg ha^{-1} mm^{-1}. Winter, freezing and spring sowing dates yielded water use efficiency for grain yield (WUE_g) values of 6.16, 5.44 and 3.97 kg ha^{-1} mm^{-1}, respectively. Significant decreases were seen in water use efficiency for grain yield (WUE_g) values with delayed sowing dates. Water use efficiency for grain yield (WUE_g) values at 325, 375, 425, 475, 525, 575 and 625 seed m^{-1} seeding rates were respectively measured as 4.18, 4.49, 4.87, 5.21, 5.67, 5.93 and 5.98 kg ha^{-1} mm^{-1}. Significant increases were seen in water use efficiency for grain yield (WUE_g) of wheat genotype with increasing seeding rates.

As the average of entire factors, water use efficiency for biomass (WUE_b) of wheat genotype was measured as 18.04 kg ha^{-1} mm^{-1}. Winter, freezing and spring sowing dates yielded water use efficiency for biomass (WUE_b) val-

Table 5 Simple correlation coefficients of some parameters with rainfall and growing degree days

	Rainfall		Growing degree days	
	Sowing-anthesis	Sowing-maturity	Sowing-anthesis	Sowing-maturity
GY	0.75**	0.22	0.54**	0.55**
TNY	0.65**	0.18	0.43**	0.45**
NUE	0.55**	0.15	0.38*	0.39*
NTE	0.70**	0.18	0.41**	0.43**
AE	0.75**	0.22	0.54**	0.55**
PE	0.83**	0.24	0.59**	0.61**
WUE_g	0.42**	–0.39*	0.56**	0.39*
WUE_b	0.08	–0.66**	0.41**	0.44**

GY grain yield, *TNY* total N yield, *NUE* N uptake efficiency, *NTE* N translocation efficiency, *AE* agronomic efficiency, *PE* physiological efficiency, WUE_g water use efficiency for grain, WUE_b water use efficiency for biomass

Significant at *0.05 and **0.01 ($n = 42$)

ues of 19.66, 18.42 and 16.03 kg ha^{-1} mm^{-1}, respectively. Water use efficiency for biomass (WUE_b) values significantly decreased with delayed sowing dates. Water use efficiency for biomass (WUE_b) values at 325, 375, 425, 475, 525, 575 and 625 seed m^{-1} seeding rates were respectively measured as 15.38, 16.30, 17.19, 18.06, 18.93, 19.87 and 20.54 kg ha^{-1} mm^{-1}. Significant increases were observed in water use efficiency for biomass (WUE_b) values with increasing seeding rates.

Simple Correlation Coefficients of Some Parameter with Rainfall and Growing Degree Days

Correlations of grain yield, total N yield, N uptake efficiency, N translocation efficiency, agronomic efficiency, physiological efficiency, water use efficiency for grain and water use efficiency for biomass parameters with rainfall and growing degree days (GDD) from sowing to anthesis and from sowing to maturity are provided in Table 5. Rainfall from sowing to anthesis had significant positive correlations with all parameters, except for water use efficiency for biomass. Rainfall from sowing to maturity had significant negative correlations with water use efficiency for grain and water use efficiency for biomass parameters and insignificant correlations with the other parameters. On the other hand, growing degree days from sowing to anthesis and from sowing to maturity had significant positive correlations with all parameters.

Discussion

N utilization efficiency is the capacity of the plant to absorb N from the soil and used for its growth process (Hirel and Lemaire 2006; Salim and Raza 2020). N is the most critical nutrient among all the nutrients used by the plants (Barker and Bryson 2016; Salim and Raza 2020). Optimum nitrogen dose plays a critical role in improving nitrogen use efficiency and storing nitrogen need of the plant within the structure of the plant (Ortiz-Monasterio et al. 1997). Nitrogen use efficiency of wheat decreased with increasing nitrogen doses (Du et al. 2021). Higher N uptake efficiencies were reported at low N levels and high N use efficiencies were reported at high N levels (Ortiz-Monasterio et al. 1997). Increasing proportion of water transpired during the vegetative phase with N fertilization can lead to particularly inefficient water use because increasing N status generally reduces the soluble carbohydrate reserves available for re-translocation to grain (Angus and Herwaarden 2001). Water plays an important role in regulating the soil N cycle and plant N uptake. In present study, wheat yield and NUE increased with water supply on sowing dates (Muchow 1994; Mandic et al. 2015; Belete et al. 2018). Rainfall-dependent water storage of the soil, thus NUE decreased as moved from winter sowing to summer sowing (Du et al. 2021). In other words, delayed sowing resulted in a reduction in nitrogen uptake efficiency (NUE) by 11.0 and 9.9% as compared to early and normal sowing, respectively, owing to reduced root length, density and dry matter accumulation before anthesis (Widdowson et al. 1987; Alignan et al. 2009; Dai et al. 2017). An average increase in nitrogen uptake efficiency (NUE) of 23.3 and 16.5% was observed with late sowing as compared to early and normal sowing, respectively, owing to a reduction in the grain nitrogen concentration. N uptake efficiency increases in longer growing periods (Dai et al. 2017; Belete et al. 2018). Winter sowing offers plant longer growing seasons. Plants have more developed root systems, thus have high nitrogen uptake and use efficiencies in winter sowings. Nitrogen uptake efficiency reaches to maximum when the plants have fully developed leaves (Karasahin 2014). Regional and annual variations in climate parameters alter nitrogen uptake efficiency. Different ecological conditions, air temperature and relative humidity also largely influence nitrogen up-

take and use efficiencies (Staley and Perry 1995). Previous researchers reported significant effects of seeding rates on nitrogen uptake and use efficiency (Zhang et al. 2016b; Dai et al. 2017; Dong et al. 2020). In present study, seeding rates significantly influenced NUE values. Increasing efficiency with increasing grain yields indicated that increasing plant density was an efficient pathway to improve the NUE (Dai et al. 2013). Therefore, optimizing plant density of winter wheat at relatively lower N input could be used as an efficient pathway to obtain high grain yield through improving NUE (Dong et al. 2020). Then it may be summarized that high N input improved N availability and consequently raised N accumulation at harvest, which limited the efficiency of N partitioning to grain and therefore reduced NUE. Increasing seeding rates increases the yield of wheat and therefore the nitrogen uptake efficiency (Dai et al. 2014). In present study, an increase in plant density from 325 to 625 plants m^{-1} increased wheat yield and NUE (%28.4) by increasing root-length density and aboveground N uptake, but N uptake did not increase further when plant density was >525 plants m^{-1}. Plant densities that are too high or too low both have negative agronomic consequences. Indeed, Muurinen et al. (2006) stated that nitrogen use efficiency was positively correlated with nitrogen uptake efficiency at different plant densities. However, in the study conducted in the USA by Walsh and Walsh (2020), it was reported that the increase in seeding rate did not provide an advantage in terms of nitrogen uptake efficiency (NUE). Moreover, Laghari et al. (2010) also reported that increasing sowing frequency decreased nitrogen uptake efficiency.

N translocation efficiency (NTE) alters N capacity of plant tissues. The uptake of less mineral N available at grain filling in DT as a consequence of greater N loss resulted in greater translocation (Zhou et al. 2007) and thereby increased efficiency. Increasing soil N content via fertilization decreased N translocation and efficiency (Khan 2017). Control plots had higher apparent N translocation efficiency (75%) than fertilized plots (Khan 2017). At optimum sowing dates, soil moisture is sufficient, thus N translocation is greater as compared to late sowings (Liang et al. 2019). Since post-anthesis dry matter accumulation varied with water availability, translocation was adjusted to a common dry matter basis (Clarke et al. 1990). This showed that N translocation per unit of dry matter accumulated post-anthesis was inversely related to water availability. This is consistent with the observation of Cox et al. (1986) that cultivars assimilating more N after anthesis and translocated less N from vegetative tissue to grain.

Nitrogen use efficiency (NUE) is defined as the ratio of the nitrogen up taken from the soil to applied nitrogen. Grain yield per unit of applied nitrogen is so called as agronomic efficiency (AE) and grain yield per unit of up taken nitrogen from the soil is so called as physiological efficiency (Moll et al. 1982). The agronomic efficiency of nitrogen is an indicator of how much of total nitrogen reflected on yield. The nitrogen agronomic efficiencies of bread wheat under different sowing dates and seeding rates varied between 28.1–44.0. The agronomic efficiency of nitrogen (AE) depends on yield. The increase in yield could be ascribed to variety improvement and agronomic managements, such as increase in planting time (sowing date), seeding rate. Researchers reported increasing vegetative development, number of tillers but decreasing spiked tiller and yields with early sowing and increasing seeding rates (Ahmed et al. 2016; Srivastava et al. 2018; Yang et al. 2019).

Nitrogen physiological efficiency (PE) is an indicator of how much nitrogen is taken by plants. The nitrogen physiological efficiencies of Kirik wheat varieties under different sowing dates and seeding rates varied between 27.1–34.4. The physiological efficiency of nitrogen depends on nitrogen uptake of plants. Climate (temperature, precipitation) and genetic factors play a great role in nitrogen uptake of plants (Yilmaz et al. 2020). As a matter of fact, while excessive rainfall causes nitrogen leaching into the soil, excessive temperatures also cause evaporation. In present study, the 2003–04 cropping year with higher annual precipitation yielded higher results in terms of N uptake efficiency (NUE), N translocation efficiency (NTE), agronomic efficiency (AE) and physiological efficiency (PE) parameters. On the other hand, the 2002–03 cropping year, when more temperatures prevailed during flowering and grain filling periods, was found to be superior in terms of water use efficiency for grain yield (WUE_g) and water use efficiency for biomass (WUE_b) parameters.

Considerable variability in the ratio of dry weight produced per unit of transpired water, usually referred to as water-use efficiency (WUE), is expected as variation in climatic factors affects photosynthesis and transpiration in different ways. Also, previous studies have shown that water supply limitations affect WUE in wheat (Abbate et al. 2004; Cayci et al. 2009). On the other hand, it is stated that high WUE was obtained in barley and wheat in arid conditions where precipitation was sufficient and temperature could not affect plant growth (Tambussi et al. 2007). Increasing water use efficiencies (WUE) are critical to enhance crop production. Because WUE is the ratio between biomass production and water use, it can be increased by increased biomass production with the same amount of water use, the same amount of biomass production with decreased water use, or a combination of the two (Blum 2005; Ma et al. 2018; Hatfield and Dold 2019; Khan et al. 2020). The interaction of sowing date and seeding rate also had significant effect on soil water consumption and WUE. Duchemin et al. (2015) and Wang et al. (2016) reported

that early sowing was more advantageous in terms of water use and one irrigation in late sowings increased yield and water use efficiency in wheat. On the other hand, Chen et al. (2003) indicated that sowing date did not significantly influence water use efficiency. In this study, water use efficiency increased both for grain yield and biomass (grain + stem) yield with increasing seeding rates. It was observed that appropriate sowing time and seeding rate (winter sowing × 525 seed/m^{-1}) increased WUE of alternative wheat by regulating the growth redundancy and physiological traits of root and shoot. On the other hand, Othmani et al. (2021) indicated that differences in water use efficiency for grain and biomass yield at different seeding rates were not significant. This is explained by the different response of wheat cultivars to water regime and seeding rate under diverse conditions.

Conclusion

Managing seeding rates and sowing dates are critical issues to improve or maintain nitrogen uptake efficiency (NUE) without reductions in grain yield of wheat. Increasing plant density resulted in increased yield and nitrogen utilization efficiency (NUE). Good soil–water management, which is one of the most important factors for agricultural production in semi-arid areas, is not enough for sustainable production itself. It should be integrated with appropriate cropping systems. Due to the limited and variable rainfall of semi-arid North-East Anatolia, a traditional winter wheat–fallow cropping system is needed to stabilize the yield. However, long-term cultivation with the same rotation system caused a low yield and weakened sustainability of the system.

Present findings revealed that freezing sowing of Kirik wheat in October was risky due to cold damage in some years. However, spring sowing until early April when temperatures are warmer reduced yield due to high temperatures during anthesis and low solar radiation during grain filling periods. Therefore, for this region of Turkey, Kirik varieties with greater cold tolerance during the vegetative stage are recommended to be sown in winter with greater available water in soil. It was concluded based on present findings that high wheat yield, nitrogen and water use efficiency could be achieved with winter sowing by increasing plant density. However, it should be noted that the amount of nitrogen applied to wheat in arid conditions is not so much that it prevents the effective use of water in the growing season. Present findings revealed that N uptake efficiency (NUE), N translocation efficiency (NTE), agronomic efficiency (AE), physiological efficiency (PE) and water use efficiency for grain yield (WUE_g) and biomass (WUE_b) of Kirik wheat varieties changed depending on sowing dates and seeding rates. It was concluded that winter sowing and 575 seed m^{-1} seeding rate during the fallow season with optimum N dozes could improve dryland wheat production by balancing the water consumption and biomass production.

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Conflict of interest The authors declare that they have no competing interests.

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