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Influence of Nitrogen Sources or Plant Growth Regulator on Improving Spring Canola Yield in Northwestern Ontario

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Abstract: Spring canola (*Brasica napus* L.) would become an important oilseed crop adapted to the Northwestern Ontario cropping systems. Newly released high yielding varieties have a potential for higher seed yield as long as nitrogen (N) does not become a limiting factor. Urea, the main N fertilizer source, does not have the ability to sustain N requirements throughout the growing season, and Environmentally Smart Nitrogen (ESN), a polymer-coated urea, alone might release N too slowly during the colder spring. Both of these two N sources could be a more environmentally sustainable mixture to provide the higher rates of N needed for the highest yielding canola varieties. A plant growth regulator (PGR) applied at the four to six leaf stages could help reduce the excessive vegetative growth at higher rates of N. Field studies in a randomized complete block design conducted over three years (2016-2017-2018) at the Lakehead University Agricultural Research Station in Thunder Bay, Northwestern Ontario, were used to evaluate the impacts of urea and urea + ESN at different rates, with or without the addition of a PGR (chlormequat chloride) on the seed yield, biomass yield, harvest index seed nutrient utilization efficiency, plant height, lodging, days to flower and maturity of Canola. Canola seed yield was highly responsive to increased N fertilizer rates in the three years for both sources of N. The highest canola seed yield response was determined at N rate 240 kg/ha from urea producing ~9,600 kg/ha seed and at N rate 180 kg/ha urea + ESN producing ~9,000 kg/ha seed. Averaged over three years, urea + ESN @ 180 kg N/ha produced 600 kg/ha more canola seed yield than urea @ 180 kg N/ha. The PGR had no effect on canola height and reduced biomass production in two of the three years. Focusing on the costs of N fertilizers, using urea or a mixture of urea + ESN over a PGR is preferable to achieve the economic benefit.

Key words: Canola, nitrogen management, PGR, urea, ESN, Northwestern Ontario.

1. Introduction

Canola (*Brasica napus* L.) is a high-value crop with a variety of end uses including edible oil, animal meal protein source, and biofuels [1, 2]. It has become a dominate field crop in Canada. Its area is over 8 million hectare with a total production of 18.7 million tones in 2020 [3]. Canola has become a promising crop to be included in crop rotations rotation in Northwestern Ontario. The research on optimizing nitrogen (N) fertilizer efficiency on canola will be a key factor for farmers' adoption in the region.

Canola is responsive to increased soil N availability; several studies from Western Canada have shown that N fertilizer can increase canola yields [1, 4, 5]. Due to the mobility of N it is vulnerable to losses from the soil throughout the growing season by leaching and denitrification [6-8]. Using the 4R Nutrient Stewardship principles can ensure a sufficient rate and timely supply from the right source of N fertilizer is important to optimize yields. Nitrogen availability has been shown to be a limiting factor in the growth and yield of canola [9-11] and therefore is an essential but costly input to reach maximum yield potential.

The use of controlled release fertilizer can increase

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fertilizer efficiency by insuring nutrients are available when crops need them thereby reducing environmental losses [12, 13]. Environmentally Smart Nitrogen (ESN) (Agrium, Inc., now Nutrien, Calgary, AB) is a polymer-coated urea designed to control the release of N from the fertilizer [1, 14, 15]. Studies have indicated that polymer-coated urea can have both positive and negative effects on yield which depended upon the crop and environmental conditions in the growing season [1, 16-18]. There is limited information on the efficacy of incorporating polymer-coated urea like ESN in crop production systems in Northwestern Ontario.

With the increased use of N fertilizers, comes the increased risk of crop lodging [19-22]. The use of plant growth regulators (PGRs) such as chlormequat chloride are commonly used in cereal and oil seed systems around the world [23]. These PGRs prevent lodging by controlling stock height. PGRs are primarily used as an added plant production product and have been shown to increase crop yields as N fertilizer rates increase [24-26]. The addition of PGRs could help protect the crop and improve canola yields.

The aim of this study was to evaluate the response of canola associated with increasing nitrogen fertilizer rates released from two sources i.e. urea and urea + ESN at a 2:1 ratio on N basis against a PGR as a means of reducing the risk of crop loading, which could become problematic at high N rates. We assume that higher yields would be achieved by the combination of PGRs and increased N fertility than would be possible with each fertilizer alone. And that urea + ESN at a 2:1 ratio, on N basis, could help improve canola yield by synchronizing nutrient release with crop demand.

2. Materials and Methods

Field studies were conducted over a three-year period (2016-2018) on Oskondoga Silt Loam (Gleyed Grey Luvisol) at the Lakehead University Agricultural Research Station (LUARS) located at Thunder Bay, Ontario (Latitude 48°18′19″ N, Longitude 89°23′12″ W). Prior to such studies in each year, soil samples were collected from the experimental sites from 4 places in a zig zag manner to a depth of 0-30 cm and composite samples were sent to A&L Canada Laboratories Inc. London, ON for analysis of total plant available N (Table 1). Temperature and rainfall data were collected using a weather station located at the experimental site or the Environment Canada weather station at Thunder Bay Airport that is located 10 km apart throughout the growing season; May to September 2016 to 2018 (Table 2).

Table 1 Soil (0-30 cm) total plant available nitrogen of experimental sites (0-30 cm depth) before canola seeding through 2016 to 2018.

Year	pH	Cation exchange capacity (meq/100g)	Ammoniacal nitrogen (NH_4^+ ppm)	Nitrate (NO_3^- ppm)	Total plant available nitrogen
2016	nd*	nd	4	18	22
2017	6.6	17.6	3	7	10
2018	6.8	19.3	9	13	22

* nd indicates “not determined”.

Table 2 Mean of monthly air temperature or precipitation of experiment sites through May to September of the growing seasons of 2016, 2017, and 2018.

	Mean air temperature (℃)					Precipitation (mm)					
Year	May	Jun.	Jul.	Aug.	Sept.	May	Jun.	Jul.	Aug.	Sept.	Total May to Sept.
2016	9.5	12.3	16.1	17.0	12.5	46	209	64	85	75	479
2017	6.1	12.0	15.8	13.9	10.9	95	76	85	51	102	409
2018	9.8	13.2	16.8	14.7	10.6	41	38	102	49	71	301

In each year, experimental sites sown with a spring cereal crop in the previous year were prepared in an identical manner and were sown with a spring cereal crop in the previous year. Experimental areas were disked then cultivated to reduce weeds prior to fertilizer application and seeding. Glufosinate resistance Liberty canola (cultivar: L5440 for 2016 and L252 for 2017/2018) was seeded at a rate of 5 kg/ha using a plot seeder, following the recommendations of OMAFRA Field Crops publication 811 [27]. Areas were seeded on 30 May 2016, 25 May 2017, and 7 May 2018. Treatment net plots measured 1.5 m wide and 3 m in length, it consisted of 10 rows of canola seeds/plants at 15 cm row spacing. Sixty-six percent of urea and the entire ESN as well as P, K, and B fertilizers were broadcast within treatment plots and incorporated with the seed drill during planting. The remaining 33% of N from urea fertilizer was top dressed prior to bolting at the three-leaf stage. Manganese sulphate was foliar applied. In each of the three years, a post-emergent herbicide application of Liberty (glufosinate) was applied at 3 L/ha to control weeds; Proline (prothioconazole) was applied at 315 mL/ha to control Sclerotinia stem rot when crop reached 20%-50% bloom; and Lorsban 4E (organophostaphate) was applied at 2.5 L/ha to control flee beetle as needed.

In the three years, a regime of fertilizers i.e. Phosphorus 30 kg P_2O_5/ha (67 kg/ha 0-45-0), Potassium 58 kg K_2O/ha (116 kg/ha 0-0-50-18), Sulfur 24 kg S/ha (116 kg/ha 0-0-50-18), Manganese 2 kg Mn/ha (6 kg/ha 0-0-0-32), Boron 1 kg B/ha (7 kg/ha 0-0-0-15), and Zinc 7 kg Zn/ha (20 kg/ha 0-0-0-35.5) were applied.

There were seven fertilizer treatments in 2016, the fertilizer treatments were of two sources of N fertilizer (urea and urea + ESN) applied at 0, 60, 120, and 180 kg N/ha. Urea + ESN was applied at a 2:1 ratio on N basis. The same fertilizer treatments were then applied with a growth regulator (Manipulator 620) at a rate of 1.8 L/ha applied at the fifth to sixth leaf stage for a total of 14 different treatments. There were nine fertilizer treatments in 2017 or 2018, the fertilizer treatments were of two sources of N fertilizer (urea and urea + ESN) applied at 0, 60, 120, 180, and 240 kg N/ha. Urea + ESN was applied at a 2:1 ratio on N basis. The same fertilizer treatments were then applied with a growth regulator (Manipulator 620) at a rate of 1.8 L/ha applied at the fifth-sixth leaf stage for a total of 18 different treatments. The growth regulator used in this trial is commercially available but is not currently registered for use on canola.

2.1 Data Collection

The two center rows of canola were hand harvested. The harvested seed yield was adjusted at 8.5% moisture content. Total biomass yield was also reported from the harvested area. Harvest index and nutrient utilization efficiency were determined for each of the treatments. An average of plant heights was measured for five random plants in each plot after harvest and the average plant height per plot was calculated. Days to flowering and days to maturity were reported. Lodging was determined on a scale from 0 to 9 (0 being standing tall and 9 being flat to the ground).

3. Statistical Analyses

The experiment was arranged in a randomized complete block design, with four replications. Data collected in each year were tested for assumptions prior to statistical analysis. An analysis of variance (ANOVA) was conducted separately for all results in each year using a generalized linear mixed model where N fertilizer rates, fertilizer source, and PGR were considered as fixed effects while block as random effect. An initial statistical analysis was conducted with year as a random effect, but the year itself had a significant interaction, so treatment effects were analyzed separately by year. When $p < 0.05$, a post-hoc Fisher's Least Significant Difference (LSD) test was used to separate treatment means. A regression analysis was also performed, the linear, quadratic, and cubic components were separated using contrast analysis. All analyses were conducted in R Studio version 3.5.2 [28].

4. Results and Discussion

4.1 Weather

Growing conditions for canola production were relatively ideal during the three growing seasons; daily air temperatures (approximately 30 °C) along with adequate precipitation for fairly maintaining decent soil moisture levels during flowering and pod set (Table 2).

4.2 Seed Yield and Biomass Yield

In this study, there was a significant effect of N fertilizer rate on the seed yield of canola in each of the three years, there was also a significant effect of N fertilizer source in 2016, and PGR in 2017 (Table 3). There is a significant interaction effect of N fertilizer rate by PGR and of N fertilizer rate by PGR source in 2017 (Table 3). There was a significant linear relationship between N fertilizer rate and seed yield in the three years and a significant quadratic and cubic relationship in both 2017 and 2018 (Table 4). The effects of N fertilizer rate, source, and PGR on mean seed yield are found in Table 4. Individual treatment means varied considerably over the years from 2,074 kg/ha to 9,592 kg/ha.

Applications of N fertilizer at rates of 60, 120, 180 and 240 kg N/ha from either urea or urea + ESN significantly improved canola seed yields in the three years when compared to the check. When a PGR was added it appears to have increased seed yield in 2016 but significantly decreased seed yield in 2018. There was a significant seed yield increase by N fertilizer source in 2016 when using the combination of urea + ESN at a 2:1 ratio on N basis over urea alone. The effects of N fertilizer rate, source or PGR on seed yield over the three years are seen in Fig. 1.

The literature indicated that N is probably the most important nutrient for canola production as its deficiency could result in seed yield reduction [4, 5, 19]. In this study, seed yield increased with increasing N fertilizer

Table 3 Main effects and interactions in ANOVA of nitrogen rate, source, and PGR on seed yield or biomass yield of canola in each year (2016, 2017, 2018) at Thunder Bay, Ontario.

Main effect	2016	2017	2018
Seed yield (kg/ha)			
N rate	< 0.001	< 0.001	< 0.001
N source	0.003	ns	ns
N rate × N source	ns	ns	ns
PGR	ns	0.024	ns
N rate × PGR	ns	0.006	ns
N source × PRG	ns	ns	ns
N rate × N source × PGR	ns	0.038	ns
Biomass yield (kg/ha)			
N rate	< 0.001	< 0.001	< 0.001
N source	0.004	ns	ns
N rate × N source	ns	ns	ns
PGR	0.042	0.008	0.037
N rate × PGR	ns	0.004	ns
N source × PRG	ns	ns	ns
N rate × N source × PGR	ns	0.040	ns

ns indicates not significant.

Table 4 Effect of nitrogen fertilizer rate, source, or PGR on seed yield and biomass yield of canola in each year (2016, 2017, 2018) at Thunder Bay, Ontario.

Treatment	Nitrogen fertilizer (kg/ha)	Seed yield (kg/ha)	Biomass yield (kg/ha)	Seed yield (kg/ha)	Biomass yield (kg/ha)	Seed yield (kg/ha)	Biomass yield (kg/ha)
		2016		2017		2018	
Urea	0	2,074	4,646	3,759	8,977	2,796	6,301
	60	2,591	6,138	6,069	14,285	4,795	11,168
	120	3,411	7,971	6,613	14,710	5,111	11,297
	180	4,311	9,942	8,117	17,982	5,316	11,840
	240			9,592	21,453	6,530	14,102
Urea + ESN	60	2,842	6,667	5,763	13,460	4,345	10,163
	120	4,106	9,521	7,808	17,349	5,510	12,769
	180	4,768	10,636	8,968	20,958	5,809	12,643
	240			8,491	19,481	6,452	14,139
Urea + PGR	0	2,058	4,865	2,869	9,222	2,133	5,030
	60	3,004	7,093	6,030	13,810	4,638	10,700
	120	3,896	8,987	6,496	14,381	5,107	11,159
	180	4,405	10,234	7,030	15,650	5,767	12,538
	240			8,102	17,711	6,343	13,368
Urea + ESN + PGR	60	3,341	7,781	6,773	15,245	3,916	9,647
	120	4,077	9,643	6,794	15,883	5,290	11,876
	180	5,349	11,908	6,459	14,990	5,418	11,992
	240			8,506	18,708	6,226	13,381
	Mean	3,618	8,347	6,958	18,708	5,083	11,339
	C.V. %	14	12	12	11	11	10
	PR>F	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
	LSD	700	1,481	1,174	2,532	798	1,641
N Rate	0	2,066	4,756	3,814	9,100	2,464	5,666
	60	2,990	7,019	6,159	14,200	4,424	10,420
	120	3,937	9,181	6,928	15,581	5,254	11,775
	180	4,758	10,735	7,643	17,395	5,577	12,253
	240	-	-	8,673	10,665	6,388	13,746
	Linear	***	***	***	***	***	***
	Quadratic	ns	ns	*	*	***	***
	Cubic	ns	ns	*	*	**	***
N Source	None	2,066	4,756	3,814	9,100	2,464	5,666
	Urea	3,603	8,394	7,256	16,248	5,451	12,021
	Urea + ESN	4,080	9,359	7,445	17,009	5,371	12,076
	Linear	***	***	***	***	***	***
	Quadratic	*	*	***	***	***	***
PGR	No	3,443	7,932	7,242	16,517	5,185	11,603
	Yes	3,733	8,644	6,673	15,067	4,982	11,076
	Linear	ns	ns	ns	ns	ns	ns

*, **, *** indicate significance of linear, quadratic and cubic polynomials as appropriate at $p = 0.05$, $p = 0.01$, and $p = 0.001$ respectively; ns: indicates not statistically significant ($p = 0.05$).

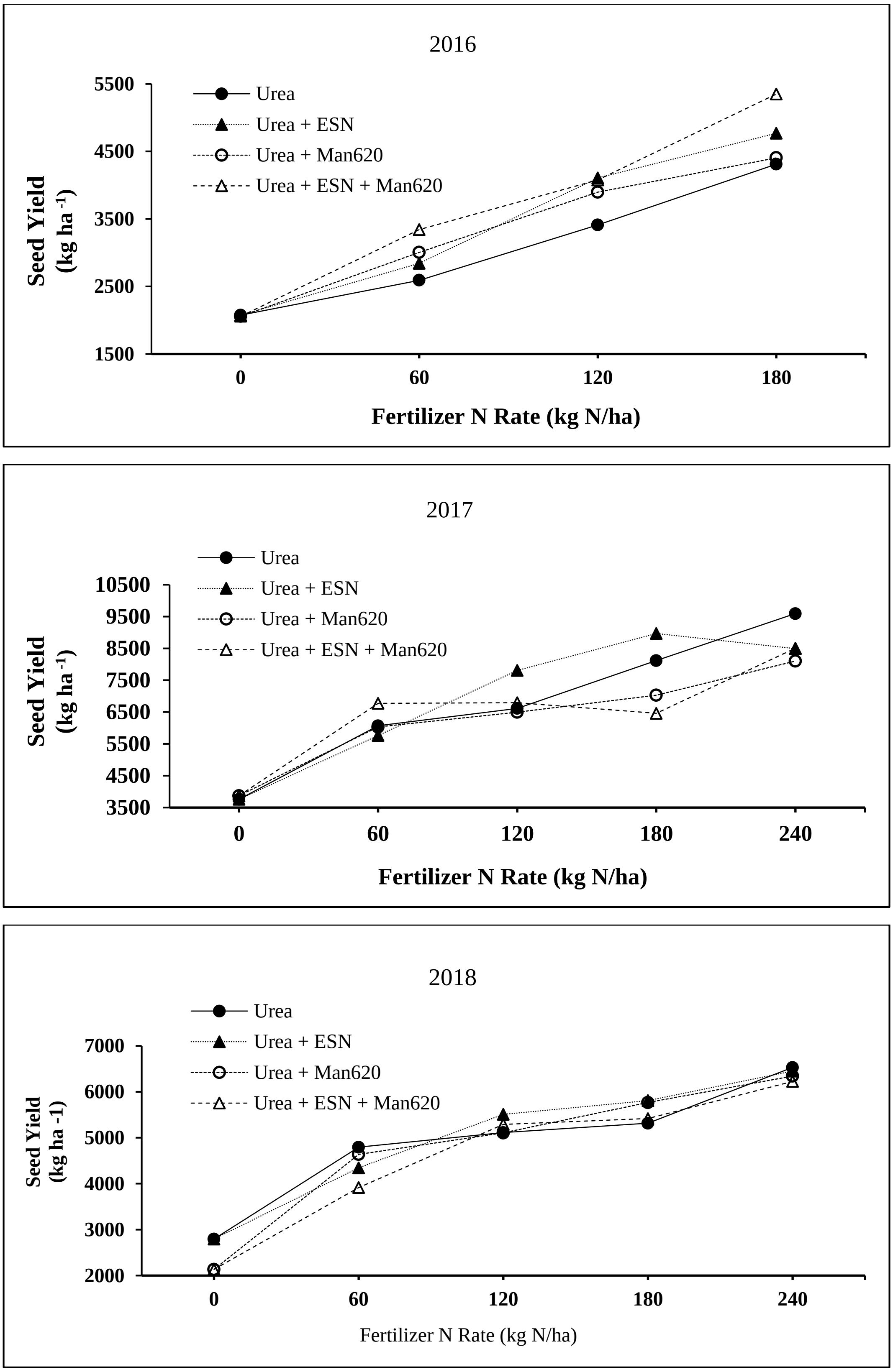

Fig. 1 Effect of application of different nitrogen rates supplied by urea, or ESN, with or without PGR (Manipulator 620) on the seed yield in each year (2016, 2017, 2018) at Thunder Bay, Ontario.

rate with urea in the three years and with urea + ESN in two of the three years. The use of ESN fertilizer has been shown to be more advantageous with higher seed yields in growing seasons that had increased precipitation [1]. The mixture of urea and the polymer-coated urea (ESN) could be a beneficial environmental management option for growers in Northwestern Ontario on canola production as it precedes the use of urea alone.

A significant effect of N fertilizer rate and PGR on the biomass yield of canola was detected in the three years. Meanwhile, a significant effect of N source was rather detected in 2016 (Table 3). A significant interaction effect of N fertilizer rate supplied PGR, and of N fertilizer rate supplied by PGR in 2017 (Table 3). There is a significant linear relationship between N fertilizer rate and biomass yield in the three years and a significant quadratic and cubic relationship in each of 2017 and 2018 (Table 4). The effects of N fertilizer rate, source and PGR on mean biomass yield are found in Table 4. Individual treatment means varied considerably from 4,646 kg/ha to 21,453 kg/ha.

Applications of N fertilizer at rates of 60, 120, 180 and 240 kg N/ha supplied by either urea or urea + ESN significantly improved canola biomass yields in the three years when compared to the check. When a PGR was added it appears to have significantly increased canola biomass yield in 2016 however a decreased biomass yield was detected in 2017 and 2018. There was a significant increase of biomass yield by N fertilizer source in 2016 upon using the combination of urea + ESN at a 2:1 ratio on N basis over urea alone. The effects of N fertilizer rate, nitrogen fertilizer source and PGR on canola plant biomass over the three years are seen in Fig. 2.

Canola in general is very responsive to increased N fertilizer applications when soil moisture levels are not a limiting factor [10, 29]. This was seen in our study as biomass yield increased with N fertilizer rates with urea in the three years and with urea + ESN in two of the three years. The use of urea or urea + ESN gave similar biomass yields in the three years, and the use of urea + ESN was seen to be more suitable source during years of high precipitation like what occurred in 2016.

4.3 Harvest Index and Seed Nutrient Utilization Efficiency

In all three years, there was a significant effect of N fertilizer rate and source on harvest index in both 2017 and 2018 (Table 5). The relationship between harvest index and N rate was linear in 2017 and 2018 but quadratic in 2016 and 2018 (Table 6). As the rate of N fertilizer application increased, the harvest index was increased in each of 2017 and 2018. Similar observations were reported by Cheema et al. [30] who reported that as the fertilizer rate increased, the harvest index increased. However, contrary to our results their research reported that harvest index decreased significantly upon the treatment of 120 kg N/ha [30].

In this study, in all three years, there was a significant effect of N fertilizer rate on seed nutrient uptake, there was also a significant effect of N fertilizer source in 2016 and of PGR in 2018 and an interaction effect of N fertilizer rate by PGR in 2017 (Table 5). There was a significant linear relationship between N fertilizer rate in all years, and a significant quadratic relationship in 2017 and a cubic relationship in 2018. As N fertilizer rates increase, seed nutrient utilization efficiency decreased in all years. Similar observations were made in research by Gan et al. [31] where as N fertilizer rates increase, seed nutrient utilization efficiency decreased.

4.4 Plant Height

Plant height is an indicator of the vegetative growth potential of the crop and is influenced by both its genetics and the environmental factors. In this study, in all three years, canola plant height was significantly affected by the rate of applied N fertilizer (Table 7).

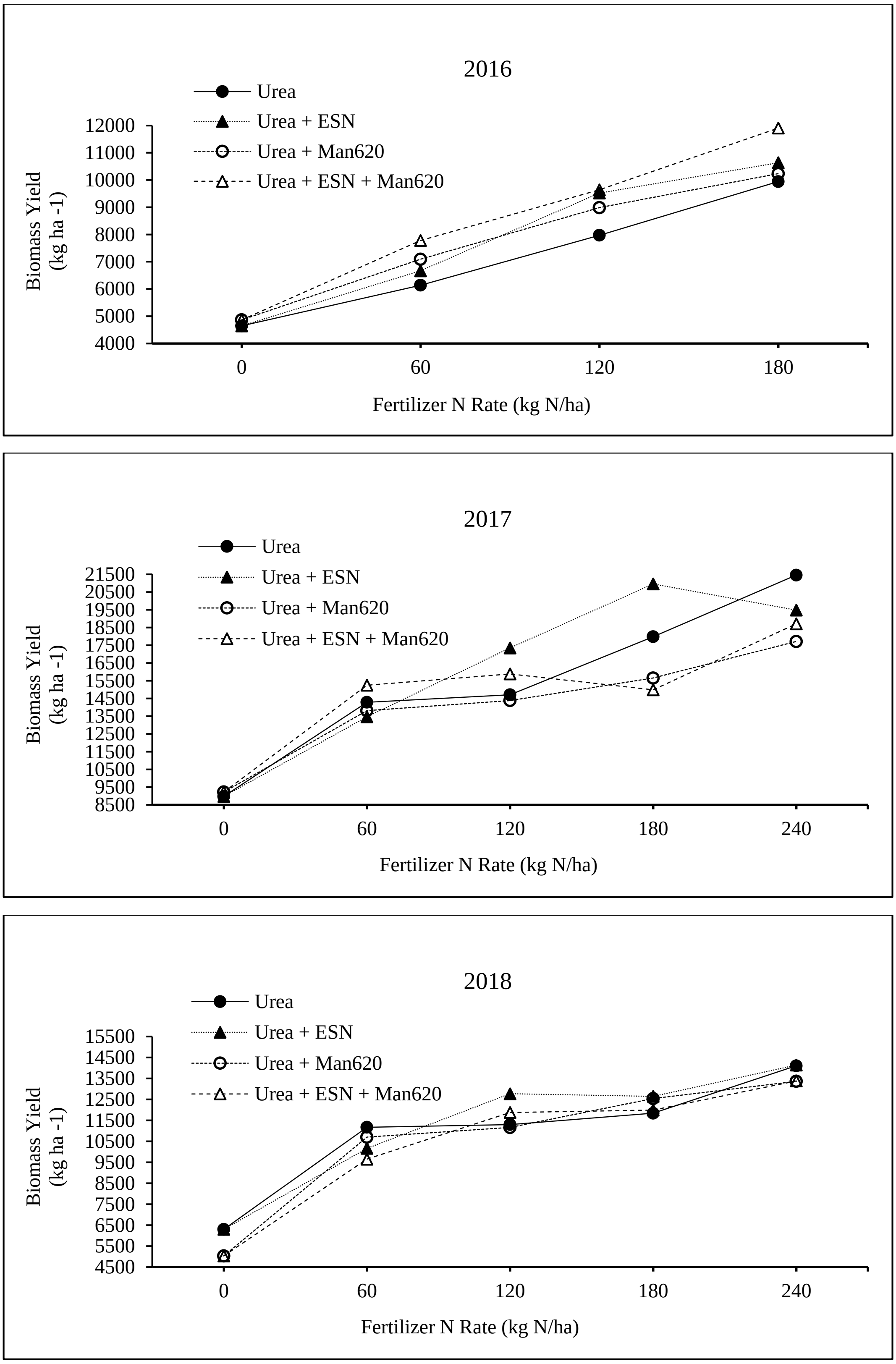

Fig. 2 Effect of application of different nitrogen rates supplied by urea or ESN fertilizer, with or without a PGR (manipulator 620) on the biomass yield of canola in each year (2016, 2017, 2018) at Thunder Bay, Ontario.

Table 5 Main effects and interactions in ANOVA of nitrogen rate, source or PGR on harvest index and seed nutrient utilization efficiency of canola in each year (2016, 2017, 2018) at Thunder Bay, Ontario.

Main effect	2016	2017	2018
Harvest index (%)			
N rate	0.018	0.002	< 0.001
N source	ns	0.019	0.004
N rate × N source	ns	ns	ns
PGR	ns	ns	ns
N rate × PGR	ns	ns	ns
N source × PRG	ns	ns	ns
N rate × N source × PGR	ns	ns	ns
Seed nutrient (kg/kg)			
N rate	0.009	< 0.001	< 0.001
N source	0.016	ns	ns
N rate × N source	ns	ns	ns
PGR	ns	ns	0.002
N rate × PGR	ns	0.046	ns
N source × PRG	ns	ns	ns
N rate × N source × PGR	ns	ns	ns

ns indicates not significant.

Table 6 Effect of nitrogen fertilizer rate, source or PGR on harvest index and seed nutrient utilization efficiency (kg/kg) of canola in each year (2016, 2017, 2018) at Thunder Bay, Ontario.

Treatment	Nitrogen fertilizer (kg/ ha)	Harvest Index (%)	Seed nutrient (kg/kg)	Harvest index (%)	Seed nutrient (kg/kg)	Harvest index (%)	Seed nutrient (kg/kg)
		2016		2017		2018	
Urea	0	44.7	23.6	41.8	42.7	44.3	31.8
	60	42.0	17.5	42.5	41.0	42.9	32.4
	120	42.8	16.4	45.0	31.8	45.3	24.6
	180	43.4	16.1	45.2	30.3	44.9	19.8
	240			44.8	29.2	46.3	19.9
Urea + ESN	60	42.3	19.2	42.8	38.9	42.6	29.4
	120	43.0	19.7	45.0	37.5	43.0	26.5
	180	44.7	17.8	43.0	33.5	45.9	21.7
	240			43.6	25.9	45.6	19.7
Urea + PGR	0	42.3	23.4	42.0	44.0	42.4	24.2
	60	42.3	20.3	43.5	40.7	43.2	31.3
	120	43.4	18.7	45.2	31.2	45.7	24.6
	180	43.1	16.4	44.9	26.2	46.0	21.5
	240			45.8	24.7	47.5	19.3
Urea + ESN + PGR	60	42.8	22.6	44.2	45.8	40.6	26.5
	120	42.2	19.6	42.6	32.7	44.5	25.4
	180	45.0	20.0	43.1	24.1	45.1	20.2
	240			45.5	25.9	46.5	19.0
	Mean	43.2	19.5	43.9	25.9	44.6	24.3
	C.V.%	3	15	4	14	3	12
	PR>F	0.009	0.022	0.002	<0.001	<0.001	<0.001
	LSD	2.0	4.3	2.2	6.5	1.8	4.0

Table 6 to be conttinued

N rate	0	43.5	23.5	41.9	43.3	43.4	28.0
	60	42.4	20.2	43.3	41.6	42.3	29.9
	120	42.9	18.9	44.5	33.3	44.6	25.3
	180	44.3	17.8	44.0	28.5	45.5	20.8
	240	-	-	44.9	26.4	46.5	19.5
	Linear	ns	***	***	***	***	***
	Quadratic	*	ns	ns	ns	ns	ns
	Cubic	ns	ns	ns	*	*	***
N source	None	43.5	23.5	41.9	43.3	43.4	28.0
	Urea	42.8	17.6	44.6	31.9	45.2	24.2
	Urea + ESN	43.4	19.8	43.7	33.0	44.2	23.5
	Linear	ns	**	**	***	ns	*
	Quadratic	ns	***	***	**	*	ns
PGR	No	43.3	18.6 ns	43.7	34.5	44.5	25.1
	Yes	43.0	20.1	44.1	32.8	44.6	23.6
	Linear	ns	ns	ns	ns	ns	ns

*, **, *** indicate significance of linear, quadratic and cubic polynomials as appropriate at $p = 0.05$, $p = 0.01$, and $p = 0.001$ respectively; ns indicates not statistically significant ($p = 0.05$).

Plants which received N applications were significantly taller compared to the check plots (Table 8). The relationship between plant height, N rate and source was linear and quadratic for the three years. Similar to our findings, Ma et al. [32] reported that canola plant height increased at different rates of N fertilizer when compared to the check. In our study, neither source of N fertilizer nor PGR had any effect on canola plant height. Previous studies on PGR have shown and indicated that the application of PGR to Canola could reduce plant height to up to 45 cm and help to prevent lodging under ideal conditions [24].

4.5 Days to Flowering, Days to Maturity and Lodging

The flowering time was not influenced by the applied treatments. Days to flowering upon treatments was not recorded in 2016 and was the same across treatments in each of 2017 or 2018 at 45 and 56 days respectively. Flowering of Canola will occur more quickly at the end of vegetative growth when N becomes a limiting factor [33]. Earlier flowering does not appear to be agronomically beneficial for canola as it is caused by limited N, which would rather limit seed yields [34].

The time to Canola maturity was not impacted by the treatments in this study. Day to maturity was the same across treatments at 88, 112, and 105 days in 2016, 2017, and 2018, respectively. Other studies have shown that an increase in N fertilizer has been shown to delay the flowering and maturity of canola [4, 33, 34]. Delayed maturity can cause late harvest and increased likelihood of under ripe “green” seed which could have a detrimental effect on Canola production in the Northwestern Ontario due to its shorter growing season.

Lodging in Canola was not affected by any treatment in this study. Ratings of lodging in Canola was at 0 for all treatments in 2016, 2017, and 2018. Several studies have shown that as N fertilizer rates increase the occurrence of lodging has increased [35-37]. Although we did not observe the effect of PGRs on lodging through this study, several other studies have shown that PGRs can be an effective management tool for reducing lodging in canola [24-26]. Increased lodging rates can decrease seed yields and create issues during harvest which can affect production costs, as such additional studies should be carried out to identify if PGRs can

Table 7 Main effects and interactions in ANOVA of nitrogen fertilizer rate, nitrogen fertilizer source, or the PGR on plant height of canola in each year (2016, 2017, 2018) at Thunder Bay, Ontario.

Main effect	2016	2017	2018
Plant height (cm)			
N rate	< 0.001	< 0.001	< 0.001
N source	ns	ns	ns
N rate × N source	ns	ns	ns
PGR	ns	ns	ns
N rate × PGR	ns	ns	ns
N source × PGR	ns	ns	ns
N rate × N source × PGR	ns	ns	ns

ns indicates not significant.

Table 8 Effect of nitrogen fertilizer rate, source, or PGR on the plant height of canola in each year (2016, 2017, 2018) at Thunder Bay, Ontario.

Treatment	Nitrogen fertilizer (kg/ha)	Plant height (cm)	Plant height (cm)	Plant height (cm)
		2016	2017	2018
Urea	0	91	113	96
	60	105	123	106
	120	106	127	104
	180	109	127	102
	240	-	127	101
Urea + ESN	60	102	123	103
	120	108	126	98
	180	109	130	99
	240	-	130	102
Urea + PGR	0	94	108	89
	60	104	122	102
	120	107	122	101
	180	110	126	102
	240	-	129	102
Urea + ESN + PGR	60	105	120	100
	120	105	126	101
	180	111	131	101
	240	-	129	101
	Mean	105	125	100
	C.V.%	5	3	4
	PR>F	< 0.001	< 0.001	0.002
	LSD	7	6	6
N Rate	0	92	111	93
	60	104	122	103
	120	106	125	101
	180	110	129	101
	240	-	129	101
	Linear	***	***	***
	Quadratic	**	***	***
	Cubic	ns	ns	**

Table 8 to be conttinued

N Source	None	92	111	93
	Urea	107	126	102
	Urea + ESN	107	127	101
	Linear	***	***	***
	Quadratic	***	***	***
PGR	No	104	125	101
	Yes	105	124	100
	Linear	ns	ns	ns

*, **, *** indicate significance of linear, quadratic and cubic polynomials as appropriate at $p = 0.05$, $p = 0.01$, and $p = 0.001$ respectively; ns indicates not statistically significant ($p = 0.05$).

still be an effective tool in managing lodging in canola production in Northwestern Ontario.

5. Conclusion

Our results suggest that canola seed yield and biomass are highly dependent on having proper N fertilizer levels available for the crop. Urea with N at 240 kg/ha offered the highest yield potential in the years it was applied. Urea and urea + ESN offered similar yield potential in the three years, and urea + ESN offered a higher seed yield in 2016 a year with higher precipitation. Averaged over three years, urea + ESN @ 180 kg N/ha produced 600 kg/ha more canola seed yield than urea @ 180 kg N/ha. Diversifying N source supplied by urea alone to when by Urea + ESN could offer increased crop protection in uncertain year at a low economic cost with a possibility of higher return. We would not advise the use of PGR in the Northwestern Ontario as it had no effect on plant height or lodging of the Canola crop. It would be more economically beneficial for that money to be put towards other uses.

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Conflict of Interests

The authors declare there are no competing interests.

Author Contributor

Tarlok Singh Sahota conceptualized the project, preformed the research, the Technicians (see acknowledgement) helped in analysis of the data and one of them, Dillon Muldoon, helped Tarlok Singh Sahota in writing the manuscript.

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