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Mineral Nitrogen Effects of Hairy Vetch (*Vicia villosa* Roth) on Maize (*Zea mays* L.) by Green Manure Amounts

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Abstract: Legume with low C-to-N is more getting acceptance as an alternative to nitrogen (N) fertilizer because of high price of N fertilizer recently. Amounts of fresh aboveground hairy vetch equivalent to N rates of 80, 160 and 240 kg ha^{-1} were incorporated into soil as alternative N source for two years of maize in Suwon, Korea and were compared to the same N amounts applied as N fertilizer, ammonium nitrate. Soil organic N was increased considerably by hairy vetch. Dry matter (DM) yields of maize increased more in hairy vetch than ammonium nitrate with N rates over 160 kg ha^{-1}. Maize N yields were not different between two N sources with N rates under 160 kg ha^{-1}, but was higher in hairy vetch than ammonium nitrate with N rate 240 kg ha^{-1} showing superior mineral N alternative of hairy vetch to N fertilizer at high N rate.

Key words: Hairy vetch, N fertilizer, maize, dry matter, N yield

INTRODUCTION

Low C-to-N winter legumes can replace chemical N fertilizer for subsequent maize by releasing considerable mineral N in addition to increase of soil C and N pools during residue decomposition (Drinkwater *et al*., 1998). Among winter annual legumes, hairy vetch is gaining acceptance as a viable alternative to N fertilizer for sustainable maize production because of its superior merits such as higher over-wintering, rapid re-growth in early spring and better matching of available N on the N requirement of subsequent maize by rapid residue decomposition after incorporation according to high plant N concentration as much as 3.6~4.1% (Stute and Posner, 1995).

Amount of aboveground hairy vetch which has most of N in the aboveground fraction as much as 90% of the total plant N (Mitchell and Teel, 1977; Seo *et al*., 2000), is proportioned to its N content owing to later maturation than other legume cover crops in spring (Smith *et al*., 1987). But, the quantities of aboveground hairy vetch available at maize planting time which is late April or early May in Korea, have fluctuated substantially from year to year due to prevailing weather conditions prior to planting maize (Teasdale *et al*., 2004).

Therefore, accurate evaluation of the mineral N effects on maize by different amounts of aboveground hairy vetch is prerequisite for making on optimum management recommendations regarding the need for supplementary N fertilizer or the timing of hairy vetch incorporation in spring, particularly on silage maize which needs much N fertilizer over 200 kg N ha^{-1} for production under Korean monsoonal weather condition which has much rainfall during summer maize production period. So, this field study was undertaken to compare the mineral N effects of aboveground hairy vetch on maize DM and N yield by incorporated amounts compared to each N rate of N fertilizer.

MATERIALS AND METHODS

The study was conducted at the upland field in Suwon, Korea (lat. 37EN, long. 127EE) from 1998 through 1999. The soil in the experiment is a well-drained Jungdong loam (coarse loamy, mixed, mesic, Typic Udifluvents), relevant physical and chemical properties are given in Table 1. The growing season (April-August) precipitations during the maize growth period were 1304 and 955 mm in 1998 and 1999, respectively, similarly with normal precipitation of

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Table 1: Physical and chemical soil characteristics of the experimental field

Soil depth (cm)	Soil texture Sand (%)	Clay (%)	Texture	Bulk density (g cm^{-3})	pH water (1:5)	Soil OM (g kg^{-1})	Available P (mg kg^{-1})	Cation exchange capacity (cmol c kg^{-1})
0-15	50	9	Loam	1.28	5.7	15	51	8.1
15-30	57	11	Loam	1.44	6.6	14	41	8.3
30-60	60	10	Sandy loam	-	6.1	10	32	7.6

Table 2: Precipitation during corn season in 1998 and 1999

Years	Precipitation (mm) April	May	June	July	August	Total
1998	105.9	86.4	213.7	306.0	591.6	1303.6
1999	73.6	121.3	76.7	345.0	338.4	955.0
30 year average	76.1	90.7	133.4	302.9	305.9	909.0

Table 3: Amounts of fresh aboveground hairy vetch to achieve targeted treatment N rates

Years	N conc. of dry matter (g kg^{-1})	Dry weight (%)	N conc. of fresh matter (g kg^{-1})	Amount of fresh matter (g m^{-2}) by N rate (kg ha^{-1}) 80	160	240
1998	39	12.0	4.68	1709	3419	5128
1999	38	13.5	5.13	1562	3126	4689

909 mm. However, the precipitation during experiment was concentrated in July and August during two maize seasons (Table 2).

The experimental design was a randomized complete block with five replicates with N treatments of 0 kg N ha^{-1}, hairy vetch 80, 160, 240 kg N ha^{-1} and ammonium nitrate 80, 160, 240 kg N ha^{-1}. Hairy vetch (variety Madison) was sown in mid September each previous year, in a field adjacent to the main experimental field. Amounts of fresh aboveground hairy vetch required to match N rates were determined by N concentration of dried hairy vetch (CNS2000, LECO, USA) and dry weight percent of fresh hairy vetch before incorporation (Table 3). Appropriate amounts of hairy vetch were cut and incorporated in the appropriate plots by rototiller at 7 days before maize planting and mixed well with soil by rototiller again at maize planting. Sufficient ammonium nitrates to reach the treatment-specific N rates were incorporated into soil at maize planting as basal N in 1998. But in 1999, half of each ammonium nitrate was applied to soil as basal N at maize planting and the other each half was sidedress applied at the six-leaf stage of maize following the conventional N application method of silage maize in Korea.

Each plot was measured 4.5 by 4.5 m. These treatments were continued for 2 years in the same plot positions. Phosphate (fused phosphate, 66 kg P ha^{-1}) and potassium (potassium chloride, 125 kg K ha^{-1}) were broadcast as basal fertilizer to all plots with basal N fertilizer. The maize variety P3352 (118 days relative maturity) was hand-seeded to a 5 cm depth on 2nd and 3rd May in 1998 and 1999, respectively, with planting density of 66,667 plants ha^{-1} (achieved by 75 cm row spacing and 20 cm hill spacing).

Soil samples for the determination of total soil C, N and microbial biomass N were taken at the soil depth 0-15 cm by auger from ten sites within each plot at maize planting and harvest. Soil samples for nitrate content over soil 0-30 cm at maize six-leaf stage were also collected at soil depth intervals of 0-15 and 15-30 cm with 3 cores (100 cm^{3}) per plot. Total soil C and N was analyzed by an automated Dumas instrument, CNS2000 (LECO, USA). Soil nitrate were determined with Griess-Ilosvay method colorimetrically followed by reduction of nitrate to nitrite by copperized cadmium column. Soil nitrate contents over 0-15 and 15-30 cm were calculated by soil bulk density of each soil layer. Soil microbial biomass N was analyzed by Joergensen and Brookes (1990) method with chloroform fumigation, 2 M KCl extraction and ninhydrin reaction.

Maize plant samples were collected and weighed in one 2 m row per plot at silking stage in mid July and in two 3 m row per plot at the black-layer stage in late August, respectively. Three maize stalks per plot were chopped at sampling times. Chopped stalks and ear were dried for 4 and 7 days, respectively, in a forced air oven at 65°C. Grains were shelled from ears. Dried stalks (with cobs) and grains were weighed and ground in a Wiley mill (Brabender, Germany) and then reduced to fine powder (<0.15 mm) in a vibrating ball mill (Heiko model TI-100). N concentrations of maize samples were also analyzed with an automated Dumas instrument, CNS2000 (LECO, USA).

RESULTS AND DISCUSSION

Soil N enrichment: Incorporation of legume with low C-to-N ratio increases soil organic N such as soil microbial biomass N and humus N along with release of mineral N from legume to soil during residue decomposition because it contains C source (Azam *et al*., 1985; Harris *et al*., 1994; Seo *et al*., 2005). Incorporation of hairy vetch with N rate 160 and 240 kg ha^{-1} resulted in increases of 0.08~0.1 g kg^{-1} in total soil N and 0.6~1.0 g kg^{-1} in total soil C, respectively (Table 4).

Soil microbial biomass N was also increased over two times by hairy vetch at three each N rate compared with no N source or N fertilizer. But soil microbial biomass N was decreased by ammonium nitrate compared with no N fertilizer implying the diminishment of soil microbial biomass by inorganic chemical N fertilizer. Judging from the increase of soil microbial biomass N by hairy vetch incorporation, soil microbial biomass N seems to retain much of the organic N fraction recovered from hairy vetch (Harris and Hesterman, 1990).

Soil nitrate contents over soil 0-30 cm at maize six-leaf stage in 1998 were 53 and 65% lower in hairy vetch with N rates of 160 and 240 kg ha^{-1} than ammonium nitrate with the same N rates, respectively showing low N mineralization from hairy vetch compared to N fertilizer. The low N mineralization from hairy vetch would be related with much conversion from hairy vetch N to soil organic N under input of C contained in hairy vetch. Earlier researches reported high recovery of legume N to soil organic N pool, particularly to soil microbial biomass N and humic compounds, relative to N fertilizer that does not contain C at the experiments with red clover (Harris *et al*., 1994) and hairy vetch (Varco *et al*., 1993; Hu *et al*., 1996). Nitrate contents over soil 0-30 cm at six-leaf stage in 1999, in the year of split application of total ammonium nitrate, were higher at the plots of hairy vetch than ammonium nitrate at six-leaf stage, which suggested that the N mineralization from hairy vetch in soil was higher than that from 50% of ammonium nitrate N at each N rate.

Maize DM yield: Maize DM at silking stage was not different between two N sources with N rate 80 kg ha^{-1} for two years. But maize DM at silking stage were 1 Mg ha^{-1} higher nearly in hairy vetch than ammonium nitrate with N rates of 160 and 240 kg ha^{-1} in 1998, in 1999 and in two years average showing early vigor growth before maize silking stage by hairy vetch green manure (Table 5).

Whole DM yield at harvest, which was consisted with stalk and grain DM yield, increased two times approximately at each plot compared with DM at silking stage mainly owing to increase of grain DM. Whole DM yield at harvest was also not different between two N sources with N rate 80 kg ha^{-1}, but increased nearly 1 and 2 Mg ha^{-1} more in hairy vetch with N rates of 160 and 240 kg ha^{-1}, respectively. Whole DM yield was the highest in hairy vetch with N rate 240 kg ha^{-1}. Whole DM yield in hairy vetch with N rate 160 kg ha^{-1} was the same with that in ammonium nitrate with N rate 240 kg ha^{-1}. It is thought that N mineralization from hairy vetch with N rates over 160 kg ha^{-1} was not limiting factor on vigorous growth of maize at the plots of hairy vetch compared to ammonium nitrate judging from higher DM yields in hairy vetch than ammonium nitrate with the same N rate.

Stalk DM yields at harvest were the same trend with whole DM yield showing 1 and 1.5 Mg ha^{-1} more in hairy vetch with N rates of 160 and 240 kg ha^{-1} than ammonium

Table 4: Changes of concentrations of total soil C, N and soil microbial biomass N over soil 0-15 cm and soil nitrate content over soil 0-30 cm during experiment

N rate (kg ha^{-1})	Total soil C (g kg^{-1})			Total soil N (g kg^{-1})			Soil microbial biomass N (mg kg^{-1})			Soil NO_3-N content (kg ha^{-1})	
N source	1998P[a]	1998H[b]	1999H	1998P	1998H	1999H	1998P	1998H	1999H	1998SL[c]	1999SL
0	8.54	8.24	8.48	0.83	0.76	0.79	12.2	16.9	20.8	26	21
80-hairy vetch	8.44	8.72	9.00	0.80	0.82	0.80	12.3	15.9	28.7	77	91
80-NH_4NO_3	8.36	8.40	8.53	0.79	0.80	0.79	11.7	13.6	13.6	75	58
160-hairy vetch	8.46	9.12	9.24	0.80	0.86	0.89	12.2	18.1	28.6	108	140
160-NH_4NO_3	8.44	8.29	8.38	0.78	0.77	0.78	11.4	12.0	13.3	206	93
240-hairy vetch	8.42	8.76	9.40	0.81	0.87	0.89	9.6	18.5	32.0	167	183
240-NH_4NO_3	8.35	8.48	8.40	0.79	0.80	0.79	10.6	14.1	11.0	258	148
LSD (5%)	NS	0.42	0.44	NS	0.05	0.05	NS	4.3	6.8	36	28

[a]P: At maize planting, [b]H: At maize harvest, [c]SL: At maize six-leaf stage

Table 5: Changes of DM at silking and DM yield at harvest of maize as affected by N rate and source in 1998 and 1999

N rate (kg ha^{-1})	DM at silking (Mg ha^{-1})			Stalk DM yield (Mg ha^{-1})			Grain DM yield (Mg ha^{-1})			Whole DM yield (Mg ha^{-1})		
-N source	1998	1999	Mean	1998	1999	Mean	1998	1999	Mean	1998	1999	Mean
0	4.2	6.2	5.2	4.4	6.9	5.6	2.1	1.4	1.7	6.5	8.3	7.4
80-hairy vetch	8.0	9.9	8.9	10.9	10.8	10.9	6.5	5.1	5.8	17.5	15.9	16.7
80-NH_4NO_3	8.2	10.5	9.3	9.7	11.6	10.6	6.4	6.0	6.2	16.1	17.5	16.8
160-hairy vetch	9.2	11.2	10.2	11.8	12.8	12.3	8.2	7.7	7.9	20.0	20.5	20.3
160-NH_4NO_3	8.8	10.3	9.5	10.4	12.0	11.2	7.9	7.7	7.8	18.2	19.6	18.9
240-hairy vetch	9.1	11.5	10.3	12.3	13.6	13.0	8.3	9.1	8.7	20.6	22.7	21.7
240-NH_4NO_3	8.4	10.2	9.3	10.2	12.7	11.5	8.3	8.1	8.2	18.6	20.7	19.6
LSD (5%)	0.8	0.7	0.6	1.1	1.1	0.9	0.7	0.9	0.6	1.5	1.7	1.3

Table 6: Changes of N content at silking and N yield at harvest of maize as affected by N rate and source in 1998 and 1999

N rate ($kg\ ha^{-1}$) -N source	N content at silking ($kg\ ha^{-1}$)			Stalk N yield ($kg\ ha^{-1}$)			Grain N yield ($kg\ ha^{-1}$)			Whole N yield ($kg\ ha^{-1}$)		
	1998	1999	Mean	1998	1999	Mean	1998	1999	Mean	1998	1999	Mean
0	31	32	31	17	20	19	26	15	20	42	35	39
80-hairy vetch	82	81	82	47	33	40	71	51	61	119	84	102
80-NH_4NO_3	94	96	95	37	34	35	79	64	71	115	97	106
160-hairy vetch	127	128	128	73	54	64	112	90	101	185	144	165
160-NH_4NO_3	144	128	136	64	65	64	109	93	101	174	158	166
240-hairy vetch	160	164	162	97	80	89	129	118	123	226	198	212
240-NH_4NO_3	153	149	151	75	80	77	122	104	113	197	185	191
LSD (5%)	9	17	9	8	11	8	11	11	9	13	16	11

nitrate with the same N rates in two years average, respectively. Grain DM yields were more affected by N rate rather than N source showing rapid increase of grain DM by increase of N rate in both N sources. Grain DM in hairy vetch with N rate 240 kg ha^{-1} was the highest as 8.7 Mg ha^{-1} in two year average.

Maize N yield: Maize accumulates 55~80% of total N yield before silking (Wang *et al*., 1990). At this experiment, maize absorbed approximate 80% of total N yield at harvest before silking showing the importance of N uptake during early maize growth stage (Table 6).

Maize N contents at silking stage increased straightly as N rate increased. Maize N contents at silking stage were lower in hairy vetch with N rate 80 kg ha^{-1} than ammonium nitrate with the same N rate in 1998 and in two years average because of its lower N concentration of maize plant in hairy vetch treatments (data not shown), but differences of maize N contents at silking stage were diminished between the two N sources as N rate of two N sources increased over 160 kg ha^{-1}. Poor maize N uptake at silking stage following hairy vetch compared to ammonium nitrate with N rate 80 kg ha^{-1} in 1998 and 1999 presumably resulted from higher N recovery to soil organic N. However, even these hairy vetch with low N rate could have considerable benefit to soil sustainability considering the higher total soil C, N and microbial biomass N. But it is thought that enough mineral N for maize growth was released from soil decomposition of hairy vetch with high N rates over 160 kg ha^{-1} because DM and N contents of maize at silking stage showed the same or higher values in hairy vetch with N rates of 160 and 240 kg ha^{-1} than ammonium nitrate with each N rate.

Whole maize N yield at harvest increased linearly by increase of hairy vetch amount similarly with ammonium nitrate, which implies that hairy vetch as N source has similar mineral N effect with N fertilizer. Whole N yield at harvest in hairy vetch with N rate 80 kg $ha^{-1}$was the same with ammonium nitrate with the same N rate though maize N content at silking stage was lower in hairy vetch than ammonium nitrate with N rate 80 kg ha^{-1}. Whole N yield was 20 kg ha^{-1} higher in hairy vetch with N rate 240 kg ha^{-1} than ammonium nitrate with the same N rate mainly owing to increase of grain N yield in hairy vetch treatment.

Stalk N yield increased clearly as N rate increased showing no difference between two N sources at each N rate. Grain N yield also increased clearly as N rate increased. Grain N yield was lower in hairy vetch with N rate 80 kg ha^{-1} but higher in hairy vetch with N rate 240 kg ha^{-1} than in ammonium nitrate with each N rate, respectively. Generally, mineral N effect on maize N yield at harvest was no difference between two N sources with three each N rate in spite of slightly lower and higher in hairy vetch with N rate of 80 and 240 kg ha^{-1}, respectively, which implies that hairy vetch could be better an alternatives to N fertilizer in case of high price of chemical N fertilizer.

Furthermore, the higher maize DM yield in hairy vetch with N rate 240 kg ha^{-1} showed promising use of hairy vetch N as mineral N source on maize. Active maize N uptake at hairy vetch with N rate 240 kg ha^{-1} compared to ammonium nitrate with the same N rate could be credited to (i) less N loss by higher immobilization of hairy vetch N to soil organic N pool than ammonium nitrate N and higher slow N remineralization from increased soil organic N pool and (ii) facilitated maize growth and DM yield by hairy vetch green manure along with absorbing more soil N, which means higher maize N use efficiency in hairy vetch green manure with high N amount through higher maize N utilization efficiency than N fertilizer (Russelle *et al.*, 1987).

Higher maize N use efficiency in hairy vetch green manure with N rates over 160 kg ha^{-1} could be more beneficial particularly in Korean weather condition with heavy rainfall during maize growth by which much mineral N from chemical N fertilizer would be leached, particularly in maize production with sandy soil at which hairy vetch growth is more vigor on the contrary than other clay soil types.

In addition, the required hairy vetch amount as N source for maize could be reduced year by year with the same mineral N effect on maize because N mineralization from organic soil N pool could be increased with yearly continuous input of hairy vetch (Bouldin, 1987), which could also increase mineral N effect on maize even in the input of hairy vetch with low N rate gradually.

CONCLUSION

Amounts of fresh aboveground hairy vetch equivalent to N rates of 80, 160 and 240 kg ha^{-1} were incorporated into soil for two years of maize in Suwon, Korea and were compared to the same N amounts applied as N fertilizer, ammonium nitrate to investigate the mineral N effect of hairy vetch green manure on maize as alternative to N fertilizer. Soil organic N such as total soil N or soil microbial biomass N was increased considerably by hairy vetch incorporation. Whole maize DM yield at harvest were higher in hairy vetch than ammonium nitrate with N rates over 160 kg ha^{-1}. Mineral N effect of hairy vetch on maize N yields was not different between two N sources at three N rates generally showing a superior mineral N alternative of hairy vetch to chemical N fertilizer. Furthermore, maize N yield in hairy vetch with N rate 240 kg ha^{-1} was higher than ammonium nitrate with the same N rate showing that hairy vetch contributed to higher potential of maize N use in high N rate as well as soil N sustainability. Incorporation of hairy vetch with N amount over 200 kg ha^{-1} at maize planting was recommended to produce high maize DM yield along with high N yield under the condition of no N fertilizer.

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