CONTINUING NITROGEN INJECTION RESEARCH

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Background Information

Turfgrass fertilization has traditionally been accomplished through surface applications. This is due to the unavailability of equipment that can place fertilizers below the soil surface without causing significant surface disruption. The introduction of the HydroJect® to the turfgrass management marketplace made subsurface placement of soluble materials in established turf a possibility. Although the HydroJect was introduced purely as a tool for soil cultivation, previous studies have concluded that injecting soluble nutrients through it may be beneficial to turfgrass.

A study was initiated during the summer of 1994 at Michigan State University's Hancock Turfgrass Research Center to examine the effects of injecting nitrogen with the HydroJect on fairway and putting green turfs. Treatments included three rates of urea, either injected or surface applied. Plots injected with urea had consistently higher clipping yields, nitrogen content in plant tissues, and color ratings than plots receiving surface applications. These differences were thought to be the result of ammonia volatilization from surface applications, even though plots were irrigated shortly after application.

This theory was tested by repeating the study in 1995 using ammonium nitrate as the nitrogen source, which is much less susceptible to volatilization than urea. Results from the 1995 study were very similar to those recorded in 1994. Clipping yields, nitrogen content in plant tissues and color ratings were all increased by injecting ammonium nitrate. Plots injected with nitrogen had longer response times to the applications than plots receiving surface applications during both years. Plots receiving surface applications had immediate flushes of growth and green up responses that faded six to eight days following application. Plots injected with nitrogen took a few days longer to green up, but increased growth and greening continued two to three weeks. Additionally, plots injected with nitrogen were less susceptible to moisture stress than plots receiving surface applications. These results suggest that by injecting nitrogen, a turfgrass manager may be able to use less total nitrogen and increase water use efficiency when compared to making surface applications.

Turf injected with nitrogen exhibited striping, due to the nozzle alignment of the HydroJect, on some dates. Striping was most evident on closely mowed putting green turf, 5 to 14 days following application. Turf striping occasionally reduced surface uniformity on putting green turf to a level probably unacceptable to most turf managers.

Plots receiving surface applications of nitrogen in these studies were never subjected to HydroJect treatment with water alone. Therefore, differences in turfgrass responses could be attributed to either the placement of nitrogen beneath the surface, or the benefits of soil aerification from the HydroJect.

Current Research Objectives

A group of studies were initiated during the 1997 growing season to compare the efficiencies of surface application and subsurface injection of nitrogen. The overall objective of the nitrogen injection studies is to determine if nitrogen application via injection is a practical and an improved means of fertilizing turfgrass. More specifically, the objectives of the 1997 studies were to compare injection and surface applications of nitrogen by:

1. Evaluating turfgrass responses to both nitrogen application methods and water injection cultivation.
2. Evaluating methods of injecting nitrogen to minimize striping of the turf.
3. Developing partial nitrogen budgets for each application method through ^{15}N application and monitoring its movement through the soil and turf.

Materials and Methods

Application Method - Water Injection Cultivation Study

The application method - water injection cultivation study was initiated in May 1997 at the Hancock Turfgrass Research Center on a one year old 'Penncross' creeping bentgrass putting green established on a root zone mix meeting USGA specifications. The experimental area is mowed at 5/32" and maintained under typical putting green management practices. Pesticides are applied on a curative basis and phosphorus and potassium are applied as recommended from soil test values. This study contained two treatment factors, management practice and nitrogen rate. There were four management practices: 1. Surface applied nitrogen without supplemental water injection cultivation, 2. Surface applied nitrogen with supplemental water injection cultivation, 3. Nitrogen injected using a #56 nozzle (approximately 3" injection depth), and 4. Nitrogen injected using a #53 nozzle (approximately 5" injection depth). The two nitrogen rates evaluated were 1. 0.5 lb. N per 1000 ft^2 per application and 2. 1.0 lb. N per 1000 ft^2 per application. These two factors yield eight individual treatments, which are summarized in Table 1. This treatment arrangement allows specific and separate analyses of the effects of nitrogen placement and water injection cultivation.

Table 1. Application Method - Water Injection Cultivation Treatment Summary

#	Management Practice	Nitrogen Rate
1.	N applied on surface with no WIC	0.5 # N per 1000 ft^2 per application
2.	N applied on surface with no WIC	1.0 # N per 1000 ft^2 per application
3.	N applied on surface plus WIC	0.5 # N per 1000 ft^2 per application
4.	N applied on surface plus WIC	1.0 # N per 1000 ft^2 per application
5.	N injected with #56 nozzle	0.5 # N per 1000 ft^2 per application
6.	N injected with #56 nozzle	1.0 # N per 1000 ft^2 per application
7.	N injected with #53 nozzle	0.5 # N per 1000 ft^2 per application
8.	N injected with #53 nozzle	1.0 # N per 1000 ft^2 per application

The nitrogen source for all applications was ammonium nitrate. Nitrogen applications were made once a month throughout the growing season. Fertilizer injections and water injection cultivations were accomplished by a HydroJect 3000 provided by the Toro Co. of Minneapolis. Nitrogen injections were achieved by pumping dissolved ammonium nitrate from a mounted tank to the intake line of the HydroJect. Surface applications were made using a CO_2 powered sprayer designed specifically for small plot applications. Water injection cultivation immediately followed surface application of nitrogen on appropriate plots. Approximately two tenths of an inch of water were applied to the experimental area immediately following treatment applications. Treatment applications were made on May 2, May 28, Jun. 27, Jul. 31, Aug. 25, Sep. 25, and Nov. 12. The November application was a double rate late fall application.

Clippings were collected by mowing two passes lengthwise on each plot with a Toro 1000® greens mower once a week from May through October. Clippings were dried at 60° C and weighed to determine yield. Dried clippings were used to determine nitrogen content in plant tissue using Karsten NIRS (near infrared spectrometry). Turfgrass quality and color ratings were taken weekly throughout the growing season. Quality ratings were based on a scale from 1 to 9, with 1 representing dead turf, 6 representing acceptable turf, and 9 representing dark green, uniform, dense turf. A similar scale was used for color ratings with 1 representing brown turf, 6 representing acceptable colored turf, and 9 representing dark green turf. Wilt ratings were taken when noticeable drying had occurred over the experimental area. A scale of 1 to 9 was used with 1 representing no wilt, 6 representing moderate wilt, and 9 representing severe wilt. A portable TDR (time domain reflectometry) unit was used to measure volumetric soil moisture content during dry down periods to estimate water use efficiency.

Striping Study

The striping study was initiated in June 1997 at the Hancock Turfgrass Research Center on a 14-year old *Poa annua* turf established on a sandy loam soil. The experimental area were mowed at 5/32" and managed under typical putting green management practices. Pesticides were applied on a curative basis and phosphorus and potassium were applied as recommended from soil test values. Seven nitrogen application methods are evaluated in the study:

1. Surface application
2. Injected with #53 nozzle (approximately 5" depth)
3. Injected with #56 nozzle (approximately 3" depth)
4. Injected with 2 orifice prototype nozzle
5. Injected with 3 orifice prototype nozzle
6. Injected with #53 nozzle while surface roller washers on (using nitrogen solution)
7. Injected with #53 nozzle at half rate making two passes in perpendicular directions

The nitrogen source and rate for all applications was ammonium nitrate applied at 1.0 lb. per 1000 ft^2. Three applications were made with approximately six week intervals during the growing season. Treatments were applied using the same equipment described in the application method - water injection cultivation study. Treatment applications were made on Jun. 25, Aug. 13, and Sep. 25.
Quality, color, and stripe ratings were taken weekly following treatment applications. Quality and color ratings were taken in the same manner described in the application method -water injection cultivation study. A scale of 1 to 5 was used to evaluate turfgrass striping with 1 representing no discernible striping, 2 representing barely discernible striping, 3 representing fairly discernible striping, 4 representing easily detected striping, and 5 representing obvious striping with sharp contrasting stripe borders.

^{15}N Nitrogen Budget Study

The ^{15}N nitrogen budget study was initiated in August 1997 at the Hancock Turfgrass Research Center on a one year old 'Penncross' creeping bentgrass putting green established on a root zone mix meeting USGA specifications. The experimental area was mowed at 5/32" and maintained under typical putting green management practices. Pesticides were applied on a curative basis and phosphorus and potassium were applied as recommended from soil test values. This study consisted of only two treatments, 1. surface applied nitrogen and 2. injected nitrogen. The nitrogen source and rate for all applications was ^{15}N labeled ammonium nitrate applied at 1.0 lb. per 1000 ft^2. Nitrogen injections were made using a HydroJect 3000 fitted with #53 nozzles (approximately 5" injection depth). Surface applications were made with a spray bottle. Approximately two tenths of an inch of water were applied to the experimental area immediately following treatment application. Clippings, verdure, thatch, roots, and soil were extracted from plots at 1, 2, 3, 7, 15, and 30 days after treatment application. Soil and plant materials are currently in the laboratory undergoing grinding and ^{15}N analysis. No data are available yet from this study.

Results

Application Method - Water Injection Cultivation Study

Clippings were harvested and analyzed for yield on 22 dates in 1997 (Table 2). As expected, plots receiving the 1.0 lb. per 1000 ft^2 rate of nitrogen had significantly higher clipping yields on 21 of 22 harvest dates. The only date where nitrogen rate had no effect on clipping yield was the first harvest date on May 9, one week following the initial treatment application. Management practices significantly affected clipping yields on 14 of 22 harvest dates. Management practices seemed to have a greater effect from mid May through August. Thereafter, there were few differences in management practice clipping yield means. On average, both nitrogen injection management practices had significantly higher clipping yields than both surface application management practices. Water injection cultivation had no significant effect on clipping yields.

Table 2. 1997 clipping yield averages from 22 harvest dates.

Management Practice	Clipping Yield Mean (g/m²/day)
injected nitrogen w/#56 nozzle	4.40 A†
injected nitrogen w/#53 nozzle	4.26 A
surface nitrogen, no W.I.C.††	2.84 B
surface nitrogen plus W.I.C.	2.68 B
$LSD_{0.05}$†††	*0.39*
Nitrogen Rate	
1.0 lb. N/1000 ft²/application	4.27
0.5 lb. N/1000 ft²/application	2.82
significance‡	***
Nitrogen Placement Contrast	
injected nitrogen	4.33
surface nitrogen	2.68
significance	***
W.I.C. Contrast	
no W.I.C treatment	2.84
W.I.C. treatment applied	2.68
significance	*n.s.*

† Factor means sharing a letter are not significantly different at the 0.05 level of probability.
†† W.I.C. – water injection cultivation.
††† Fisher's protected least significant difference at the 0.05 level of probability.
‡ ***, *n.s.* – significant at the 0.01 level of probability and not significant respectively.

To date, clippings from 16 of the 22 harvest dates have been analyzed for plant tissue nitrogen content (Table 3). Plots receiving the 1.0 lb. per 1000 ft² rate of nitrogen had significantly higher nitrogen content on 15 of 16 harvest dates. The only date where nitrogen rate had no effect on nitrogen content was the first harvest date on May 9, one week following the initial treatment application. Management practices significantly effected nitrogen content on 13 of 16 harvest dates. On average, nitrogen injection management practices had significantly higher nitrogen content than surface application management practices. Water injection cultivation had no significant effect on nitrogen content.

Table 3. 1997 plant tissue nitrogen content averages from 16 harvest dates.

Management Practice	Nitrogen Content Means (%)
injected nitrogen w/#56 nozzle	4.37 A†
injected nitrogen w/#53 nozzle	4.37 A
surface nitrogen plus W.I.C.††	4.01 B
surface nitrogen, no W.I.C.	4.00 B
$LSD_{0.05}$†††	*0.07*
Nitrogen Rate	
1.0 lb. N/1000 ft²/application	4.44
0.5 lb. N/1000 ft²/application	3.94
significance‡	***
Nitrogen Placement Contrast	
injected nitrogen	4.37
surface nitrogen	4.01
significance	***

W.I.C. Contrast	
W.I.C. treatment applied	4.01
no W.I.C treatment	4.00
significance	*n.s.*

† Factor means sharing a letter are not significantly different at the 0.05 level of probability.
†† W.I.C. – water injection cultivation.
††† Fisher's protected least significant difference at the 0.05 level of probability.
‡ ***, *n.s.* – significant at the 0.01 level of probability and not significant respectively.

Quality and color ratings were taken on 21 dates in 1997 (Table 4 and 5). On average, quality and color was generally low for all treatments throughout the study. This was partly due to two, two week dry down periods and to dollar spot infestation in August through October.

Plots receiving the 1.0 lb. per 1000 ft^2 rate of nitrogen ranked significantly higher in quality and color on 19 of 21 rating dates. The only dates where nitrogen rate had no effect on quality and color ratings were the first harvest date on May 9, one week following the initial treatment application and July 30, following a severe dry down period.

Management practices significantly effected quality ratings on 13 of 21 rating dates and color on 16 of 21 rating dates. Management practices seemed to have a greater effect from mid May through mid August. Thereafter, there were few differences in management practice quality and color rating means. On average, nitrogen injection management practices had significantly higher quality and color than surface application management practices. Water injection cultivation raised quality significantly during dry down periods, but had no significant effect on seasonal average quality and color ratings.

Table 4. 1997 quality rating averages from 21 rating dates.

Management Practice	Quality Rating Means†
injected nitrogen w/#56 nozzle	5.2 A††
injected nitrogen w/#53 nozzle	5.1 A
surface nitrogen plus W.I.C.†††	4.3 B
surface nitrogen, no W.I.C.	4.1 B
$LSD_{0.05}$‡	*0.24*
Nitrogen Rate	
1.0 lb. N/1000 ft^2/application	5.2
0.5 lb. N/1000 ft^2/application	4.2
significance§	***
Nitrogen Placement Contrast	
injected nitrogen	5.1
surface nitrogen	4.3
significance	***
W.I.C. Contrast	
W.I.C. treatment applied	4.28
no W.I.C treatment	4.11
significance	*n.s.*

† 1.0 - dead turf, 6.0 - minimum acceptable quality, 9.0 - dark green, dense, uniform turf.
†† Factor means sharing a letter are not significantly different at the 0.05 level of probability.
††† W.I.C. – water injection cultivation.
‡ Fisher's protected least significant difference at the 0.05 level of probability.
§ ***, *n.s.* – significant at the 0.01 level of probability and not significant respectively.

Table 5. 1997 color rating averages from 21 rating dates.

Management Practice	Color Rating Means†
injected nitrogen w/#56 nozzle	5.8 A††
injected nitrogen w/#53 nozzle	5.7 A
surface nitrogen plus W.I.C.†††	4.8 B
surface nitrogen, no W.I.C.	4.7 B
$LSD_{0.05}$‡	*0.23*
Nitrogen Rate	
1.0 lb. N/1000 ft^2/application	5.7
0.5 lb. N/1000 ft^2/application	4.7
significance§	***
Nitrogen Placement Contrast	
injected nitrogen	5.7
surface nitrogen	4.8
significance	***
W.I.C. Contrast	
W.I.C. treatment applied	4.8
no W.I.C treatment	4.7
significance	*n.s.*

† 1.0 - brown turf, 6.0 - minimum acceptable color, 9.0 - dark green turf.
†† Factor means sharing a letter are not significantly different at the 0.05 level of probability.
††† W.I.C. – water injection cultivation.
‡ Fisher's protected least significant difference at the 0.05 level of probability.
§ ***, *n.s.* – significant at the 0.01 level of probability and not significant respectively.

The experimental area subjected to two dry down periods during the growing season, one in July and another in October. Only the July dry down produced visible moisture stress symptoms as October was relatively wet and mild. A wilt rating taken on July 29 revealed that plots receiving injected nitrogen and plots receiving water injection cultivation treatment had significantly less moisture stress symptoms plots receiving no injection treatment. TDR moisture readings were taken on the same date and demonstrated that wilt severity was correlated to volumetric soil moisture.

The 1997 data from the application method - water injection cultivation method substantiate data recorded from previous nitrogen injection studies. Increased clipping yields, nitrogen content in plant tissues, quality ratings, and color ratings on plots injected with nitrogen were the result of nitrogen placement beneath the surface, not the cultivation effect of the HydroJect. However, decreased moisture stress in these same plots was the result of both water injection cultivation and subsurface nitrogen placement.

Striping Study

Quality, color and stripe ratings were taken on thirteen dates beginning five days after the first treatment application on June 30, and continuing through November 3. Seasonal average quality, color, and stripe ratings are summarized in Tables 6, 7, and 8.

Quality ratings were less than acceptable on all plots for most of the growing season because of severe earthworm activity. On average, surface applications and nitrogen injections made while leaving the surface roller washers on resulted in the highest turfgrass quality. The closely mowed *Poa annua* turf reacted strongly to the nitrogen applications and most plots injected with nitrogen exhibited prominent striping. The striping generally reduced turf quality significantly lower than surface applications. Leaving the surface roller washers on masked the striping and resulted in turf with quality equal to that of surface applications.

Table 6. 1997 quality rating averages from 13 rating dates.

Application Method	Quality Rating Means†
#53 nozzle with roller washers	5.6 A††
surface applied	5.4 AB
prototype 2 orifice nozzle	5.1 BC
#53 nozzle 2 perpendicular dir.	5.0 C
prototype 3 orifice nozzle	5.0 C
#53 nozzle	4.9 C
#56 nozzle	4.8 C
$LSD_{0.05}$†††	*0.35*

† 1.0 - dead turf, 6.0 – minimum acceptable quality, 9.0 - dark green, dense, uniform turf.
†† Factor means sharing a letter are not significantly different at the 0.05 level of probability.
††† Fisher's protected least significant difference at the 0.05 level of probability.

Color ratings averaged below acceptable for most of the plots during the growing season because the six week intervals between treatment applications left the turf nitrogen deficient during the final weeks of application intervals. On average, injecting nitrogen with the surface roller washers on resulted in color ratings equal to those of surface applications and superior to those of all other injection methods. Injecting nitrogen with the prototype 3 orifice nozzle was the only injection treatment ranking inferior in color to surface applications.

Table 7. 1997 color rating averages from 13 rating dates.

Application Method	Color Rating Means†
#53 nozzle with roller washers	6.0 A††
surface applied	5.9 A
#53 nozzle	5.7 B
prototype 2 orifice nozzle	5.7 BC
#56 nozzle	5.6 C
#53 nozzle 2 perpendicular dir.	5.6 C
prototype 3 orifice nozzle	5.5 C
$LSD_{0.05}$†††	*0.35*

† 1.0 - brown turf, 6.0 – minimum acceptable color, 9.0 - dark green turf.
†† Factor means sharing a letter are not significantly different at the 0.05 level of probability.
††† Fisher's protected least significant difference at the 0.05 level of probability.

As expected, plots injected with nitrogen using #53 and #56 nozzles alone exhibited significantly greater striping than all other treatments. These plots typically showed strong striping on the closely mowed *Poa annua* turf three to five days after treatment application and did not completely fade until four weeks thereafter. Injecting nitrogen in two perpendicular directions resulted in intermediate striping while the prototype nozzles and the injecting with the surface roller washers on resulted in striping equal to that of surface applications.

Table 8. 1997 stripe rating averages from 13 rating dates.

Application Method	Stripe Rating Means†
#56 nozzle	2.5 A††
#53 nozzle	2.2 A
#53 nozzle 2 perpendicular dir.	1.7 B
Prototype 2 orifice nozzle	1.3 BC
Prototype 3 orifice nozzle	1.2 C
#53 nozzle with roller washers	1.2 C
surface applied	1.0 C
$LSD_{0.05}$†††	*0.35*

† 1.0 – no striping, 5.0 severe striping.
†† Factor means sharing a letter are not significantly different at the 0.05 level of probability.
††† Fisher's protected least significant difference at the 0.05 level of probability.

This study was conducted in conditions favoring striping prevalence (closely mowed, nitrogen deficient, *Poa annua* turf) more so than in previous nitrogen injection experiments. It may be concluded from this study that injecting nitrogen with standard #53 nozzles while leaving the surface roller washers on results in surface characteristics equal to those of standard surface applications. All other forms of nitrogen injection resulted in one or more surface characteristics deviating below those of surface applications. Further research will be required to substantiate if supplementing injecting nitrogen with surface washers results in the benefits (higher nitrogen content in plant tissues, greater clipping yields, higher color ratings under normal conditions, reduced moisture stress) observed in previous nitrogen injection. studies.

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