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# Assessing Nitrogen Fertilization Needs for Irrigated Orchardgrass in the Intermountain Region of California

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## Abstract

Nitrogen fertilization is a critical component of maximizing yield for grass hay production. However, the steady increase in fertilizer price along with concerns for off-site N movement make prudent use of N important. On-farm studies in northeastern California were conducted in irrigated orchardgrass to examine the influence N fertilizer rates and application times have on forage yield, forage quality, soil nitrate, and economics for retail hay. N rates up to 400 lb/acre increased annual yield and net return in a three-cut system. N fertilizer also increased crude protein. Applying fertilizer in split applications gave higher yield, crude protein, and economic return for second and third cut compared to a single fertilizer application at grass green-up. Apparent N recovery decreased with increasing fertilizer rate and ranged from 80 to 38%. N fertilizer did not influence forage neutral detergent fiber. At the highest N fertilizer rates, forage $NO_3$-N at first and second-cut was above 1500 ppm. Fertilizing with N at 600 lb/acre/season elevated fall soil $NO_3$-N at the 24 to 36-inch soil depth compared to the control at multiple sites. Split applications of N fertilizer are imperative to maximize yield, crude protein, and economic return, but excessive N fertilization can increase the likelihood of high forage nitrate and nitrate accumulation below the root zone.

## Introduction

Fig. 1. Unfertilized orchardgrass (right) and orchardgrass fertilized with 100 lb N per acre at grass green-up (left) at first-cut harvest.

Orchardgrass (*Dactylis glomerata*) is a popular irrigated grass species grown in the intermountain region of California. Orchardgrass is desired for hay, and it produces high quality forage with proper irrigation and fertilization. Most intermountain orchardgrass fields are managed with efficient irrigation systems (center-pivot, wheel-line, or laser-leveled flood) and cut for hay three times per season. Grass hay prices are high — hay for horses often brings a price greater than dairy-quality alfalfa (4) — making grass hay more valuable than pasture.

With high fuel, fertilizer, and energy costs, producers must maximize yield and production efficiency to be profitable (2). N fertilization is necessary to obtain high grass yields, but applying too much or too little N has negative economic or environmental consequences.

Several studies have examined N fertilization of cool-season perennial grasses (2,3,8,10). These studies showed that forage yield increases with increasing N rate, but apparent N recovery (ANR) decreases with high N rates. They also found split applications of N usually produce higher yields compared to applying all the N in early spring.

Discrepancies between published studies emerge with optimal N fertilization rates, application timings, and ANR and are likely the result of differences in climate, soil, and management between experiments (9). Management practices, cutting schedules, economics, and soils in the intermountain region of California differ greatly from previous N fertilization research published in the literature, especially since many of these studies were conducted under rain-fed systems east of the Mississippi. Thus, our objective was to determine the optimum N fertilization rate and timing to maximize yield, N use efficiency (NUE), ANR, and returns for orchardgrass grown for retail hay in the intermountain region of California.

## N Fertilization Study

The study was conducted at four orchardgrass sites (McArthur, Ft. Jones, Doyle, and Lookout) in 2005 and two orchardgrass sites (Montague and Susanville) in 2006. Sites' soil and climate attributes are shown in Table 1. The experiment at every site was a completely random design with 4 replicates and 8 N fertilization treatments. Plot size was 20 by 20 ft. Soil samples were collected at each site before initiating the experiment, and sites were fertilized with phosphorus, sulfur, or potassium if the pre-treatment soil test suggested a deficiency. Watermark soil moisture sensors (Irrometer Co., Riverside, CA) were buried at an 8-inch depth at all sites before N treatments were applied to measure soil moisture throughout the growing season.

Table 1. Site soil and climate attributes.

| **Site** | **Soil type** | **Mean annual temperature** (°F) | **Mean annual precipitation** (inches) | **Elevation** (feet) |
|---|---|---|---|---|
| Doyle | Calpine sandy loam<br>*Aridic Haploxerolls* | 50.6 | 11.4 | 4275 |
| Ft. Jones | Stoner gravelly sandy loam<br>*coarse-loamy, mixed, active, mesic Typic Haploxerepts* | 50.5 | 20.6 | 2747 |
| Lookout | Modoc sandy loam*mesic Vitritorrandic Durixerolls* | 48.5 | 15.8 | 4144 |
| McArthur | Esperanza loam<br>*fine, smectitic, mesic Pachic Argixerolls* | 50.6 | 19.1 | 3311 |
| Montague | Montague clay<br>*fine, montmorillonitic, mesic Typic Chromoxererts* | 51.7 | 19.5 | 2634 |
| Susanville | Mottsville gravelly loamy course sand<br>*mixed, mesic, Torripsammentic Haploxeroll* | 49.4 | 14.3 | 4258 |

N treatments were applied by hand in the form of urea (46-0-0) at the rates listed in Table 2. Treatments totaled 100, 200, 300, 400, or 600 lb of N per acre for the entire season. N application rates at grass green-up in March were 0, 100, 200, or 300 lb/acre. Split application rates after first and second cutting were 0, 50, 100, or 200 lb/acre and were applied immediately before the first irrigation after first and/or second harvest. All fertilizer applications were incorporated into the soil with rainfall or irrigation ≥ 0.5 inch within one to two days of application. The first harvest occurred when grasses were in the flowering stage, and the second and third harvest occurred 40 to 50 days after the previous cutting. Drought stress occurred in mid-summer at the Doyle, Lookout, and Ft. Jones sites in 2005. Therefore, the crop at these sites was only harvested twice, once at flowering and again in early fall.

Yield was measured by harvesting a 3- by 20-ft strip at a 3-inch stubble height from each plot with a Carter Harvester (Carter Mfg. Co. Inc., Brookston, IN). Forage samples were oven-dried at 140°F for dry matter (DM) determination and forage quality analysis. Dried forage samples were analyzed for total extractable nitrate N ($NO_3$-N), total N (N), total crude protein (CP) and neutral detergent fiber (NDF) using University of California ANR Analytical Lab preparation and analyses methods (UC ANR Analytical Lab, Davis, CA) (7).

In the fall after the last cutting, soil was sampled for $NO_3$-N at three depths: 0 to 12 inches, 12 to 24 inches, and 24 to 36 inches. Soil cores were taken from 10 random locations in each plot for three fertilization treatments (unfertilized, 100-100-100, and 200-200-200). Soil was air-dried and analyzed for $NO_3$-N using University of California ANR Analytical Lab methods (UC ANR Analytical Lab, Davis, CA).

Yield, forage quality, and soil nitrate data were analyzed by analysis of variance (ANOVA) followed by a comparison of treatment means using Fischer's least significant difference (LSD) at $P \leq 0.05$. Regression analysis was used to determine the relationship between first-cutting yield and N fertilizer rate applied in early spring (SAS Institute Inc., Cary, NC). Site data were pooled for analysis if a site by treatment interaction was not significant at $P \leq 0.05$.

## Influence on Forage Dry Matter Yield and NUE

Both N fertilizer rate and application timing had a significant effect on orchardgrass yield (Table 2). First-cut harvest produced more forage than second- or third-cut harvest (Table 2). First-cut orchardgrass yield increased rapidly from 0 to 100 lb N per acre, however the yield response diminished at rates above 100 lb N per acre (Fig. 1). At the moisture-stressed 2-cut sites, orchardgrass yield almost doubled from 0 to 100 lb N per acre, but the yield increase from fertilization lessened from 100 to 200 lb N per acre, and leveled off at fertilizer rates above 200 lb N per acre (Fig. 1). At 3-cut sites, the relationship between first-cut yield and fertilizer was similar to 2-cut sites, but yield at 3-cut sites increased slightly from 200 to 300 lb N per acre (Fig. 1).

Applying N fertilizer in split applications produced higher second- and third-cut yield compared to applying all N at grass green-up (Table 2). Second-cut yield was 0.26 to 0.66 ton/acre higher if fertilizer was applied at 100 lb N per acre in early spring and 100 lb N per acre after first cutting (100-100) compared to 200 lb N per acre in early spring (200-0) (Table 2). Second-cut yield was 0.15 to 0.78 ton/acre higher if fertilizer was applied at 200-100 compared to 300-0 (Table 2).

Split applications of N fertilizer were essential for increasing third-cut yield. Even at the highest single N rate (300 lb/acre), yield did not differ from the unfertilized plots if fertilizer was only applied in early spring (Table 2). In contrast, applying fertilizer in split applications at 100-50-50, 100-100-100, or 200-100-100 increased third-cut yield by at least 190% compared to unfertilized plots (Table 2).

Table 2. The effect of nitrogen rate and application time on orchardgrass yield and nitrogen use efficiency.

| Orchardgrass sites | | **100% Dry matter yield** (tons/acre) | | | | **N use efficiency**[x] (lbs) |
|---|---|---|---|---|---|---|
| | | **1st cut** | **2nd cut** | **3rd cut** | **Total** | |
| **2-cut** | 0-0[y] | 1.51 | 0.88 | - | 2.39 | - |
| | 100-0 | 2.71 | 1.11 | - | 3.82 | 29 |
| | 100-50 | 2.75 | 1.68 | - | 4.43 | 27 |
| | 200-0 | 3.05 | 1.50 | - | 4.55 | 22 |
| | 100-100 | 2.82 | 1.96 | - | 4.78 | 24 |
| | 300-0 | 3.13 | 1.66 | - | 4.79 | 16 |
| | 200-100 | 3.13 | 2.15 | - | 5.28 | 20 |
| | 200-200 | 3.08 | 2.27 | - | 5.36 | 15 |
| | LSD (*P* = 0.05) | 0.27 | 0.28 | - | 0.42 | 4 |
| **3-cut** | 0-0-0 | 1.93 | 0.91 | 0.41 | 3.26 | - |
| | 100-0-0 | 3.22 | 1.31 | 0.54 | 5.08 | 35 |
| | 100-50-50 | 3.29 | 1.77 | 1.22 | 6.28 | 30 |
| | 200-0-0 | 3.42 | 1.29 | 0.49 | 5.20 | 18 |
| | 100-100-100 | 3.25 | 1.95 | 1.37 | 6.58 | 22 |
| | 300-0-0 | 3.86 | 1.37 | 0.55 | 5.78 | 17 |
| | 200-100-100 | 3.48 | 2.15 | 1.38 | 7.01 | 19 |
| | 200-200-200 | 3.47 | 1.92 | 1.30 | 6.68 | 11 |
| | LSD (*P* = 0.05) | 0.31 | 0.22 | 0.19 | 0.47 | 7 |

[x] N use efficiency represents lbs of additional forage for each lb of applied N. It was calculated as [(total yield at $N_x$ – total yield at $N_0$) * 2000 ÷ lb N per acre applied at $N_x$], where x = N rate > 0.

[y] N fertilizer treatments shown as lb of N per acre applied: at spring green-up – after first cut – after second cut.

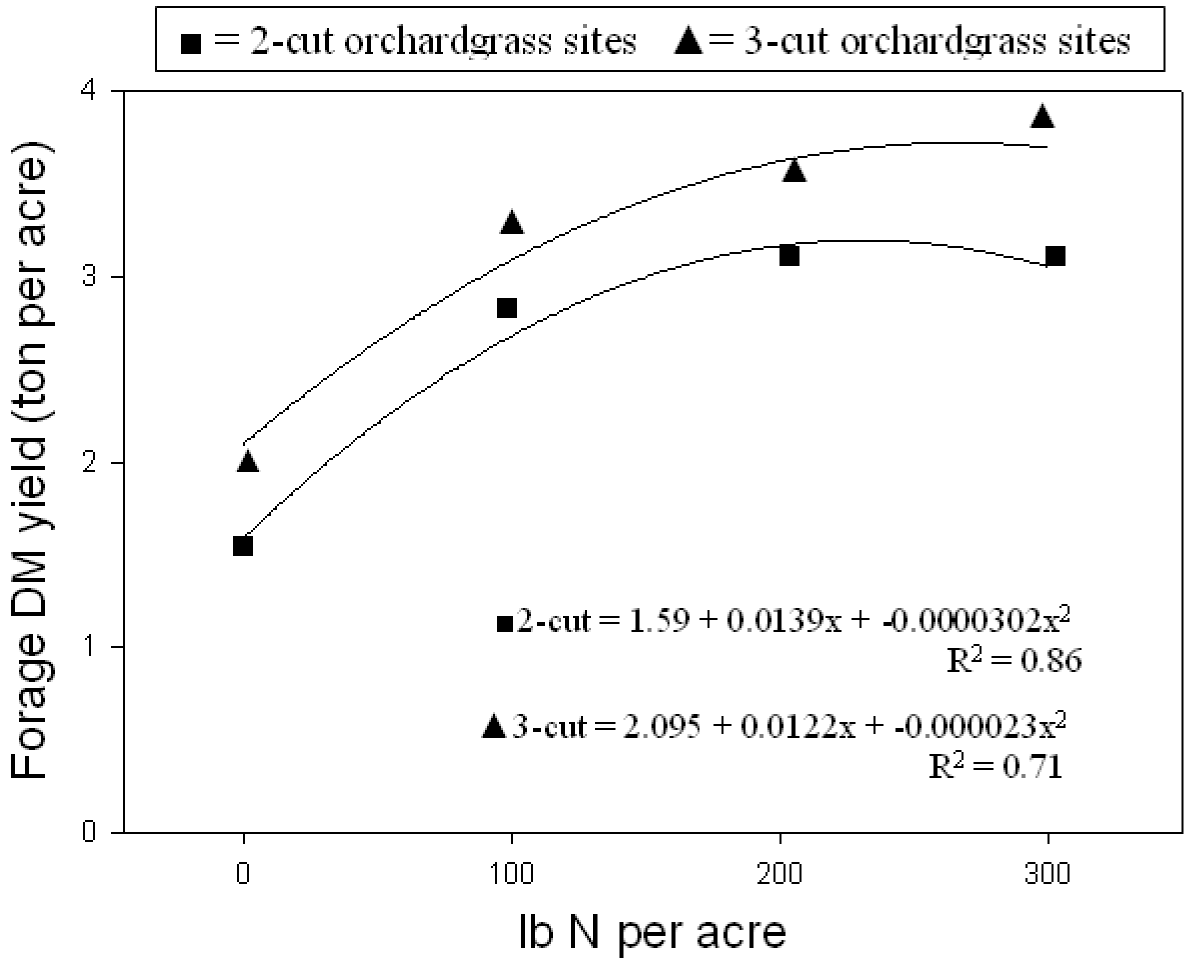



Fig. 1. The relationship between first cut forage dry matter yield and fertilizer N. Data from Doyle, Lookout, and Ft. Jones in 2005 (2-cut sites) were pooled. Data from McArthur in 2005 and Susanville and Montague in 2006 (3-cut sites) were pooled. The model was fitted on data from all plots while symbols illustrate mean dry matter yield response for a given N treatment.

NUE is commonly used to determine the optimal fertilizer strategy and represents pounds of additional forage DM for each lb of applied N. NUE at 2-cut sites (sites drought stressed in mid-summer) ranged from 29 to 15 lb DM forage/lb N, and NUE at 3-cut sites ranged from 35 to 11 lb DM forage/lb N (Table 2). Fertilizer treatments 100-0-(0 for 3-cut sites) and 100-50-(50) gave the highest NUE, and fertilizer treatments 300-0-(0) and 200-200-(200) gave the lowest NUE for 2- and 3-cut sites (Table 2). Although treatments 300-0-(0) and 200-200-(200) produced high yields, their low NUE suggest these N fertilizer rates exceeded orchardgrass needs. Taking into consideration total yield and NUE for the eight treatments, the optimum fertilization strategy was 100 to 200 lb N per acre applied at grass green-up and 50 to 100 lb applied after first and second cutting.

## Impact on Forage Quality

NDF is an estimate of the plant's cell wall content and is important in ration formulation because as NDF increases, dry matter intake will generally decrease (6). N fertilizer treatments did not influence NDF, but NDF differed between cuttings (*data not shown*). Averaged across 3-cut orchardgrass sites, NDF content decreased with each successive cutting ($P \leq 0.01$): 60.9% for first-cut, 57.5% for second-cut, and 51.4% for third-cut.

N fertilizer had a significant effect on orchardgrass crude protein (CP) content. First-cut forage CP content increased approximately 1 to 2 percentage points from 0 to 100 lb N per acre, 2 to 4 % from 100 to 200 lb N per acre, and 2 to 3 percentage points from 200 to 300 lb N per acre applied at grass green-up

(Table 3). The relationship between N fertilizer and CP during second- and third-cutting was similar to N fertilizer's influence on yield. Applying fertilizer in split applications frequently resulted in higher CP (especially at third-cutting) compared to applying the same amount of total fertilizer in one application at grass green-up (Table 3).

Table 3. Orchardgrass forage crude protein and nitrate concentration.

| Orchardgrass sites | | Crude protein (%) | | | Nitrate ($NO_3$-N) (ppm) | | |
|---|---|---|---|---|---|---|---|
| | | 1st cut | 2nd cut | 3rd cut | 1st cut | 2nd cut | 3rd cut |
| **2-cut** | 0-0-0* | 8.5 | 10.2 | - | 10 | 10 | - |
| | 100-0 | 9.7 | 10.8 | - | 20 | 13 | - |
| | 100-50 | 10.2 | 12.2 | - | 100 | 20 | - |
| | 200-0 | 14.3 | 10.6 | - | 789 | 10 | - |
| | 100-100 | 10.3 | 12.5 | - | 53 | 119 | - |
| | 300-0 | 17.4 | 12.5 | - | 2840 | 21 | - |
| | 200-100 | 14.4 | 14.1 | - | 857 | 455 | - |
| | 200-200 | 13.9 | 16.9 | - | 835 | 1420 | - |
| | LSD ($P$ = 0.05) | 2.8 | 2.5 | - | 841 | 720 | - |
| **3-cut** | 0-0-0[b] | 8.3 | 10.7 | 10.8 | 3 | 20 | 30 |
| | 100-0-0 | 10.7 | 13.1 | 11.8 | 208 | 137 | 20 |
| | 100-50-50 | 10.6 | 13.7 | 14.8 | 75 | 427 | 87 |
| | 200-0-0 | 13.0 | 13.2 | 12.3 | 316 | 273 | 3 |
| | 100-100-100 | 10.6 | 14.3 | 17.2 | 160 | 573 | 633 |
| | 300-0-0 | 15.0 | 14.0 | 13.2 | 1586 | 593 | 17 |
| | 200-100-100 | 12.8 | 14.8 | 16.5 | 522 | 1224 | 610 |
| | 200-200-200 | 13.0 | 18.1 | 18.0 | 579 | 3160 | 708 |
| | LSD ($P$ = 0.05) | 2.7 | 2.8 | 3.0 | 810 | 931 | 792 |

* N fertilizer treatments shown as lb of N per acre applied: at spring green-up – after first cut – after second cut.

An increase in fertilizer rate always increased forage CP, however some N fertilizer treatments produced elevated nitrate levels in forage (Table 3). The safe level of nitrate in forage can differ significantly depending on the class of livestock as well as feeding and environmental conditions, but forage with less than 1000 ppm nitrate-N ($NO_3$-N) is generally safe to nonpregnant livestock (1). Forage $NO_3$-N levels for most fertilizer treatments at 2- and 3-cut sites were below 1000 ppm, but $NO_3$-N in first-cut forage from the 300-0-0 treatment, second-cut forage from the 200-200-200 treatment, and second-cut forage from the 200-100-100 treatment at 3-cut sites averaged higher than 1200 ppm (Table 3). Second-cut forage $NO_3$-N from the 200-200-200 treatment at 3-cut sites exceeded 3000 ppm (Table 3).

## Impact on N Yield, Apparent N Recovery, and Soil Nitrate

N yield was calculated by multiplying DM yield by the concentration of N in the harvested forage. Total N yield represents the sum over all cuttings. As expected, total N yield increased with increasing fertilizer rate (Table 4). N yield exceeded the amount of applied fertilizer N for treatments 100-0 and 100-50 at 2-cut sites and treatments 100-0-0, 100-50-50, and 200-0-0 at 3-cut sites (Table 4), suggesting orchardgrass acquired N from the soil in addition to applied N for these treatments.

Table 4. Orchardgrass total N yield and apparent N recovery.

| **Orchardgrass sites** | | **Total N yield**[x] (lb/acre) | **Apparent N recovery**[y] (%) |
|---|---|---|---|
| **2-cut** | 0-0[z] | 69.8 | - |
| | 100-0 | 131.0 | 61 |
| | 100-50 | 160.4 | 60 |
| | 200-0 | 190.0 | 60 |
| | 100-100 | 178.1 | 54 |
| | 300-0 | 232.6 | 54 |
| | 200-100 | 234.3 | 55 |
| | 200-200 | 254.8 | 46 |
| | LSD (*P* = 0.05) | 16.4 | 6 |
| **3-cut** | 0-0-0 | 96.7 | - |
| | 100-0-0 | 176.2 | 80 |
| | 100-50-50 | 239.4 | 71 |
| | 200-0-0 | 217.3 | 60 |
| | 100-100-100 | 267.7 | 57 |
| | 300-0-0 | 281.3 | 62 |
| | 200-100-100 | 322.2 | 56 |
| | 200-200-200 | 326.3 | 38 |
| | LSD (*P* = 0.05) | 18.3 | 7 |

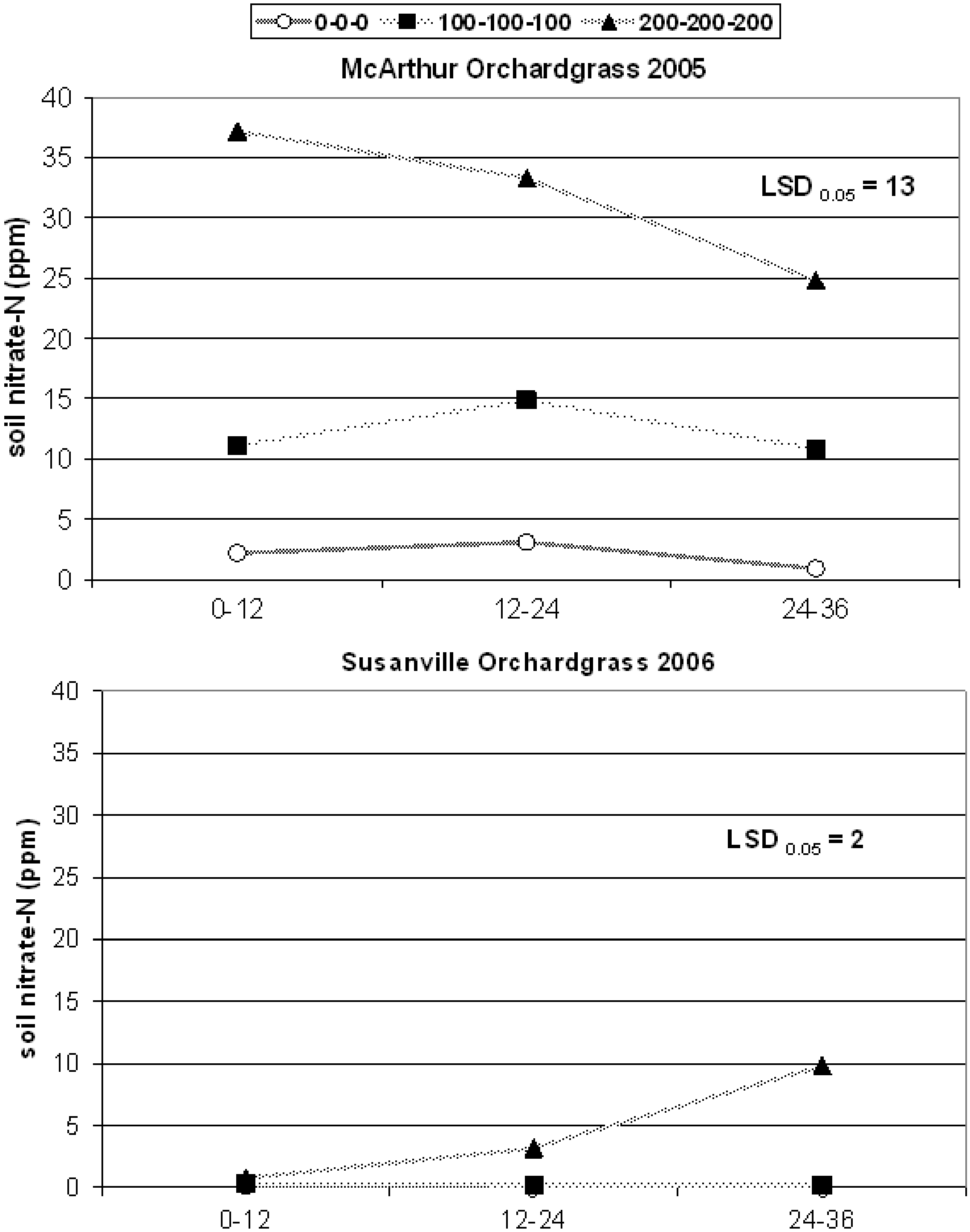
[x] Total N yield is the sum of all cuttings. N yield was calculated by multiplying plant dry matter yield per acre by the concentration of nitrogen in the harvested forage.

[y] Apparent N recovery for the total season was calculated as 100 × [(total N yield at $N_x$ – total N yield at $N_0$) ÷ lb of N applied at $N_x$], where x = N rate > 0.

[z] N fertilizer treatments shown as lb of N per acre applied: at spring green-up – after first cut – after second cut.

Apparent N recovery (ANR) was calculated using total N yield [100 x (total N yield at $N_x$ – total N yield at $N_0$) ÷ lb of N applied at $N_x$] and represents the percentage of N recovered from the pool of applied and mineralized N available to plants in the soil. When comparing fertilizer treatments, ANR generally decreased with increasing fertilizer rate and ranged from 80 to 38% for 3-cut sites and 61 to 46% for 2-cut sites (Table 4).

At all sites and depths, soil $NO_3$-N in unfertilized plots was less than 5 ppm signifying background nitrate-N levels were low (Fig. 2). The McArthur site had the greatest difference in soil $NO_3$-N between fertilizer treatments (Fig. 2). At all three soil depths, soil $NO_3$-N was highest in the 200-200-200 treatment compared to the unfertilized and 100-100-100 treatment at this site. At Susanville, soil $NO_3$-N did not differ between treatments at the 0 to 12 and 12 to 24-inch depths, but soil nitrate was higher in the 200-200-200 treatment at the 24 to 36-inch depth (Fig. 2). At Montague, soil nitrate did not differ between treatments at the 0 to 12-inch depth, but a gravelly hardpan prevented soil sampling below 12 inches.


0-0-0
100-100-100
200-200-200
McArthur Orchardgrass 2005
soil nitrate-N (ppm)
LSD 0.05 = 13
0
5
10
15
20
25
30
35
40
0-12
12-24
24-36
Susanville Orchardgrass 2006
soil nitrate-N (ppm)
LSD 0.05 = 2
0
5
10
15
20
25
30
35
40
0-12
12-24
24-36

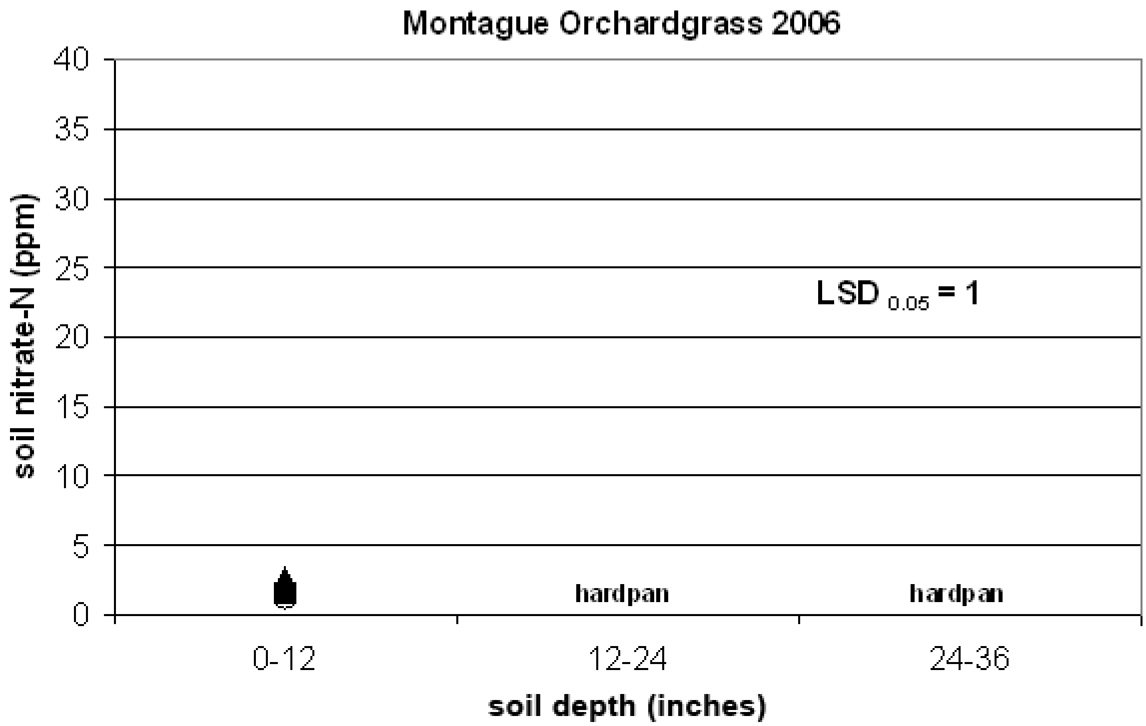



Fig. 3. Soil nitrate in fall after the third cut at three soil depths for low, moderate, and high fertilizer treatments. All sites shown were cut three times. Fertilizer amounts shown in the legend represent lb N per acre applied: at spring green-up – after first cut – after second cut.

Elevated soil $NO_3$-N at the 24 to 36-inch depth for the 200-200-200 treatment at multiple sites suggests fertilizer rates greater than 600 lb N per acre may pose a nitrate leaching risk especially since few grass roots were observed below 24 inches. The low ANR for the 200-200-200 treatment is a further indication that 600 lb N per acre is excessive for orchardgrass production.

The difference in the soil nitrate levels in the 200-200-200 treatment at Susanville and McArthur was possibly related to soil type. The McArthur soil had more clay than the coarse sand soil at Susanville (Table 1). Soil moisture data showed both sites received ample irrigation. An explanation for elevated soil $NO_3$-N at McArthur at all soil depths is nitrate moved slower through the soil profile compared to the sandy soil at Susanville. At Susanville, elevated $NO_3$-N was only found at the 24 to 36-inch depth likely because it was rapidly leached through the root-zone.

## Economics

A partial economic budget for N fertilization of retail grass hay was developed considering fertilizer price, application cost, forage DM yield, and hay price. Under current economic conditions, the benefit of N fertilization for increasing gross return greatly outweighs the cost of fertilizer. N fertilization increased net return (gross return — fertilizer cost) $182 to $385/acre compared to the unfertilized treatment (Table 5), assuming a hay price of $185/ton, a fertilizer cost of $0.75/lb N, and a fertilizer application cost of $8/acre/application.

Split applications of N fertilizer were more economical than applying all fertilizer in early spring. Split fertilizer treatments increased net return more than $132/acre for 3-cut orchardgrass and more than $34/acre for 2-cut orchardgrass compared to a single application at grass green-up (Table 5). Even though split applications had a higher fertilizer application cost, the yield increase more than compensated for the added cost.

Table 5. Gross return, fertilizer cost, and net return for orchardgrass N fertilization treatments.

| Orchardgrass sites | | Gross return[w] | Fertilizer cost[x] | Net return above fertilizer cost[y] |
|---|---|---|---|---|
| | | ($ per acre) | | |
| 2-cut | 0-0[z] | 442 | 0 | 442 |
| | 100-0 | 707 | 83 | 624 |
| | 100-50 | 820 | 129 | 691 |
| | 200-0 | 842 | 158 | 684 |
| | 100-100 | 884 | 166 | 718 |
| | 300-0 | 886 | 233 | 653 |
| | 200-100 | 977 | 241 | 736 |
| | 200-200 | 992 | 316 | 676 |
| 3-cut | 0-0-0 | 603 | 0 | 603 |
| | 100-0-0 | 940 | 83 | 857 |
| | 100-50-50 | 1162 | 174 | 988 |
| | 200-0-0 | 962 | 158 | 804 |
| | 100-100-100 | 1217 | 249 | 968 |
| | 300-0-0 | 1069 | 233 | 836 |
| | 200-100-100 | 1297 | 324 | 973 |
| | 200-200-200 | 1236 | 474 | 762 |

[w] Gross return was calculated as total DM yield (tons/acre) * hay price ($185/ton for orchardgrass). Hay prices were based on the average price reported in the USDA-AMS 2007 July Year-to-date Annual Hay Market Summary for Intermountain Northern California.

[x] Fertilizer cost was calculated as urea fertilizer price/acre ($0.75 per lb of N) + fertilizer application cost ($8/acre/application).

[y] Net return above fertilizer cost was calculated as gross return – fertilizer cost. Net return above fertilizer cost does not reflect other costs such as irrigation, harvest, and pesticides. These costs were assumed to stay the same across treatments.

[z] N fertilizer treatments shown as lb of N per acre applied: at spring green-up – after first cut – after second cut.

Fertilizer price has steadily increased in recent years, but the price is still below the breakeven point. For example, NUE for the 200-100-100 fertilizer treatment was 19. This means the price per lb of N would need to reach $1.76 for fertilizer price to offset the value of additional forage at current hay prices. The fertilization treatment that maximizes yield and NUE will usually maximize net return since forage DM yield is the primary factor for gross return.

The value of increased CP from N fertilization was not factored into the economic evaluation because most grass hay in the West is not sold based on a forage quality analysis as is alfalfa. Although CP was not factored into grass hay price, the increase in CP from fertilization will increase economic return for livestock producers growing hay for their own livestock since CP should increase daily weight gain in most livestock classes.

## Summary and Conclusions

N fertilization of orchardgrass was critical to maximize DM yield, CP content, and economic return. Yield and net return reached a plateau around 400 lb N per acre in a 3-cut system. Inadequate irrigation in mid-summer stressed orchardgrass causing a mid-summer growth slump that only permitted 2 cuttings per year resulting in lower yield and economic return compared to 3-cut sites. However, fertilization, albeit at lower rates, was still beneficial in the 2-cut system.

Split fertilizer applications were advantageous and increased second and third cut yield and CP content compared with applying all the fertilizer at spring green-up. The yield increase from split fertilizer application also translated into more economic return even with the higher application cost associated with a split application.

Fertilizing with N in accord to each cutting's yield potential is very important to maximizing orchardgrass yield and economic return. Since first-cut yield is disproportionably large compared to second- and third-cut, high rates (100 to 200 lb N per acre) are required at spring grass green-up to maximize first-cut yield. Depending on irrigation and summer growth rates, lower rates (50 to 100 lb N per acre) should be applied after first and/or second cutting to maximize second- and third-cut yield.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