Nitrogen Fertilization and Irrigation Affects Tuber Characteristics of Two Potato Cultivars

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ABSTRACT

Nitrogen fertilization, irrigation, and cultivars affect tuber characteristics such as tuber size, specific gravity, and N concentration. Few studies, however, have investigated the interaction of irrigation and N fertilization on the tuber characteristics of potato cultivars, particularly in Atlantic Canada. The objective of this on-farm study, conducted at four sites in each of three years, 1995 to 1997, was to determine the effects of supplemental irrigation and six rates of N fertilization (0-250 kg N ha^{-1}) on the number of tubers per plant, the average fresh tuber weight, tuber N concentration, nitrate (NO_3-N) concentration, and specific gravity of the cultivars Shepody and Russet Burbank. Nitrogen fertilization increased the average fresh tuber weight, tuber N and NO_3-N concentrations, and decreased specific gravity. Effects of increasing N fertilization on tuber characteristics were often more pronounced for Shepody than for Russet Burbank, and for irrigated than for non-irrigated conditions. Shepody had greater average fresh tuber weight and tuber N concentration, lower specific gravity, and fewer tubers per plant than Russet Burbank. Supplemental irrigation increased the average fresh tuber weight and the number of tubers per plant, but it had a limited effect on specific gravity and tuber N and NO_3-N concentrations. Tuber NO_3-N concentration and specific gravity were strongly related to tuber N concentration, which in turn depended primarily on N fertilization. Incidents of lowest specific gravity and highest NO_3-N concentration occurred with a relative yield close to or equal to 1.0. We conclude that the risks of low specific gravity and high tuber NO_3-N concentration are greater when fertilization exceeds the N requirements to reach maximum tuber yield.

Accepted for publication April 24, 2002.
ADDITIONAL KEY WORDS: *Solanum tuberosum* L., specific gravity, Russet Burbank, Shepody, nitrogen, nitrate.

INTRODUCTION

Supplemental irrigation and N fertilization generally increased tuber yield of two potato cultivars in New Brunswick

but the response varied with sites and climatic conditions (Bélanger et al. 2000). Nitrogen fertilization, irrigation, and cultivars also affect tuber characteristics such as tuber size, specific gravity, and N concentration (Gregory and Simmonds 1992; Harris 1992; Storey and Davies 1992). In the potato-producing region of Atlantic northeast North America (Prince Edward Island, New Brunswick, and Maine), increased N application reduced the specific gravity of tubers (White and Sanderson 1983; MacLean 1984; Porter and Sisson 1991, 1993). In Maine, irrigation reduced the specific gravity and increased the tuber size of the cultivar Superior (Porter et al. 1999), and N fertilization increased the tuber size of Russet Burbank and Shepody (Porter and Sisson 1991).

Public concern about the need to reduce nitrate (NO_3) concentrations in human food and water followed reports that high NO_3 concentrations in food and water are associated with increased gastric cancer and methaemoglobinaemia in infants. In the European community, the maximum concentrations for NO_3 in spinach and lettuce is set at 2500 mg NO_3 kg^{-1} fresh product (approximately 2800 mg NO_3-N kg^{-1} DM) (Anonymous 1997). To our knowledge, there are no maximum regulatory limits for NO_3 in potato tubers in North America and Europe. Carter and Bosma (1974), in Idaho, concluded that NO_3 accumulation in tubers does not represent a health hazard. However, we know of no studies on tuber NO_3 concentration in Atlantic Canada.

The objective of this study was to determine how supplemental irrigation and N fertilization affect the tuber characteristics of Shepody and Russet Burbank, two widely grown potato cultivars in Atlantic Canada.

MATERIALS AND METHODS

The study was conducted for three years (1995 to 1997) at four different sites in the upper St- John River Valley of New Brunswick, Canada. The sites are referred to as S1 to S4 in 1995, S5 to S8 in 1996, and S9 to S12 in 1997. At each site, the experiment consisted of two large areas (irrigated and non-irrigated) within one field. Each area was divided into four replicates of a split-plot arrangement of the experimental treatments, with cultivars as main plots and N fertilization as sub-plots. Two potato (*Solanum tuberosum* L.) cultivars were used with a row spacing of 0.75 m and different in-row spacings; 0.30 m for Shepody and 0.46 m for Russet Burbank. Nitrogen, in the form of ammonium nitrate (containing 0, 50, 100, 150, 200, or 250 kg N ha^{-1}) was banded 2 cm to the side and 2 cm below the seedpiece at planting. Individual plots consisted of six rows 7.6 m in length. Borders between plots within a block were 1.5 m wide, with 24.3 m between the irrigated and non-irrigated areas. Phosphorus (165 kg P_2O_5 ha^{-1}) and potassium (165 kg K_2O ha^{-1}) were surface broadcast prior to planting as a 0-15-15 blend. Plots were planted between 18 May and 6 June (Bélanger et al. 2000).

Irrigation was scheduled with the Wisdom© computer software program (IPM Software, Madison, WI), which uses a water budget approach (Curwen and Massie 1984). Water was applied when soil moisture reserves were 65% or less of the soil's water-holding capacity. The potential evapotranspiration (PET) was calculated using the Priestly-Taylor equation, but adjusted for canopy cover. Daily maximum-minimum air temperature and rainfall were recorded at each experimental site, and daily water balances were calculated by subtracting PET from the rainfall. Irrigation was applied at a rate of 0.68 cm h^{-1} with a portable, overhead irrigation system. The experimental sites and other experimental procedures are described in Bélanger et al. (2000).

Plots were harvested between 3 October and 17 October. The middle two rows of each plot were harvested to count the number of tubers and to determine total tuber yield. The number of tubers per plant in the middle rows was calculated by dividing the number of tubers by the number of plants after emergence. The average fresh tuber weight at harvest was measured from a 22.7-kg sample. Specific gravity was measured using the weight-in-air and weight-in-water method. Tuber N and NO_3-N concentrations were determined on samples from four N rates: 0, 50, 100, and 250 kg N ha^{-1} at nine of the 12 sites: S3 in 1995, S5 to S8 in 1996, and S9 to S12 in 1997. Tubers greater than 5 cm in length were washed in distilled water to remove any soil, blotted dry, and sliced into strips that were 10 mm wide but of differing lengths. The strips were dried at 65° C for 48 h and then ground to pass through a 1-mm stainless steel sieve. Total N concentration was determined by dry combustion using a LECO CNS 1000 analyser (LECO Corporation, St. Joseph, Michigan, USA). Nitrate was extracted from a 3-g dried ground tuber sample added to 50 ml distilled water and shaken for 45 min. After filtering, NO_3 concentration was determined colorimetrically using Cd-reduction (Maynard and Kalra 1993) and expressed as mg NO_3-N kg^{-1} oven dry tissue.

Analyses of variance across sites were calculated (Table 1; Genstat 5 Committee 1993). Because irrigation treatments were not replicated, we could not statistically analyze the effect of irrigation for each site. We therefore considered sites as a random effect, and their interaction with irrigation was used to test the

TABLE 1–*Analysis of variance*[1] *across sites (S) for average fresh tuber weight, number of tubers per plant, specific gravity, nitrogen (N) and nitrate (NO_3-N) concentrations.*

Sources of variation	d.f.	Mean square values				
		Average tuber weight ($x10^4$)	Tubers plant^{-1}	Specific gravity ($x10^{-3}$)	N concentration	NO_3-N concentration
Sites (S)	11(8)[2]	68.4	85.7	234.1	3.099	37204
Irrigation (I)	1	159.9**	47.16*	4.0	0.295	38852
Residual (Error A)	11 (8)	14.7	9.17	16.4	0.140	9382
Replications (S*I)	72 (54)	1.1	1.48	2.4	0.046	1125
Cultivars (C)	1	662.2***	4339.28***	167.1***	2.128***	4385
I × C	1	10.0*	3.57	69.7***	0.197	1576
Residual (Error B)	94 (70)	1.7	4.43	4.5	0.035	1698
Nitrogen (N)	5 (3)	45.4***	3.72***	180.8***	7.398***	197912***
N linear (N_l)	1	212.6***	0.47	875.8***	21.867***	584567***
N quadratic (N_q)	1	13.7***	14.2***	1.4	0.196*	8006*
I × N	5 (3)	4.8***	0.13	10.5***	0.074	3691
I × N_l	1	16.4***	0.32	49.8***	0.213*	10959**
I × N_q	1	3.7**	0.09	0.1	0.008	65
C × N	5 (3)	3.2***	0.52	3.3	0.148**	236
C × N_l	1	13.3***	0.01	13.0***	0.304**	556
C × N_q	1	1.8	0.64	2.4	0.128	151
I × C × N	5 (3)	1.3*	0.06	1.9	0.017	589
Residual (Error C)	940	0.6	0.60	1.6	0.034	1518

[1] Sites were considered random effects and the site x irrigation interaction was used to test for the effect of irrigation.
[2] Values in parentheses are for N and NO_3 concentrations.
*, **, *** Significant at $P<0.05$, $P<0.01$, and $P<0.001$, respectively.

effect of irrigation. Any fixed effect (e.g., irrigation) can be tested with its interaction term with sites; the interaction term will be a random effect in the model and the F-statistic assesses the differential due to irrigation when sampled over sites (K B. McRae, pers. comm.). Regression analyses were performed with Genstat (Genstat 5 Committee 1993). Relative yield was calculated as the ratio between potato yield for each rate of N fertilizer and the maximum potato yield at each site. Statistical significance was chosen at $P<0.05$.

RESULTS AND DISCUSSION

Average Fresh Tuber Weight and Tubers per Plant

The average fresh tuber weight increased with increasing N application, and the linear and quadratic components were both significant (Table 1; Figure 1). This agrees with results reported by Porter and Sisson (1991) and Harris (1992). The interaction between the linear component of the response to N and cultivar was significant; average fresh tuber weight increased more for Shepody than for Russet Burbank with each N increment (Figure 1a). The increase in average fresh tuber weight with increasing N was greater with irrigation than without irrigation (Figure 1b), as indicated by the interaction between irrigation and both linear and quadratic components of the N response (Table 1).

The average fresh tuber weight of Shepody was greater than that of Russet Burbank, and the difference was greater with irrigation. Without irrigation, the average fresh tuber weight was 147 g tuber^{-1} for Russet Burbank and 189 g tuber^{-1} for Shepody; with irrigation, the average fresh tuber weight was 160 g tuber^{-1} for Russet Burbank and 219 g tuber^{-1} for Shepody. In Alberta, Shepody had a greater average fresh tuber weight than Russet Burbank, but there was no significant interaction between water stress and cultivar (Lynch and Tai 1989).

Irrigation significantly increased the average fresh tuber weight by 14% (Table 1; Figure1b). In Maine, Porter et al. (1999) reported an increased tuber size with supplemental irrigation for two out of three years. Ojala et al. (1990) reported that a water stress during mid-bulking reduced tuber size in Idaho.

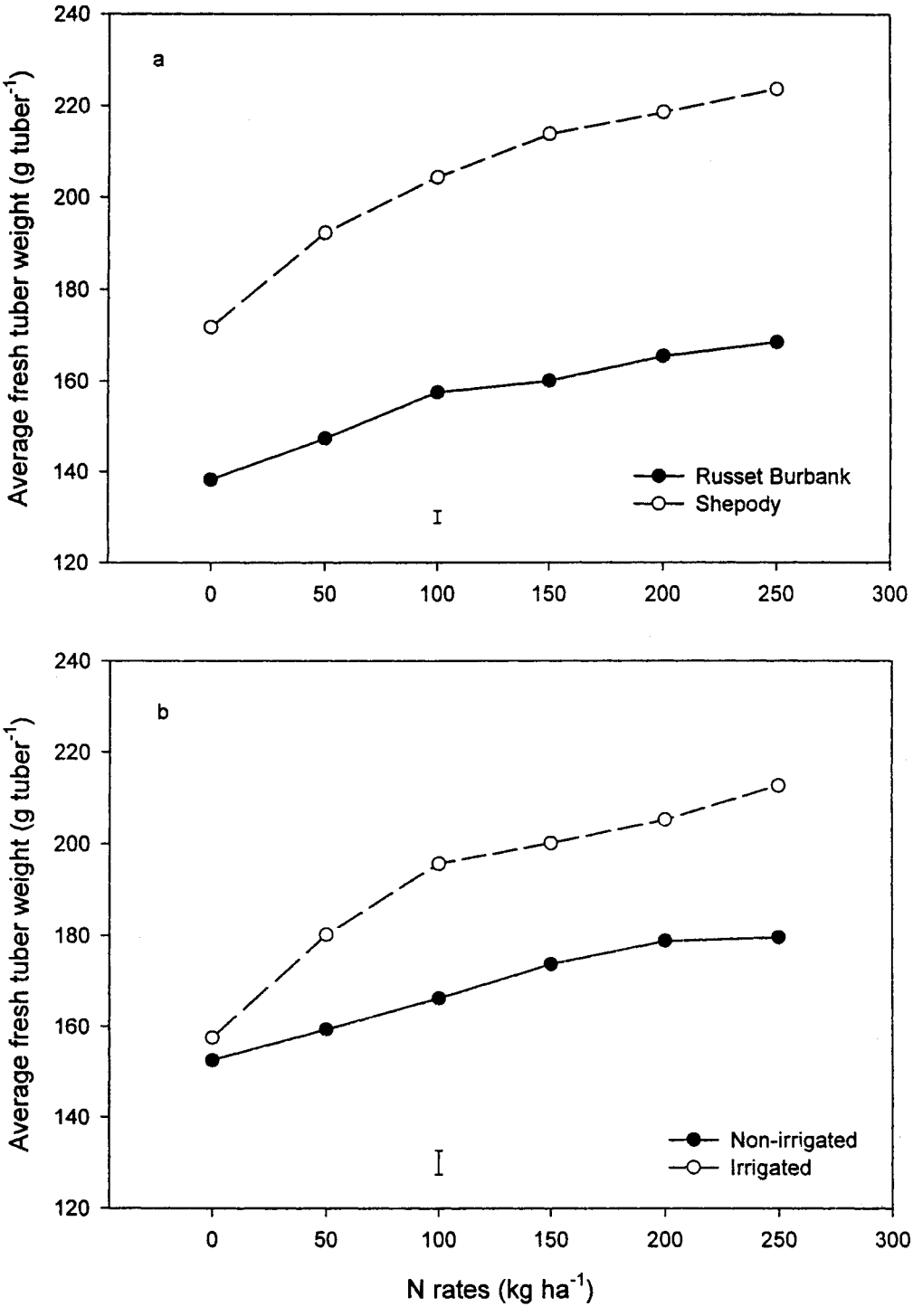

FIGURE 1.
Average fresh tuber weight as a function of applied N in interaction with cultivars (a) and irrigation treatments (b). Data averaged over 12 sites. Bars indicate the standard error of the mean for N by cultivar interaction (a) and N by irrigation interaction (b).

The number of tubers per plant was significantly different for cultivars and was affected by N application and irrigation; there were no significant interactions (Table 1). The response of the number of tubers per plant to N application was quadratic; the number of tubers per plant increased from 6.5 with no N applied to 6.9 with 100 kg N ha^{-1}, followed by a decrease to 6.7 with 250 kg N ha^{-1}. Both positive and negative effects of N fertilization on the number of tubers per plant have been reported (Sommerfeldt and Knutson 1968; Dubetz and Bole 1975; De la Morena et al. 1994).

Russet Burbank had more tubers (8.7 tubers $plant^{-1}$) than Shepody (4.8 tubers $plant^{-1}$). A similar result was reported in Alberta by Lynch and Tai (1989). The number of tubers per plant was greater under irrigation (6.9 tubers $plant^{-1}$) than without irrigation (6.5 tubers $plant^{-1}$). Lynch and Tai (1989) reported a decrease in the number of tubers per stem with a moisture stress in Alberta.

It could be argued that cultivar differences in average fresh tuber weight and number of tubers per plant is an artifact of the greater plant density of Shepody (4.4 plants m^{-2}) compared to that of Russet Burbank (2.9 plants m^{-2}) since both average fresh tuber weight and

number of tubers per plant depend on plant density (Allen and Wurr 1992). The average fresh tuber weight of Russet Burbank was around 75% of that of Shepody in our study and 70% in the study of Lynch and Tai (1989) who used the same plant density for both cultivars. Lynch and Tai (1989) also reported a greater number of tubers per plant for Russet Burbank compared to Shepody, a finding similar to ours. Hence, even though we used different in-row spacings for Russet Burbank and Shepody, our results agree with those obtained by Lynch and Tai (1989) who used the same in-row spacing for both cultivars.

Specific Gravity

Increasing N fertilization significantly decreased specific gravity (Table 1). Applied N often reduces specific gravity (White and Sanderson 1983; MacLean 1984; Porter and Sisson 1991; Porter and Sisson 1993). The change in specific gravity with N depended on irrigation (Table 1). With 50 kg N ha^{-1} or less, the specific gravity was greater with irrigation than without (Figure 2b). With 150 kg N ha^{-1} or more, however, the specific gravity was

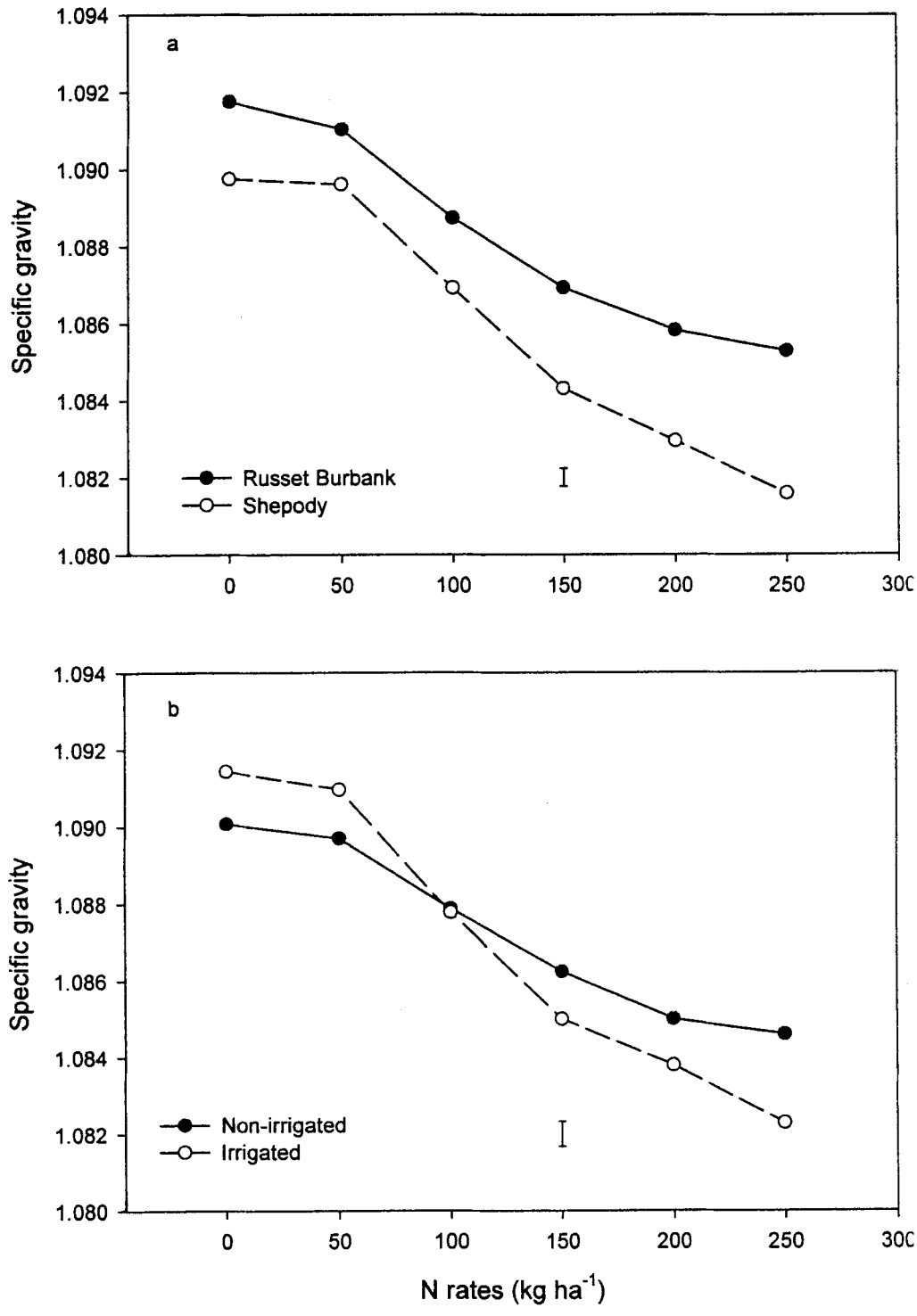

FIGURE 2.
Specific gravity of potato tubers as a function of applied N in interaction with cultivars (a) and irrigation treatments (b). Data averaged over 12 sites. Bars indicate the standard error of the mean for applied N by cultivar interaction (a) and applied N by irrigation interaction (b).

greater without irrigation. The probability of irrigation having a negative effect on specific gravity is, therefore, less under N-deficient conditions than under N-sufficient conditions. The interaction between the linear component of applied N and cultivar was significant (Table 1). The decrease in specific gravity with increasing N applications was greater for Shepody than for Russet Burbank (Figure 2a).

The specific gravity of Russet Burbank was significantly higher (1.088) than that of Shepody (1.086) (Table 1; Figure 2a). The specific gravity of late-maturing cultivars is reported to be greater than that of early-maturing cultivars (Storey and Davies 1992). Russet Burbank is a late-maturing cultivar as compared with Shepody, and this might partially explain its greater specific gravity in our study. Our results also show that specific gravity is affected by N fertilization and cultivars, and that the response of specific gravity to N fertilization depends on the degree of water stress and the cultivar.

The main effect of irrigation on specific gravity was not significant (Table 1), and equaled 1.087 with and without irrigation. In Maine, irrigation reduced specific gravity only when tuber yield was increased by more than 10 t ha^{-1} (Porter et al. 1999). Although irrigation increased tuber yield by more than 9 t ha^{-1} at four sites (S1, S2, S9, and S11) in our study (Bélanger et al. 2000), it reduced specific gravity at only one of these sites (S11). While water stress will increase specific gravity in general, its intensity and whether it occurs during tuber initiation, bulking, or both is also important (Storey and Davies 1992).

The irrigation cultivar interaction was significant (Table 1), with a greater effect on Shepody (1.085 with irrigation and 1.087 without irrigation) than on Russet Burbank (1.088 with irrigation and 1.089 without irrigation). Our results suggest that the way in which irrigation affects specific gravity depends on the cultivar grown.

Nitrogen Concentration in the Tubers

Tuber N concentration increased linearly with increasing N (Table 1; Figure 3) . The positive effect of N fertilization on tuber N concentration has been reported (Carter and Bosma 1974; White and Sanderson 1983; Millard 1986). Tuber N concentration was significantly greater for Shepody (1.36%) than for Russet Burbank (1.24%) (Table 1; Figure 3a). The difference in tuber N concentration between cultivars increased with increasing N, as indicated by the significant N cultivar interaction (Table 1; Figure 3a).

Cultivar differences in tuber protein concentration are reported in a study of the cultivars Kennebec, Norchip, and Norland in Minnesota (Snyder et al. 1977). During tuber bulking, protein concentration decreases with increasing average fresh tuber weight (Snyder et al. 1977) or increasing tuber yield (Duchenne et al. 1997); this is attributed to the increased proportion of the N-poor storage component during starch accumulation. We could hypothesize from this that cultivars with larger tubers would have a lower N concentration. In our study, however, Shepody had a greater average fresh tuber weight and a greater N concentration than Russet Burbank. The greater tuber N concentration of Shepody most likely can be attributed to a greater N-uptake potential. Shepody also had a greater N concentration in the combined shoot and tuber biomass than Russet Burbank during the growing season (Bélanger et al. 2001).

The main effect of irrigation on tuber N concentration was not significant (Table 1). A significant interaction between the linear component of applied N and irrigation indicates that the tuber N concentration tended to be greater without irrigation than with irrigation under low N fertility (Figure 3b). Tuber N concentration was negatively affected by early and mid-season irrigation in Turkey (Günel and Karadogan 1998). In Idaho, tuber N concentration of Russet Burbank was reduced by applying more water, and this was attributed to the greater movement of soil N below the root zone by the irrigation (Carter and Bosma 1974).

Nitrate Concentration in the Tubers

Nitrogen fertilization significantly increased tuber NO_3-N concentration (Table 1). Other studies reported similar results (Carter and Bosma 1974; Nitsch and Varis 1991). The irrigation N linear component interaction was significant (Table 1). The increase in NO_3-N concentration with increasing applied N was greater without irrigation than with irrigation (Figure 4).

Shepody and Russet Burbank did not differ significantly in tuber NO_3-N concentration (Table 1) even though Shepody had a greater tuber N concentration than Russet Burbank. Consequently, the proportion of N in the NO_3-N form was significantly greater for Russet Burbank (0.33%) than for Shepody (0.26%). Cultivar differences in non-protein N concentration were reported in Minnesota (Snyder et al. 1977).

The main effect of irrigation on tuber NO_3-N concentration was not significant (Table 1). Carter and Bosma (1974) reported that tuber NO_3-N concentration in Idaho was inversely proportional to the amount of water applied at each irrigation.

Tuber NO_3-N concentrations in our study are similar to or less than those reported in other areas of the world (Carter and Bosma 1974; Biedmond and Vos 1992). Since NO_3-N concentrations are higher in the skin, peeled tubers destined for processing would have lower concentrations of NO_3-N (Carter and Bosma 1974). Boiling and draining the cooking water should also reduce NO_3-N concentration. Tuber NO_3-N concentration at harvest never exceeded 200 mg NO_3-N kg^{-1} DM. This concentration is much lower than the 2500 mg NO_3 kg^{-1} fresh product (2809 mg NO_3-N kg^{-1} DM) set as a maximum level for spinach and lettuce in the European community (Anonymous 1997).

Relationships between Tuber N and Nitrate Concentration, Specific Gravity and Relative Yield

Specific gravity was negatively related to tuber N concentration (Figure 5a) for both Russet Burbank and Shepody. A linear parallel curve analysis with grouped data (Genstat 5 Committee 1993) indicated that the relationship between specific

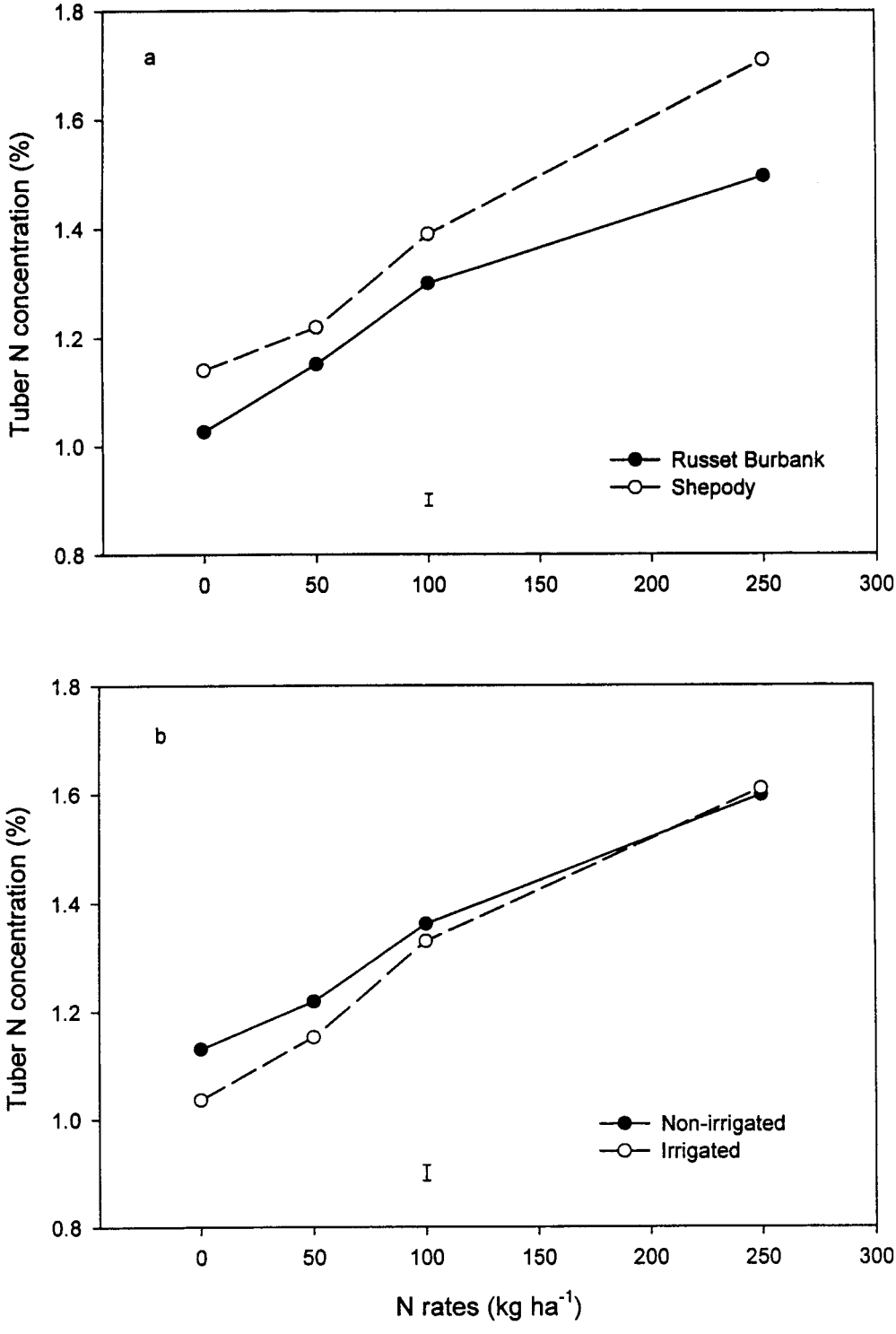

FIGURE 3.
Nitrogen concentration (DM basis) of potato tubers as a function of applied N in interaction with cultivars (a) and irrigation treatments (b). Data averaged over nine sites. Bars indicate the standard error of the mean for applied N by cultivar interaction (a) and applied N by irrigation interaction (b).

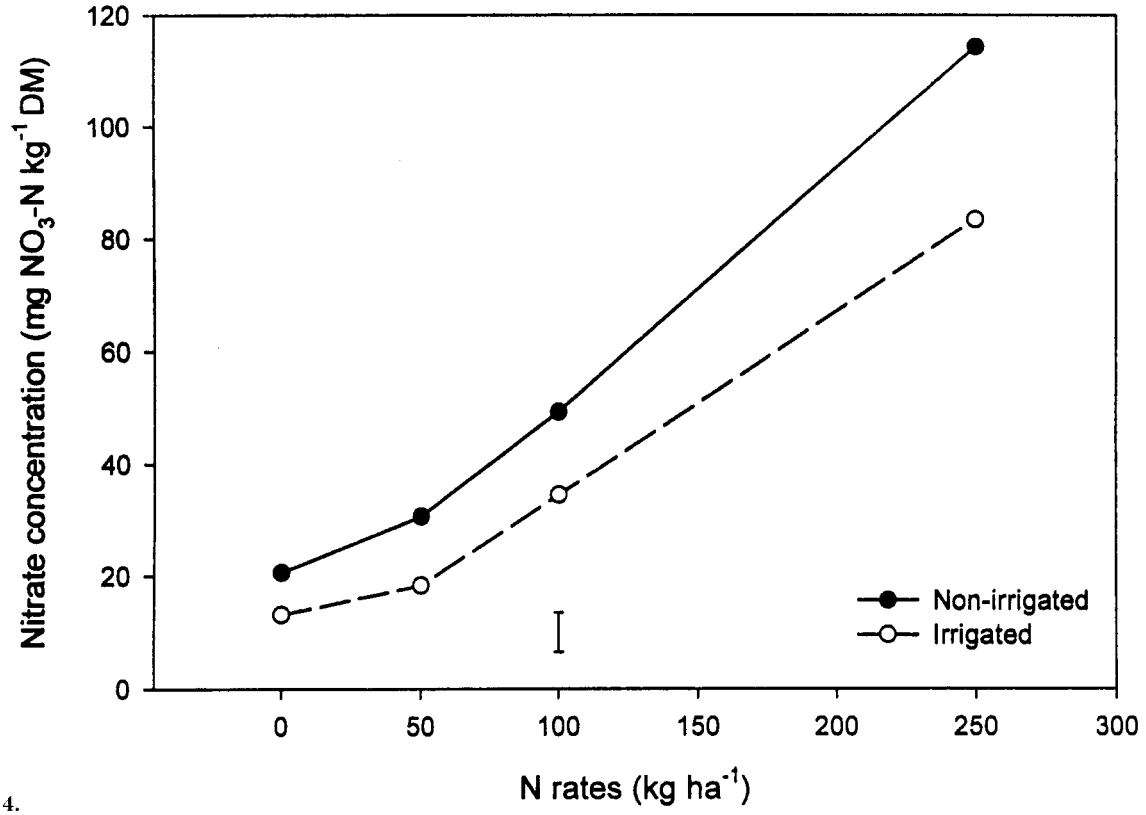

FIGURE 4.
Nitrate concentration of potato tubers as a function of increasing applied N under irrigated and non-irrigated conditions. Data averaged over nine sites and two cultivars. Bar indicates the standard error of the mean for applied N by irrigation interaction.

gravity and tuber N concentration did not differ for Russet Burbank and Shepody (data not shown). A negative relationship between DM concentration and N concentration was also reported for a grass species (Thornton et al. 1999). The implication of this relationship for potato tubers is not clear. Because N concentrations in the tissue water of N-deficient and N-sufficient barley were similar, Leigh and Johnston (1985) concluded that any difference in N concentration on a dry matter basis would be mainly due to differences in water content. We could, therefore, hypothesize that there would be no differences in tuber N concentration in our study if it was expressed on a water basis rather than on a dry matter basis. The importance of expressing N concentration on a dry weight basis, as compared with a fresh weight basis, is discussed by Leigh and Johnston (1985) and Thornton et al. (1999) in the context of using N concentration to diagnose plant N deficiencies. Tuber N concentration at harvest might be used to indicate the supply of N, in which case expressing N concentration on a dry weight basis may help to differentiate between limiting and non-limiting conditions.

Tuber NO_3-N concentration was strongly related to tuber N concentration for both Russet Burbank and Shepody (Figure 5b). The shape of the relationship between NO_3-N concentration and N concentration indicates that the proportion of N in the NO_3-N form increases with increasing N fertilization; this increase is greater for Russet Burbank than for Shepody. The proportion of NO_3-N in tuber N ranged from 0.15% in Russet Burbank and 0.12% in Shepody, with no N applied, to 0.66% in Russet Burbank and 0.54% in Shepody with 250 kg N ha^{-1}. Similar results are reported by Carter and Bosma (1974) and Biemond and Vos (1992). The NO_3- N concentration was less than 30 mg kg^{-1} DM, with tuber N concentrations below 1.2%. These results are in agreement with Biedmond and Vos (1992).

Both tuber specific gravity and NO_3-N concentration of Russet Burbank and Shepody were related to relative yield (Figure 6). Specific gravity decreased with increasing relative yield (Figure 6a). The seven data points with the greatest specific gravity

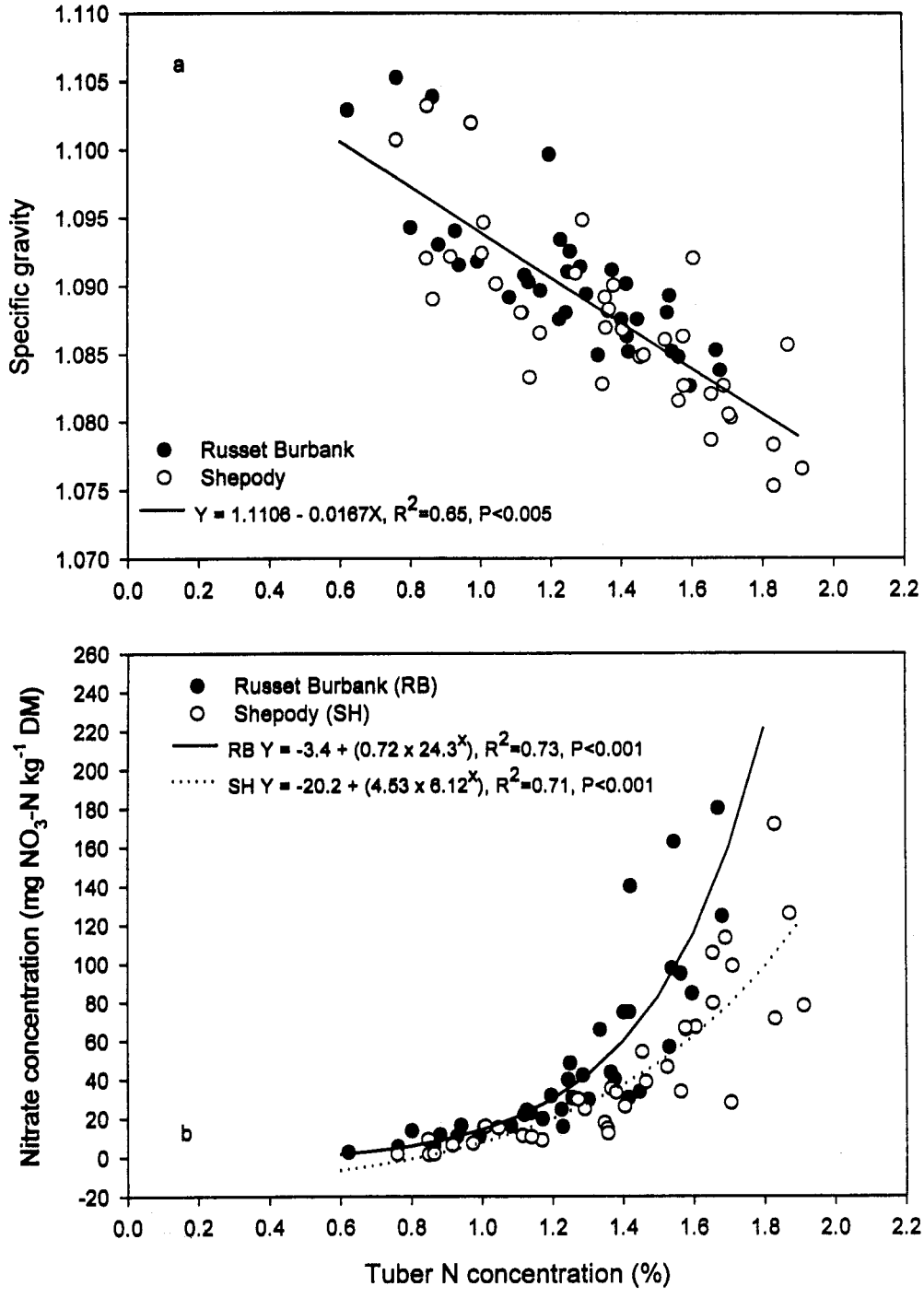

FIGURE 5.
Relationship between specific gravity and N concentration (a) and between NO_3-N concentration and N concentration of potato tubers (b) for Russet Burbank and Shepody. Data averaged over nine sites and two irrigation treatments.

were from S5; tuber N concentration was also the lowest at S5. We have no satisfactory explanation for this result, but it does highlight the close relationship between specific gravity and N concentration. The incidents of lowest specific gravity and highest NO_3-N concentration occurred with a relative yield close to or equal to 1.0 (Figure 6 a,b). Our results confirm that nitrate accumulation and the reduction in specific gravity occurs when potatoes do not respond to increasing rates of N fertilization, that is, when an increase in N rate does not result in increased yield. Consequently, the risks of having low specific gravity and high tuber NO_3-N concentration will be greater with over-fertilization.

CONCLUSIONS

Nitrogen fertilization increased average fresh tuber weight and tuber N and NO_3-N concentrations, but it decreased specific gravity. Effects of high N fertilization on tuber characteristics were often more pronounced for Shepody than for Russet Burbank, and for irrigated rather than for non-irrigated conditions. Shepody had a greater average fresh tuber weight and tuber N

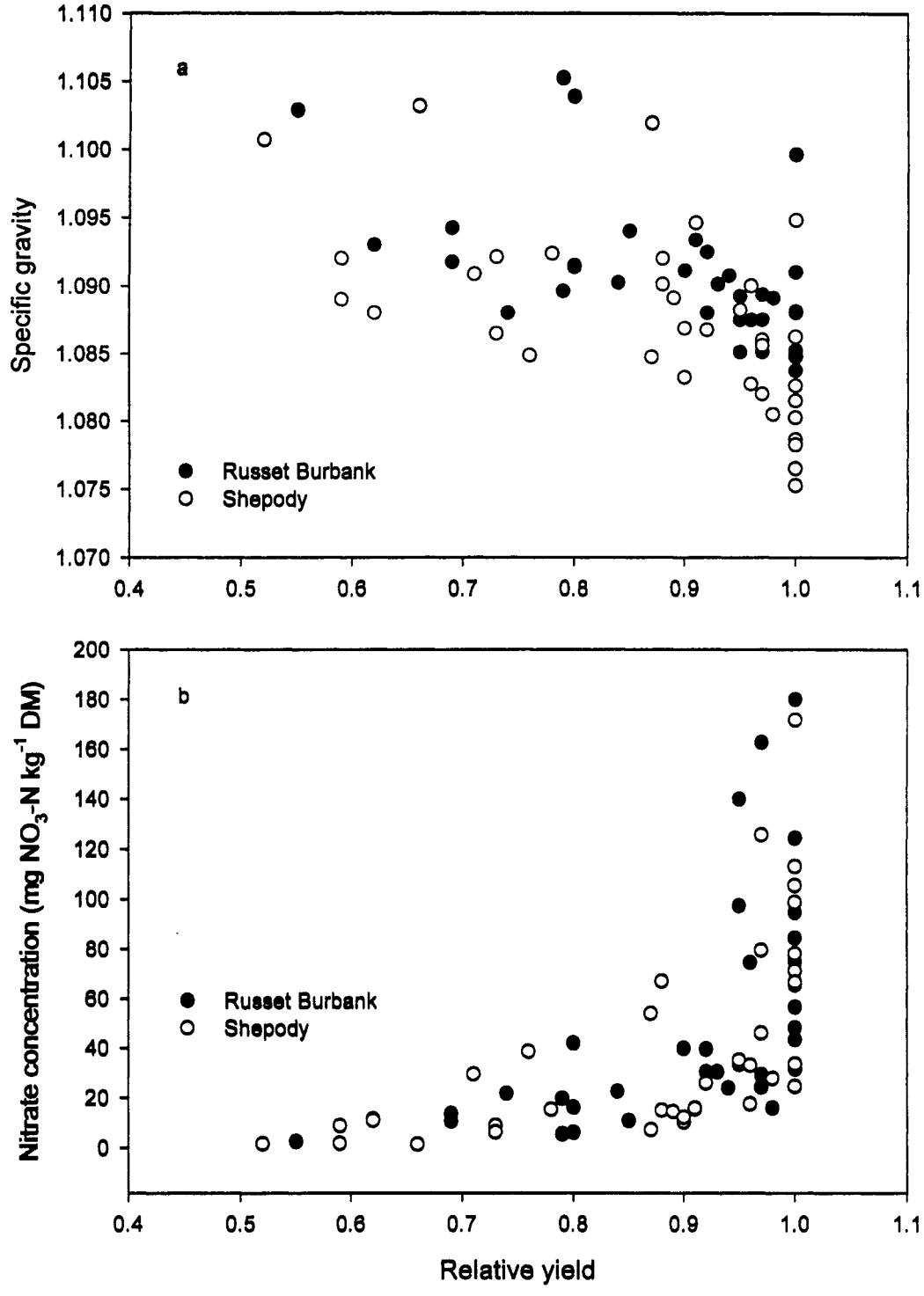

FIGURE 6.
Relationship between specific gravity and relative yield (a) and tuber NO_3-N concentration and relative yield (b) for Russet Burbank and Shepody. Data averaged over nine sites and two irrigation treatments.

concentration, and a lower specific gravity than Russet Burbank. Supplemental irrigation increased the average fresh tuber weight and the number of tubers per plant, but it had a limited effect on specific gravity and tuber N and NO_3-N concentrations. The risks of low specific gravity and high tuber NO_3-N concentration are greater when fertilization exceeds the N requirements to reach maximum tuber yield.

ACKNOWLEDGMENTS

We acknowledge the excellent technical assistance provided by numerous technicians during this project. Editorial assistance was provided by C. A. McRae from Editworks and advice on statistical analysis by K. B. McRae. This is contribution no. 732 , of Soils and Crops Research and Development Centre.

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