

CHAPTER 2

A MODEL FOR MAKING FIELD-BASED NITROGEN RECOMMENDATIONS FOR WINTER WHEAT IN WESTERN OREGON

ABSTRACT

Early determination of crop N status allows for greater options in N fertilizer management. Incorporating information about crop N requirements, soil testing, and plant analysis at early growth stages will be very helpful towards optimizing the fertilizer N recommendations for winter wheat.

An early spring soil and tissue analysis based model was developed and evaluated for predicting the need for additional N fertilizer on winter wheat. Standard N response on-farm trials were established in three years to develop model and two validation field-scale trials were run in one year. On-farm trials were conducted in growers fields at three different location across the Willamette Valley of western Oregon during 1994-1996 growing seasons. Each site of these experiments represented a crop rotation system that is commonly used in the Valley. Rotations used were soft white winter wheat following grass seed, sweet corn or a legume. Four treatments, including a check receiving no nitrogen, were used at each site during the 1993-94 and 1994-95 growing seasons. In 1996-97, two trials were conducted to further check the validity of the proposed model.

Rotations were soft white winter wheat following grass seed and sweet corn. Three treatments were used at each site. At the wheat following corn rotation site, the predicted optimum N rate was 168 kg N ha⁻¹. A low (84 kg N ha⁻¹) and intermediate (140 kg N ha⁻¹) rate were selected as other treatment in this trial. At the wheat following grass seed rotation site, N was applied at the rate of 84, 112, and 140 kg N ha⁻¹. The 112 kg N ha⁻¹ rate was the recommended rate from our model. The 84 kg N ha⁻¹ and 140 kg N ha⁻¹ rate were selected to bracketing recommended rate (± 28 kg N ha⁻¹).

The response of winter wheat to fertilizer N varied greatly among rotations and years in this study. Wheat following corn rotation was high responsive to added fertilizer N while wheat follow grass were less responsive. Wheat following grasses had high soil supplied N which depressed the yield even at moderately high fertilizer N rates. This finding contradicts conventional wisdom that suggests higher N rates are needed following grasses. This study documents a difference between perennial grasses and cereals grain crops in rotation. The average yield with no fertilizer for wheat following corn and wheat following legumes were about to same.

Optimum N rates predicted by our proposed model were closely related to the N rates require to obtain maximum economic yield. This study overall shows that the model appears to accurately assess field-specific optimum fertilizer N status and that it can be used to make fertilizer N recommendations for the region.

INTRODUCTION

The assessment of optimum N fertilizer rates for winter wheat (*Triticum aestivum* L.) is important for economic and environmental sustainability. Nitrogen alters plant growth more than any other mineral nutrient. In wheat a suboptimal supply of N can dramatically reduce dry matter and subsequently grain yield (Power and Alessi, 1978; Robinson et al., 1979; Donohue and Brann, 1984; Nielsen and Halvorson, 1991), while oversupply of N may cause lodging, disease and lower grain quality (Boquest and Johnson, 1987; Beuerlein et al., 1992; Memon and Jamro, 1988).

The determination of optimum N fertilizer rates for winter wheat is a major unsolved problem in most humid region of the world (Stanford, 1982). Determining precise N fertilizer rates requires the consideration of yield goals, N requirement of the crop, soil N tests, and plant analysis. The amount of fertilizer N necessary will vary depending on yield desired, residual N and the N supplying capacity of the soil.

Fertilizer N recommendations are mostly influenced by yield goals. Nearly 80% of growers overestimate their yield goals and apply excess N fertilizer (Goos and Prunty, 1990; Schepers et al. 1986). Realistic yield goals for each field are very crucial in determination of optimum fertilizer N rates.

An estimate of the fertilizer N needs of a particular crop cannot be determined quantitatively without a knowledge of the crop's requirement for this

element. Crop N requirement is a function of yield potential and the amount of N required per unit of yield. Stanford and Legg (1984) defined the N requirement as the minimum amount of N in the above ground portion of crops associated with maximum production. Nitrogen rate experiments are the most effective way of determining N requirements for a crop. Yield will continue to increase as N is supplemented when N is a limiting factor in plant growth. There is essentially no further increase in yield with increasing N content once the crop requirement of N is met.

Soil mineral N ($\text{NH}_4\text{-N} + \text{NO}_3\text{-N}$) testing before spring fertilization has been proven a useful tool for adjusting N fertilizer requirements in the semi-arid and semihumid regions of the U.S. (Maples et al., 1977; Westall, 1984; Rauschkolb et al., 1984; Cox, 1985). Despite complications such as mobility, leaching and, nitrification, soil tests for residual $\text{NO}_3\text{-N}$ have been found to be useful in determining N fertilizer needs of crops (Gelderman et al. 1988). A soil nitrate test before planting appears to be well related to the fertilizer requirements of spring wheat in the Northern plains (Fox and Piekielek, 1978). In a study conducted on the Eastern Shore of Maryland, Meisinger et al. (1987) found that the N requirement of a wheat crop could be effectively adjusted by measuring residual spring N status of the soil.

Soil tests for residual N can improve prediction of crop N fertilizer requirements in humid region of U.S., but their adaptation in fertilizer recommendation depends on the frequency of significant profile $\text{NO}_3\text{-N}$ carryover

(Matias and Bundy, 1994). In humid Midwest measurement of NO_3^- in soil profile before corn (*Zea mays* L.) planting effectively predicted N response and the amount of supplement N needed for profitable production (Schmitt et al., 1991; Bundy et al., 1992). Usefulness of a soil N test in humid region was also reported by Vanotti and Bundy (1994). Their results illustrated that a large variations, 32 to 106 kg N ha⁻¹, in N carryover makes soil testing for profile $\text{NO}_3\text{-N}$ an important tool to optimize N fertilizer use in the humid region of Wisconsin. Wehrmann and Scharpf (1979) found a strong correlation between optimum fertilizer rates and soil mineral N. They developed a predictive system (the N_{min} method) from this relationship which not only predicts the optimum fertilizer N but also identifies the field not needing fertilization. Many researchers used their approach to optimize fertilizer N for winter wheat (Beathgen and Ally, 1989; Beauchamp and Kachanoski, 1991; Bundy et al. 1992).

Soil supplied N is derived either from residual inorganic N, ammonium ($\text{NH}_4\text{-N}$) and/or nitrate ($\text{NO}_3\text{-N}$) or from organic N that becomes converted to inorganic N by soil microbes. Researchers have long been aware that a small percentage of organic N is mineralized in the course of the growing season and can significantly contribute to nitrogen requirements of the crop (Forth and Ellis, 1988; Harper, 1984; Power and Doran, 1984; Marumoto et al., 1982). Biological immobilization of soil inorganic N occurs simultaneously with mineralization. A significant portion of mineralized N is immediately assimilated by soil microbial biomass and transformed into organic cell constituents (Mary and Recous, 1994).

During mineralization-immobilization, soil micro biomass itself temporarily serves as source and sink of easily mineralizable nitrogen (Simath, 1994). Soil microbial biomass predominantly assimilates $\text{NH}_4\text{-N}$ during the immobilization process, but in the absence of $\text{NH}_4\text{-N}$, they use $\text{NO}_3\text{-N}$ as an energy source (Recous et al., 1988; Aazam et al., 1986). The difference between gross rates of mineralization and immobilization is net mineralization. Net mineralization is strongly depended on C/N ratio of the organic matter (Whitmore and Groot, 1994; Bruin et al. 1994; Neve et at. 1994). The amount of N returned to the soil by crop residues depends on the quality and quantity of the substrate.

Crops grown in rotation often produce more and higher quality plant dry matter than those grown in monoculture (Copeland and Crookston, 1992, Collins et al. 1992). Change in crop sequence changes soil temperature, soil moisture, crop rooting and residue inputs. Fertilizer N requirement for optimum grain yield is often reduced in rotation compared to monoculture (Heichel and Barnes, 1984, Franzluebbers et al. 1994). Cereal crops grown after a legume often have a higher yield as compared to grown after a non-legume crop (Wani et al. 1990). This is because legume residues generally have a low C/N ratio and large fraction of readily available N. Breland (1994) studied the decomposition dynamics of white clover in a controlled environment. Net mineralization was estimated as the difference between that in amended and unamended soil, respectively. He found that 38-56 percent of the nitrogen in clover shoot matter was mineralized during the initial period (52 days) of rapid mineralization. Thick

et al. (1993) found that the decomposition of incorporated legume residues can have significant, but extremely variable, impact on total N mineralization.

McKenney et al. (1995) concluded that legume residues can provide a definite advantage compared with grass and corn residue in term of N conservation depending on the aeration status of the soil. Legume residues not only provide a great source of readily available N to other crops (Azam, 1990), but can also increase long-term soil fertility (Plam and Sanchez, 1991). This increase is mainly because of the conversion of a portion of biologically-fixed N into the stable humus form (Azam et al, 1993). In addition to the enhancement of N fertility, legumes also affect soil properties such as water holding capacity, cation exchange capacity, buffer capacity, soil porosity and infiltration (Burnett, 1975; Cook, 1988; Fyson and Osks, 1990).

In western Oregon, a variety of crop rotations create large differences in soil N supplying capacity which are not reflected in soil tests for inorganic N. In a study carried out in western Oregon, Sebastian (1995) measured N recovery by unfertilized winter wheat ranging from 96 kg h⁻¹ to 192 kg h⁻¹. Assessment of mineralizable N at the beginning of the growing season and coupling the results with soil mineral and plant analysis could be helpful in improving fertilizer N recommendations in the region.

Plant tissue analysis at early growth stages are another important method of estimating optimum fertilizer N rates and have successfully been used as an indicator of N fertilizer requirements for wheat by many researchers (Engel and

Zubriski, 1982; Donohue and Brann, 1984; Becker and Aufhammer, 1982). In regions where soil testing for N has been impractical due to heavy precipitation, plant tissue testing could be a promising method of estimating fertilizer N requirements for winter wheat (Fox and Pieckieleck, 1984). Many fertilizer N recommendations are based on the analysis of plant tissue samples taken at Feekes 5 stage (Large, 1954) in the spring. Vaughan et al (1990) found that late tillering (Feekes 5) is the most appropriate and usable growth stage for plant sampling in order to making tissue based N recommendations. They also suggested that total N should be calculated from whole plant samples. Roth et al. (1989) reported that whole N concentration at Feekes 5 rather than N uptake is the most accurate method of predicting N deficiency. Scarf (1993) found tissue N content a useful tool in adjusting optimum N rate in Virginia.

A method for making field-specific N rate recommendation for winter wheat at early growth stages was reported by Baethgen and Alley (1989). Their method used crop N uptake or plant N concentration at Feekes 5 as the basis of the N rate recommendations. Strong correlation was found between uptake or plant N concentration at Feekes 5 and optimum N rates. Similar results were reported by Batey (1977). He also found a high correlation between crop uptake in spring and the rate of fertilizer N required to obtain maximum grain yield. Peter et al. (1993) used this approach and also found a good relationship between tissue N and optimum fertilizer N rates. Economic analysis indicated that tissue-based N rate recommendation increased profit by an average of 36 \$ ha⁻¹

relative to traditional N applications.

Application of fertilizer N is often necessary to supplement soil supplied N in commercial cropping systems. Efficient N management utilizes soil N as much as possible, adding fertilizer N to enhance crop growth only when necessary (Sebastian, 1995). The amount of fertilizer N necessary will vary depending on yield desired, residual N and the N supplying capacity of the soil. Incorporating information about crop N requirements, soil testing, and plant analysis at early growth stages will be very helpful towards optimizing the fertilizer N recommendations for winter wheat. The objective of this study was to evaluate the suitability of a N balance model for predicting the need for additional N fertilizer on winter wheat under western Oregon conditions.

MATERIAL AND METHODS

Nitrogen Balance Model

A model was developed to calculate optimum fertilizer N rates similar to that proposed by Rice and Havlin (1994). Recommended nitrogen rates were determined by this model:

$$\text{Recommended N} = 300 - (N_r + N_{\min} + N_{\text{up}}) \quad [1]$$

Where,

N_r = Residual inorganic N ($\text{NH}_4\text{-N} + \text{NO}_3\text{-N}$) kg ha^{-1} at Feekes 5

N_{\min} = Soil mineralizable N kg ha^{-1} at Feekes 5

N_{up} = Plant N uptake kg ha^{-1} at Feekes 5

The 300 N kg ha^{-1} is the total N (residual N + mineralizable N + fertilizer N) estimated to be required to obtain maximum yield in Willamette Valley of western Oregon. Analysis of nitrogen response wheat trial data by Neil Christensen and John Hart, soil Scientists, Department of Crop and Soil Science, Oregon State University, suggested that this rate optimized yield over an array of environmental and production conditions. Data from over twenty years and dozens of trials were analyzed. Optimum N rate was estimated by adding the amount of N recovered in unfertilized plots (an estimate of mineralized N) to the amount of applied fertilizer N that gave maximum yield in each trial. The average optimum N rate was about 300 kg N ha^{-1} (unpublished data) and showed little variation. This

uniformity in N needed to optimize yield under an array of environmental conditions suggested that it may be possible to model N need. Standard N response trials were established in three years to develop model and two validation field-scale trials were run in one year. Each type of trial is discussed below.

On-farm Trials

On-farm trials were conducted in growers fields at three different location across the Willamette Valley of western Oregon during 1994-1996 growing seasons. The 1993-94 experiment was part of fellow graduate student Kevin Sebastian's (1994) MS Thesis. Each site of these experiments represented a crop rotation system that is commonly used in the Valley. Rotations used were soft white winter wheat following grass seed, sweet corn or a legume. The experimental design was a randomized complete block with three replications on each site. Plot size varied site-to-site depending on size of machinery used by the grower. An average 90m X 10m plot size was used. Nitrogen fertilizer was applied as urea (46-0-0) at approximately Feekes 5 in one application with drop or spinner spreader. Four treatments, including a check receiving no nitrogen, were used at each site during the 1993-94 and 1994-95 growing seasons. At corn and legume rotation sites, N was applied at the rate of 0, 56, 112 and 168 kg N ha⁻¹. Since less residual nitrogen was expected following grass in rotation, slightly higher rates - 0, 67, 134, 201 kg N ha⁻¹ - were used in the first two years.

During the 1995-96 growing season, five N rates - 0, 56, 112, 168 and 224 kg N ha⁻¹ - were used in all three rotations. The location, soil series, cropping history and wheat varieties used in the experiments are listed in Table 2-1.

Soil samples were collected at approximately one month intervals from each site during the 1993-94 and 1994-95 growing seasons. Samples were taken at four depths- 0-30, 30-60, 60-90 and 90-120 cm. A single composite sample representing the entire plot area was used prior to spring fertilization.

Approximately ten cores were taken to make this composite sample. Analysis of soil data for NH₄-N and NO₃-N from these two growing season indicated that a 30 cm depth sample taken at Feekes 5 was adequate to assess soil N status (data not shown). During the 1995-96 growing season, pre-fertilization soil samples were collected from individual plots at 30 cm depth. Each sample was a composite of approximately 10 cores. Intensive soil sampling was performed just after harvesting at each site on each plot in all years to three depths- 0-30, 30-60, and 60-90 cm.

To calculate total N uptake, plant tissue samples were taken at Feekes GS 5 (prior to fertilizer application) and at maturity. At Feekes 5, ten representative samples of 30 cm of row were collected from each plot by cutting the plants at soil level. Whole plant samples were weighed, ground and analyzed for nitrogen content. At maturity, nine one-meter row sections were cut at soil level from each plot to determine dry matter. Heads from plants were removed and threshed separately. Representative subsampling was performed for each sample.

Subsamples of grain, straw and chaff were analyzed for nitrogen content. Plant N uptake (kg N h^{-1}) was calculated by multiplying the N concentration in the tissue by dry matter production (kg DM h^{-1}). Plant height and lodging measurements were taken prior to harvest. Grain yield was obtained from individual plots. Growers used their equipment to harvest the plots. Grain yield was determined on site through use of a weigh wagon accurate to ± 1 kg. A grain sample was saved for test weight, protein and 1000 kernel weight determination.

Small Plot Research Station Trials

Fertility trials were established during the 1993-94 growing season at the Hyslop Experimental Station of the Department of Crop and Soil Science, Oregon State University, Corvallis, Oregon. Work continues on these trials. The experiment is arranged as a split plot design with four replications having rotation (clover or oat) as main plot and fertilizer treatments as sub-plot. Rotation strip size is 12m X 45m, while sub plot fertilizer treatment size is 12m X 10m. Five fertilizer treatments - 0, 50, 100, 150 and 200 kg N ha^{-1} - are used. Rotations include winter wheat following clover and winter wheat following oat. The site had been fallow in 1993. Crimson clover was planted on all plots in fall 1994. In spring 1995, two plots per replication were fallowed, one was planted to oat and the fourth was left in clover. Clover and oat were allowed to mature, were harvested and crop residue was incorporated. Wheat was planted on the clover and oat stubble plots in fall 1995 and crimson clover on one of the fallowed plots

to establish the next rotation cycle. Oats were planted in spring 1996. Data were collected for 1995-96 and 1996-97 growing seasons.

Soil samples were collected pre-plant and post-harvest. An intensive preplant sampling was done in fall 1995 by taking soil at 30 cm increments to a depth of 150 cm from individual plots. This was done to assess the residual nitrogen status of the experimental site. Post-harvest sampling was performed on 0, 150 and 200 kg N ha⁻¹ treatment plots. Samples were analyzed for ammonium and nitrate concentrations.

Plant tissue samples were taken at Feekes 5 and at maturity for dry matter yield and nitrogen uptake. Four above ground plant samples of 1.5 meter of row were cut from drill strips in each sub-plot. Heads were cut, threshed and weighed. Grain and straw were analyzed separately for their nitrogen content by combustion analyzer. Plant N uptake (kg N h⁻¹) was calculated by multiplying the N concentration in the tissue by dry matter production (kg DM h⁻¹). Plant height and lodging were measured prior to harvest. Plots were harvested with a small plot combine harvester. Harvested grain was cleaned and analyzed for yield, test weight, protein content by whole grain NIR analyzer and 1000 kernel weight.

Model validation Trial

In 1996-97, two trials were conducted to further check the validity of the proposed model. The model developed N rate trials were conducted in growers fields at two location in the Willamette Valley. Rotations were soft white winter

wheat following grass seed and sweet corn. The experimental design was a randomized complete block with three replications at each site. Plot size varied depending on size of machinery used by the grower. An average 90m X 10m plot size was used. Nitrogen fertilizer was applied as urea (46-0-0) at approximately Feekes 5. Three treatments were used at each site. We were not interested in N response per se but bracketing N rates were used at each site. At the wheat following corn rotation site, the predicted optimum N rate was 168 kg N ha⁻¹. Previous corn rotation trials had not shown an economic yield respond beyond this rate hence a low (84 kg N ha⁻¹) and intermediate (140 kg N ha⁻¹) rate were selected as other treatment in this trial. The cooperating grower was interested in lower N rate. Spreader collaboration error resulted in an intermediate rate of 132 kg N ha⁻¹ At the wheat following grass seed rotation site, N was applied at the rate of 84, 112, and 140 kg N ha⁻¹. The 112 kg N ha⁻¹ rate was the recommended rate from our model. The 84 kg N ha⁻¹ and 140 kg N ha⁻¹ rate were selected to bracketing recommended rate (± 28 kg N ha⁻¹). The location, soil series, cropping history and wheat varieties used in the experiments are listed in Table 2-1.

Soil samples were collected before fertilizer application and after harvest. At pre-fertilization, a soil sampling was collected at 30 cm depth while afterharvest samples were taken at three depths- 0-30, 30-60, and 60-90 cm from individual plots. Each sample was a composite of approximately 10 cores.

Plant tissue samples were taken at Feekes GS 5 (prior to fertilizer application) and at maturity to calculate total N uptake. At Feekes 5, ten

representative samples of 30 cm of row were collected from each plot by cutting the plants at soil level. Whole plant samples were weighed, ground and analyzed for nitrogen content. At maturity, nine one-meter row sections were cut at soil level from each plot to determine dry matter. Heads from plants were removed and threshed separately. Representative subsampling was performed for each sample. Subsamples of grain, straw and chaff were analyzed for nitrogen content. Nitrogen uptake (kg N h^{-1}) was calculated from dry matter production (kg DM h^{-1}) and corresponding plant N concentration.

Maximum Economic Yield Equations

The validity of the N balance model was checked by comparing the recommended N rates determined by the model with N rates determined in 1996-97 trials to obtain maximum economic yield. To calculate the fertilizer rate required for maximum economic yield, regression equations were developed from response curves of wheat grain yield to N fertilizer applied at Feekes 5 for each level of N (Baethgen and Alley, 1989). The relationship between yield and fertilizer was quadratic in shape for each rotation (Mason, 1987). The quadratic equation used is as follows:

$$Y = a + b_1N - b_2N^2 \quad [2]$$

Where,

Y = Grain yield (kg ha^{-1})

a = Intercept

b = Slope

N = Fertilizer N rate (kg ha⁻¹)

The maximum economic rate value for any given response curve is the fertilizer rate value that makes the first derivative of the response function equal to the price ratio of N fertilizer to wheat (\$kg N to \$ kg wheat)(Heady et al. 1955).

The fertilizer rate for maximum economic was calculated as follows:

$$Y = a + b_1N - b_2N^2 \quad [2]$$

Set the first derivative equal to N price/wheat price

$$X = r - b_1 / 2b_2 \quad [3]$$

Where,

r = ratio price ratio of N fertilizer to wheat (\$kg N to \$ kg wheat)

b₁ and b₂ are slopes of the curve.

Soil Analyses

Soil and plant tissue samples were analyzed in the Central Analytical Lab (CAL) at Oregon State University, Corvallis, Oregon. The N content of wheat grain and straw was determined by dry chemical analysis using a FISON CARLO ERBA NA 1500 Series 11 carbon/nitrogen analyzer.

Soil inorganic N (NH₄-N and NO₃-N) was determined using the modified KCl extraction method described by Keeny and Nelson. Twenty-gram soil samples were placed in 250 mL bottles and 75 mL of 2 N KCl extracting solution

was added. Vessels were shaken on a mechanical shaker for one hour. The extraction solution was filtered through Whatman No. 42 filter paper. The $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ content of the extract was determined with an ALPKEM rapid flow analyzer (RF-300).

Anaerobic incubation

Soil mineralizable N was determined using a short-term anaerobic incubation method described by Keeney (1982) slightly modified by increasing the sample size. Through use of a sample splitter, a 20 g soil sample was obtained and placed in a 250 mL extraction bottle. Fifty mL of distilled water was added to each bottle so that the soil become completely saturated. Bottles were made air tight by putting a plastic cover under their lids. Samples were placed in an incubator for 7 days (168 h) at 40 °C plus or minus 0.5 °C. After incubation, samples were carefully removed from the incubator and 50.0 mL of KCl was added. Vessels were shaken on a mechanical shaker for one hour. The extraction solution was filtered through Whatman No. 42 filter paper. Final NH_4^+ content of the extract solution was determined from incubated samples. Initial NH_4^+ values were subtracted from the final values to obtain the amount of N mineralized.

Table 2-1: Location, previous crop, variety and soil series for experimental sites.

Grower	County/City	Previous crop	Wheat variety	Soil Series
1994				
Jones	Polk/Amity	Clover	Madsen	Amity Fine-silty, mixed mesic, Argiaquic Xeric Argialbolls
Volker	Benton/Monroe	Corn	Gene	Malabon Fine, mixed, mesic Pachic Ultic Argixerolls
Van Leeuwen	Linn/Halsey	Tall Fescue	Gene	Malabon Fine, mixed, mesic Pachic Ultic Argixerolls
1995				
Rudden	Polk/Amity	Clover	Gene	Amity Fine-silty, mixed mesic, Argiaquic Xeric Argialbolls
Volker	Benton/Monroe	Corn	Gene	Chehallis Fine-silty, mixed, mesic Cumulic Ultic Haploxerolls
Van Leeuwen	Linn/Halsey	Tall Fescue	Stephens	Woodburn Fine-silty, mixed, mesic Aquultic Argixerolls
1996				
Rudden	Polk/Amity	Clover	Gene	Amity Fine-silty, mixed mesic, Argiaquic Xeric Argialbolls
Volker	Benton/Monroe	Corn	Gene	Malabon Fine, mixed, mesic Pachic Ultic Argixerolls
Chipman	Benton/Albany	Perennial Raygrass	Madsen	Willamette Fine-silty, mixed mesic Ultic Haploxeralfs
1997				
Mulkey	Polk/Monmouth	Annual Raygrass	Madsen	Willamette Fine-silty, mixed mesic Ultic Haploxeralfs
Jones	Benton/Corvallis	Corn	Stephens	Chehallis Fine-silty, mixed, mesic Cumulic Ultic Haploxerolls

RESULTS AND DISCUSSION

Optimum fertilizer N rates for winter wheat were estimated by the following N balance model.

$$\text{Recommended N} = 300 - (N_r + N_{\text{min}} + N_{\text{up}}) \quad [1]$$

Where N_r and N_{min} are the soil inorganic N ($\text{NH}_4\text{-N} + \text{NO}_3\text{-N}$) and soil mineralizable N kg ha^{-1} at Feekes 5 before fertilizer application, respectively, and N_{up} is the total N (kg ha^{-1}) taken up by the crop at Feekes 5 prior to fertilization. The 300 N kg ha^{-1} is the total N (residual N + mineralizable N + fertilizer N) assumed to be needed for maximum yield in Willamette Valley of western Oregon. The parameters used in the model were determined at the time of spring fertilization in order to assess optimum N rates. parameter values and predicted fertilizer N need for the various trials conducted as part of this study are shown in Table 2-2.

At on-farm sites, the amount of soil inorganic N in the top 30 cm of soil at the time of spring fertilizer application was minimal and uniform through all rotations over years. The average inorganic N across all rotations over years was only 27 kg N h^{-1} (Table 2-2). This is likely because of leaching and/or denitrification losses due to heavy precipitation during winter months (Sebastian, 1994). Soil mineralizable N in the top 30 cm of soil varied greatly among rotation over years. Amount measured prior to spring fertilization ranged from 53 kg N h^{-1} in the wheat following corn to 116 kg N h^{-1} in the wheat following grass. In 1995

Table 2-2: Assessment of optimum N rates for each rotation using the N balance model

Rotation	Total N [†]	Mineralizable	Soil N [§]	Plant N	Recommended
		N ^{††}		Uptake ^{§§}	N rate ^{¶¶}
		----- kg ha ⁻¹ -----			
<u>On-farm</u>					
1994					
Clover-Wheat	300	94.9	22.9	19.0	163
Corn-wheat	300	106.5	18.4	18.0	157
Grass-wheat	300	84.4	38.8	20.0	157
1995					
Clover-Wheat	300	72.2	36.1	25.6	166
Corn-wheat	300	53.2	25.8	31.1	190
Grass-wheat	300	91.6	24.9	38.6	145
1996					
Clover-Wheat	300	60.4	26.6	26.1	187
Corn-wheat	300	74.4	33.3	15.1	177
Grass-wheat	300	116.0	26.7	42.8	114
<u>Small Plot</u>					
1996					
Oat-wheat	300	55.1	33.7	17.6	193
Clover-wheat	300	59.7	43.1	14.3	179
1997					
Oat-wheat	300	63.2	13.1	6.5	217
Clover-wheat	300	85.3	14.4	31.7	168

[†] Total N (residual N + mineralizable N + fertilizer N) to obtain maximum yield in Willamette Valley of western Oregon.

^{††} Soil mineralizable N kg ha⁻¹ at Feekes 5 before fertilizer application

[§] Residual N (NH₄-N + NO₃-N) kg ha⁻¹ at Feekes 5 before fertilizer application

^{§§} Whole plant N uptake kg ha⁻¹ at Feekes 5 before fertilizer application

^{¶¶} Recommended N rate obtained by using model: $N = 300 - (N_r + N_{min} + N_{up})$ [1]

and 1996, wheat following grass had relatively high soil mineralizable N. The amount of N taken up by the crop at the point of fertilization was also comparatively high in wheat following grass in 1995 and 1996 which indicates high N availability in grass rotation (Table 2-2).

In small plots, in 1996 and 1997, the soil inorganic N in the top 10 cm of soil at Feekes 5 was similar in both oat and clover rotation (Table 2-2). In 1996, the soil mineralizable N in the top 10 cm of soil was also same for two rotations with average of 57 kg N h⁻¹, but in 1997, wheat following clover had a higher soil mineralizable N compared to wheat following oat. A similar pattern was found for plant N uptake at Feekes 5 where in 1996 the N uptake was not significantly different between rotations but in 1997, clover-wheat had a significantly higher N uptake 32 kg N h⁻¹ compare to 6.5 kg N h⁻¹ for wheat following oat (Table 2-2). Based on the proposed model recommended N rates ranged from 114 to 217 kg N h⁻¹.

Grain Yield Response

The grain yields for each site-year are summarized in Table 2-3. There was a significant yield response to fertilizer N across all site-years. In all rotations, a significant yield increase occurred with the first increment of N fertilizer. The effects of additional N varied among rotations and years. This variation in yield response to added fertilizer N among rotations and years may have been due to the factors such as soil types and texture, water availability, soil

Table 2-3: Mean grain yield and protein content of on-farm trials for the 1994-96 growing season.

Total N †	Previous crop								
	Clover		Corn		Grass				
applied	1994	1995	1996	1994	1995	1996	1994	1995	1996
kg ha ⁻¹									
0	5842a	4950a	4697a	7880a	5207a	4559a	6752a	3191a	4520a
56	7082b	5731b	6518b	9147b	6295b	6178b	9165b	5499b	5704b
112	7020bc	6138bc	7987c	9742c	7549c	7897c	9180bc	5853bc	6331bc
168	8076d	6258cd	8794d	10315d	7957cd	8111cd	10272d	6288cd	5915bcd
224			9082de			8251cde			5551bcde
PLSD	949	517	513	493	975	690	935	925	720
CV %	6	4	3	2	7	6	5	9	5
P-value	0.008	0.004	0.000	0.008	0.009	0.003	0.001	0.000	0.00

† In 1995 and 1996 wheat following grass fertilizer N rates were used as 0, 67, 134, 201 kg N ha⁻¹

nutrient levels and weather per se. Curvilinear yield-N response surfaces that conformed with grain yield trends were observed in the study (Figs 2-1). Similar observations have been reported by Entz and Flower (1989) and others. The regression equations that best described grain yield-N fertilizer response in each site and their R² are given in Table 2-4.

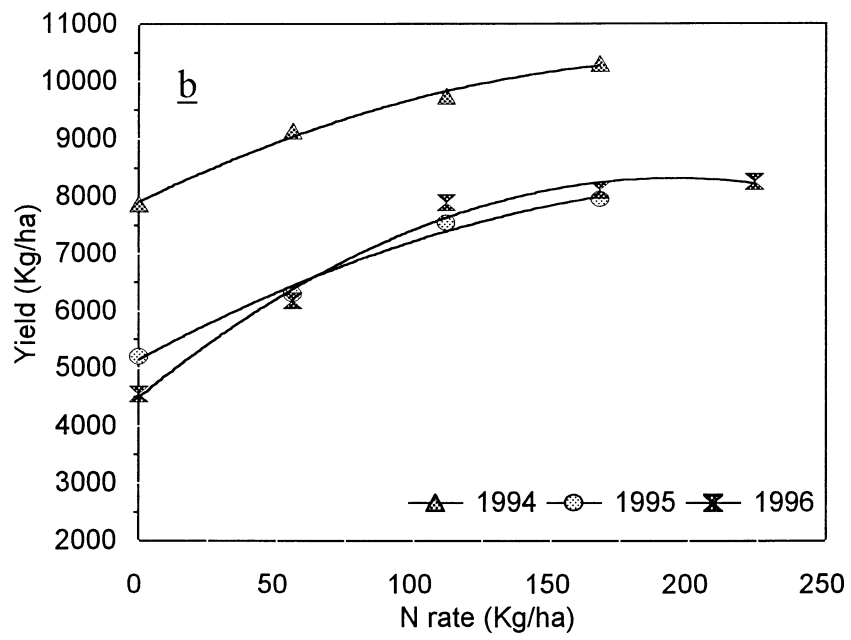
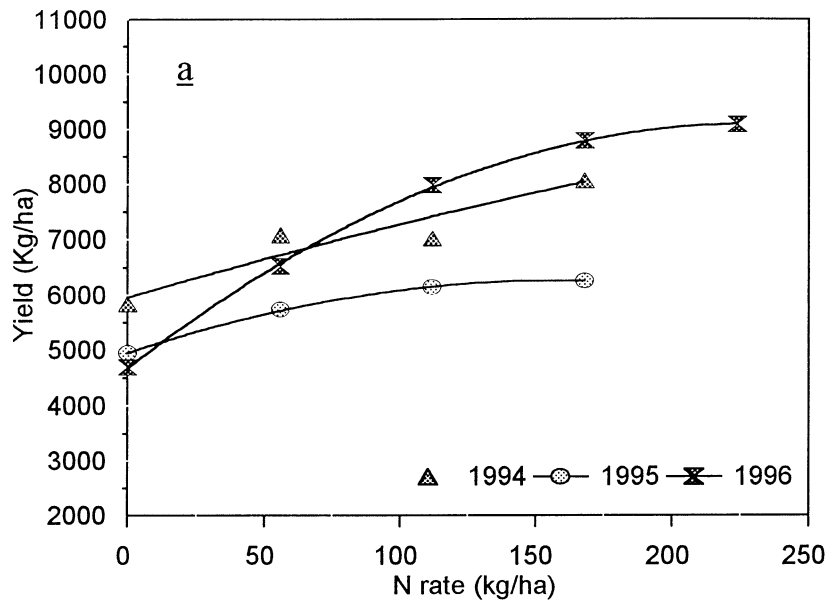
In the 1994, yields were higher across all rotations (Table 2-2). The average yield across all rotations with no fertilizer was 6824 kg ha⁻¹ - a yield above the long term yield average for the region. The USDA Agriculture Statistics Service reported yields 15% above the long term average in western Oregon during 1994 (USDA, 1994). In the wheat following corn rotation, each increment of N fertilizer significantly ($p < 0.05$) increased yields. The high response to N fertilizer for wheat following corn could be because corn provided a large quantity of a residue with a high C:N ratio. Echeverria et al. (1992) also found that wheat after corn responded most to N fertilizer as compare to soybean and sunflower. Wheat following clover in 1994 had lowest overall mean yields ranging from 5842 kg ha with no fertilizer to 8076 kg ha⁻¹ with 168 N kg ha⁻¹. No significant yield response was observed for 56 and 112 N kg ha⁻¹ treatments (Table 2-3). Current western Oregon fertilizer recommendations for wheat following clover are less than for wheat following row crops, but varies depending on how vigorous the clover crop was. A less than average stand would result in less available N for the subsequent wheat crop. The check yield for wheat following grass was 6752 kg ha⁻¹. As was observed for wheat following clover rotation, the fertilizer N

Table 2-4: Regression equations for nitrogen response curves of on-farm trials for the 1994-1996 growing season.

Rotation	Regression equation	r ²
<u>On-farm Trials</u>		
1994		
Clover-wheat	$G = 5963 + 14.34 * N - 0.11 * N^2$	.66
Corn-wheat	$G = 7913 + 23.40 * N - 0.05 * N^2$	.78
Grass-wheat	$G = 6925 + 30.50 * N - 0.73 * N^2$	.98
1995		
Clover-wheat	$G = 4955 + 16.59 * N - 0.53 * N^2$	.77
Corn-wheat	$G = 5156 + 26.07 * N - 0.05 * N^2$	.84
Grass-wheat	$G = 3324 + 35.61 * N - 0.10 * N^2$	.92
1996		
Clover-wheat	$G = 4674 + 38.75 * N - 0.85 * N^2$	.82
Corn-wheat	$G = 4499 + 39.40 * N - 0.10 * N^2$	.77
Grass-wheat	$G = 4359 + 24.08 * N - 0.09 * N^2$	.67
<u>Small Plots Trial</u>		
1996		
Oat-wheat	$G = 2193 + 40.77 * N - 0.06 * N^2$	.97
Clover-wheat	$G = 4027 + 36.80 * N - 0.07 * N^2$	.89
1997		
Oat-wheat	$G = 1171 + 43.38 * N - 0.06 * N^2$	.97
Clover-wheat	$G = 3566 + 51.61 * N - 0.14 * N^2$	.94

increments of 56 and 112 N kg ha⁻¹ did not significantly increased the yield (Table 22). In 1995, response to N fertilizer for wheat following corn was similar to 1994 observations. Yield increased significantly with each increment of N fertilizer except at the highest N rate. Mean grain yields were, in general, greater in wheat following corn compared to wheat following clover or grass. The wheat following grass rotation had the lowest check yield (3191 kg ha⁻¹) but the largest response to initial N increment. Adding 68 N kg ha⁻¹ increased the yield by over 2300 kg ha⁻¹. At the highest N fertilizer rate, the mean yield of wheat following clover and grass were the same, 6258 kg ha⁻¹ and 6288 kg ha⁻¹, respectively. In addition, the yield increase form 56 to 112 N kg ha⁻¹ was not significant for clover-wheat and grass-wheat rotations.

As 1994-95 data suggested there many be a response to higher N rate, a 224 N kg ha rate was included in 1995-96 experiments. No additional yield response was obtained for this higher rate in any rotation. Interestingly, the check yield for all three rotations was similar with an average value of 4592 kg ha⁻¹. At higher N rates, mean yields of wheat following clover and corn were about the same, while yields of wheat following grass were less. In fact, the highest yield of wheat following grass was achieved with 112 N kg ha⁻¹. Yield dropped considerably when the fertilizer N was applied at the rates of 168 and 224 N kg ha⁻¹ (Fig. 2-1 c). This reduction in yield at high N rates may be due to increase disease frequency, water stress, or to physiological reactions by the plant itself (Blade and Baker, 1991). No lodging occurred in any rotation. It was observed



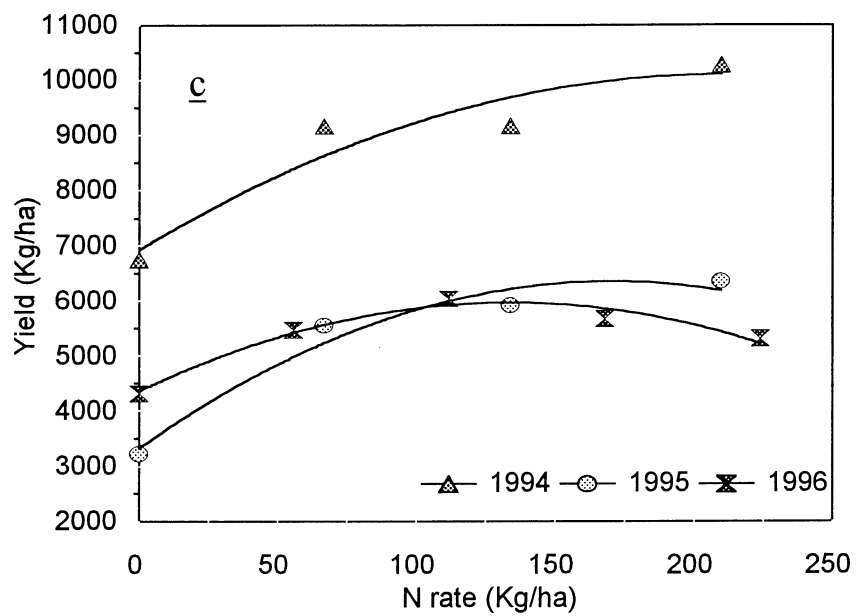
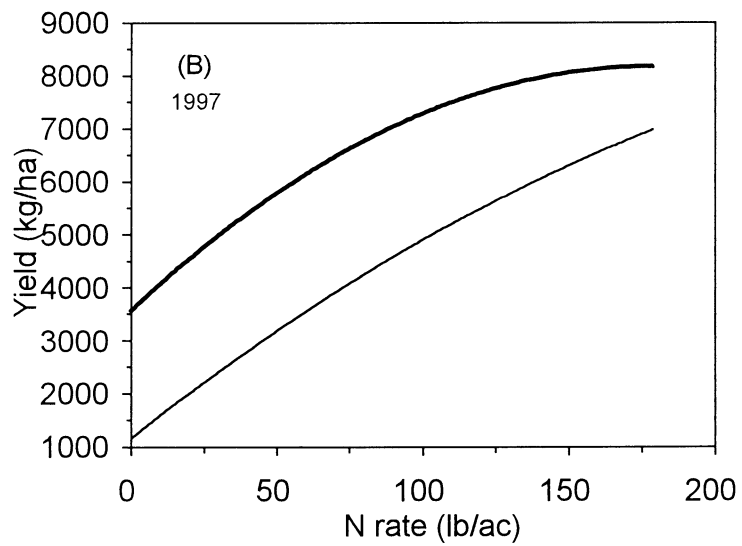
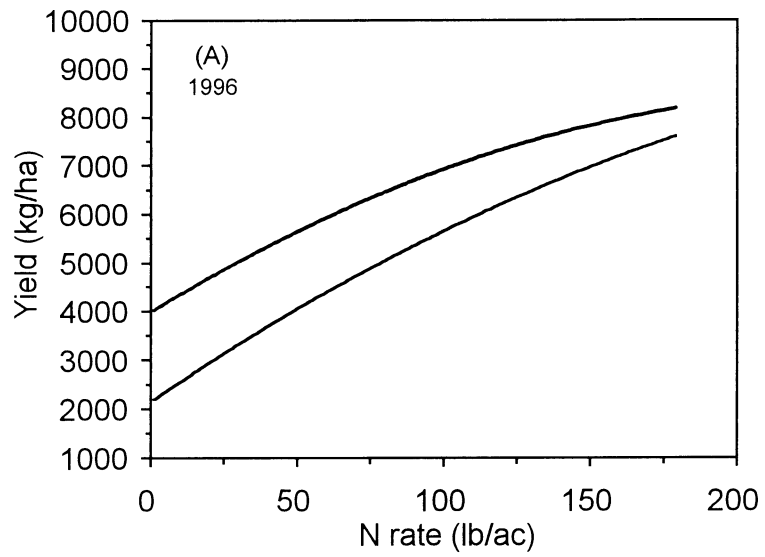


Fig. 2-1 Yield response of (a) Clover-wheat (b) Corn-wheat (c) Grass-wheat rotations to fertilizer N rates of on-farm trials for the 1994-96 growing season



— Oat-wheat — Clover-wheat

Fig. 2-2: Yield response of clover-wheat and oat-wheat rotations to fertilizer N rates (A) 1996 and (B) 1997 of small research plots trials.

throughout the study that wheat following grass had relatively higher soil N availability (Table 2-2) and higher N uptake (data not shown) as compare to wheat following clover and wheat following corn.

Determination of Nitrogen Rates for Optimum Grain Yield

Figures 2-1 show yield as a function of total fertilizer for wheat following clover, corn and grasses. The yield data fit a quadratic model using total applied N as an independent variable. Regression equations for yield response curves and their corresponding correlation coefficient (r^2) are given in Table 2-3.

The amount of N fertilizer required at Feekes 5 to produce optimum yield (NOPT) in each rotation and years was determined by using the N balance model. The NOPT rates predicted by this model were compared with actual N rates required to obtain maximum economic yields (NMAX). The amount of fertilizer N required for maximum economic yield were calculated from each response curve at each rotation site. The NMAX value for any given response curve is the fertilizer rate value that makes the first derivative of the response function equals to the price ratio of N fertilizer to wheat [3]. Two N fertilizer/wheat price ratios were used in this study to calculate NMAX. The difference between the NMAX values (N_1 and N_2) was not significant ($p > 0.8$), consequently N, is used in comparisons.

In 1994, the NMAX rates for wheat following clover and wheat following corn exceeded the largest N fertilizer rate used in study, therefore, highest N rate

of 168 N kg ha⁻¹ was considered as NMAX rate. The comparison of NOPT and NMAX values are given in Table 2-5.

At on-farm sites in 1994, model underestimated NMAX by 5 N kg ha⁻¹, 11 N kg ha⁻¹ and 18 N kg ha⁻¹ for wheat following clover, corn and grass, respectively. In 1995, the model overestimated N need in the clover rotation by 54 N kg ha⁻¹. This was the largest difference observed in this study. In 1995, corn and grass rotation NOPT and NMAX rates were very close. In 1996, good agreement was found between NOPT and NMAX values for all three rotations with the largest difference only ± 7 N kg ha⁻¹. Average NOPT and NMAX rates, 174 and 178 N kg ha⁻¹, respectively, were highest for wheat following corn. Due to high soil N, low average NOPT and NMAX rates (141 and 143 N kg ha⁻¹) were observed for wheat following grasses. A good correlation between NOPT and NMAX ($r=0.77$) was observed across rotations and years.

In small plot trials the predicted fertilizer N rates by the model were also fairly closed to the N rates required to obtain NMAX rates. In 1996, due to high response of grain yield to N fertilizer (Fig. 2-2), the NMAX rates for wheat following oat and wheat following clover exceeded the largest N fertilizer rate, therefore, high rate of 200 was considered as NMAX rates. In 1997, NOPT and NMAX rates were very similar. Wheat following oat had higher NOPT and NMAX NOPT rates- 35 kg N h⁻¹ more.

Table 2-5. Comparison of calculated and observed N rates

Rotation	Yield at recommended N rate	N [†] rate recommended by model	N ^{††} rate for Max. Econ. Yield	
			N1	N2
----- Kg ha ⁻¹ -----				
<u>On-farm Trials</u>				
1994				
Clover-wheat	7994	163	168	168
Corn-wheat	10216	157	168	168
Grass-wheat	9908	157	175	182
1995				
Clover-wheat	6258	166	112	121
Corn-wheat	8007	190	196	200
Grass-wheat	6287	145	147	152
1996				
Clover-wheat	8951	187	190	196
Corn-wheat	8290	177	170	175
Grass-wheat	5956	114	107	112
<u>Small Plot Trials</u>				
1996				
Oat-wheat	7953	200	200	193
Clover-wheat	9154	200	179	189
1997				
Oat-wheat	7915	200	200	217
Clover-wheat	8145	165	162	168

[†] Recommended N rate calculated by using equation [1].

^{††} N rate to obtain maximum economic yield. N1 and N2 are the rates where the price of wheat was set equal to \$3.5 and \$4 per bushel, respectively, and price of N fertilizer was \$0.25.

Model Validation

In 1996-97, N rate trials were conducted to further check the validity of the proposed model. Recommended N rates and subsequent yield and grain protein concentration are given in Table 2-5. The recommended fertilizer N rates were 112 N kg ha⁻¹ and 168 N kg ha⁻¹ for wheat following grass and corn, respectively. Cooperating growers selected other N treatments in these trials. Bracketing treatments were chosen at the grass site, lower rates at the corn site.

In both rotations, the mean yield for the recommended rate was significantly higher than the other two treatments used in the experiment (Table 2-4). In the grass rotation, mean yield dropped at the higher fertilizer N rate and there was no significant difference in yield between the high and low fertilizer N rate treatments. Soil analyses also revealed high residual N (NH₄-N and NO₃-N) at the end of the season (data not shown). The plant N uptake at the end of the season was also higher for wheat following grass compared to wheat following corn (data not shown). Similar results were observed for wheat following grass of on-farm trials in 1996 where mean yield dropped considerably at higher fertilizer N rates, while total biomass and grain protein content increased significantly as higher fertilizer N was added (Fig. 2-3). Costa and Kronstad (1994) reported that the redistribution of N from vegetative plant growth accounted for at least 50% of grain protein N. Higher levels of biomass observed in the study due to higher levels of N, could potentially increase the amount of N to be redistributed which contributes to a higher grain protein N concentration. In the wheat following corn

rotation each increment of N fertilizer significantly increased grain yield. These results are similar to observations for wheat following corn in 1994-96 in on-farm trials (Table 2-2).

Table 2-6: Main yield and protein content for model validation trials conducted during 1996-97 winter wheat growing season

N rate	Yield	Protein content
<u>Grass-wheat rotation</u>		
84	4651a	9.8a
112 †	5168b	9.7ab
140	4875ab	10.5c
PLSD	381	0.15
CV	2	1
P-value	.004	.000
<u>Corn-wheat rotation</u>		
84	6476a	8.0a
132	7237b	8.7b
168 †	7946c	9.5c
PLSD	577	0.56
CV (%)	3	3
P-value	.005	0.01

† Recommended N rate by using model [1]

CONCLUSIONS

Optimum N rates predicted by our proposed model were closely related to the N rates require to obtain maximum economic yield. In 1996-97, the model validation experiment also gave promising results. This study overall shows that

the model appears to accurately assess field-specific optimum fertilizer N status and that it can be used to make fertilizer N recommendations for the region.

The response of winter wheat to fertilizer N varied greatly among rotations and years in this study. Wheat following corn rotation was high responsive to added fertilizer N while wheat follow grass were less responsive. Wheat following grasses had high soil supplied N which depressed the yield even at moderately high fertilizer N rates. This finding contradicts conventional wisdom that suggests higher N rates are needed following grasses. This study documents a difference between perennial grasses and cereals grain crops in rotation. The average yield with no fertilizer for wheat following corn and wheat following legumes were about to same.

Further recommendations

Research efforts should be directed to further evaluate the validity of the model over range of soil and crops. On-farm research efforts are also needed to examine the high N source in wheat following grasses.

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