EFFECT OF RATE, TIMING AND PLACEMENT OF NITROGEN ON SPRING WHEAT IN FARMERS' FIELDS IN THE YAQUI VALLEY OF MEXICO

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Abstract

The objective was to validate, in farmers' fields in the Yaqui Valley, N-management practices that had resulted, under experimental conditions, in reduction of trace-gas emissions while maintaining grain yield and quality. Trials were variously established in five different farmers' fields. The local management practice was compared with a new alternative, under various rates of N. The farmers managed all aspects of the trials, except for fertilizer application. The new N-management practice resulted in higher yield, protein and fertilizer recovery. The SPAD chlorophyll meter was found to be a promising tool for predicting grain-protein concentration. The method of application, broadcast vs. banding, did not affect fertilizer-N recovery. We conclude that it is possible to improve N-uptake efficiency in wheat grown in the Valley by delaying most of the N application close to the time of the first auxiliary irrigation.

1. INTRODUCTION

High levels of inputs, including N fertilizer, are used on irrigated spring wheat in developing countries. The inefficient use of this fertilizer can affect farmer income and have environmental consequences, such as nitrate leaching and emission of trace gases.

In the Yaqui Valley of Sonora, Mexico, wheat is produced with high inputs of N fertilizer (250 kg N ha^{-1}). Therefore, losses to the environment are potentially significant. A multi-disciplinary group of scientists at CIMMYT and Stanford University has been investigating N-uptake efficiency in irrigated wheat systems in the Yaqui Valley, from agronomic, environmental and economic perspectives. Experiments established at a research station compared local farmers' rotations and management practices with alternatives that included reducing the amount of N applied and changing the timing of its application. Farmers apply 75% of 250 kg N ha^{-1} a month before planting, zero at planting, and the rest at six weeks after planting, designated 75–0–25.

The best alternative practice reduced the amount of N to 180 kg ha^{-1}, one-third applied at planting and two-thirds 6 weeks later, designated 0–33–66; emissions of nitrous and nitric oxide were cut by half, although yields and grain quality were maintained. There was a saving of US$55–76 ha^{-1}, equivalent to 12–17% in after-tax profits [1]. Since fertilization is the highest production cost in the Yaqui Valley, such an incentive may induce farmers to alter their N-management strategies.

The on-farm trials have been established over the last two years in a total of twenty eight locations. The results reported in this paper are from a subset of five of those experiments that were established the first year. The main objective of this paper is to show one possibility in the analysis of fertility trials over locations. The results and conclusions from this paper may not necessarily be the same as those of the final report that will include all the locations.

TABLE I. CROP ROTATION AND SOIL TEXTURE OF FIVE FARM LOCATIONS

Trial	Rotation	Soil Texture	Crop
K801	Maize-Wheat	Clay	Altar C84
K802	Cotton-Wheat	Sandy Clay Loam	Altar C84
K804	Cotton-Wheat	Clay	Altar C84
K805	Wheat - Wheat	Clay	Altar C84
K814	Cotton-Wheat	Sandy Clay Loam	Rayon F89

TABLE II. TREATMENTS USED IN THE EXPERIMENTS ESTABLISHED IN FARMERS' FIELDs

Treatment[1]	Proportion and Timing[2]	Method[3]
1. 0 Control	0-0-0	broadcast
2. 75	75-0-25	broadcast
3. 150	75-0-25	broadcast
4. 225	75-0-25	broadcast
5. 300	75-0-25	broadcast
6. 75	0-33-66	broadcast
7. 150	0-33-66	broadcast
8. 225	0-33-66	broadcast
9. 300	0-33-66	broadcast
10. 150	0-33-66	band
11. 225	0-33-66	band
12. 225	0-0-100	band
13. Farmers' sample[4]		

1 The total rate of N applied in kg/ha.

2 The three numbers represent the percentage of the total rate applied at three times; pre-plant, planting and 1[st] irrigation (about 45 to 55 days after planting).

3 There were two methods of application as a broadcast over the field or as a band in the furrows.

4 This sample was collected from the farmers field in plots adjacent to the experiment.

TABLE III. MEAN SQUARES FOR GRAIN YIELD (GY), YELLOW BERRY (YB), TOTAL NITROGEN IN THE ABOVEGROUND BIOMASS (NTOT), GRAIN PROTEIN (GP) AND CHLOROPHYLL READING IN FLAG LEAVES (CHL). ALL VARIABLES ANALYZED HAD MISSING VALUES

Sources of variation	**df[1]**	**GY**	**YB**	**df**	**NTOT**	**GP**	**df**	**CHL**
Loc	4	7564086**	5443**	4	12634**	30.312**	4	260.43**
Rep (Loc)	10	200428	486**	10	447	1.115**	10	3.75
NTrt	12	12077843**	4350**	12	16605**	16.441**	12	149.78**
Farmer Lin.	1	64040139**	21764**	1	75082**	71.002**	1	700.30**
Farmer Quad.	1	4944054**	361	1	602	0.007	1	9.220
New Lin.	1	71958485**	28807**	1	112376**	111.413**	1	970.742**
New Quad.	1	20741398**	2044**	1	8820**	4.448**	1	157.671**
Farmer vs New	1	8407080**	2560**	1	15660**	14.405**	1	136**
Loc x NTrt	48	328603	414**	48	423	0.6630**	48	7.596
Error	112			111			102	

*,** Significance at the 0.05 and 0.01 probability levels, respectively.

[1] df = degrees of freedom

Therefore, this information should be taken as an example of data analysis and not of the final conclusions of the study. This study, on farmers' fields, was undertaken with the following objectives:

- To compare the alternative 0–33–66 N-management practice with the farmers' 75–0–25,
- To estimate the N contribution from the soil,
- To test the SPAD chlorophyll meter as a diagnostic tool for predicting grain protein at maturity.

2. MATERIALS AND METHODS

Five N-management trials were variously established in farmers' fields in the Yaqui Valley of Mexico, near Cd. Obregon, Sonora, during the 1996–97 cropping cycle (Table I). Each trial was composed of thirteen treatments (Table II) with various rates, times and methods of N application, arranged as a randomized complete block design with three replications. A combined analysis of variance across locations was used to analyze the five experiments. The analysis of the N treatments was divided into several single-degree-of-freedom comparisons (SDFCs) (Table III). Four of the SDFCs were used to test the linear and quadratic effects of the farmers' method and the new practice. The other SDFC examined the average effect across rates of the two approaches.

The fields on which the experiments were established were identified before the farmer applied fertilizer. The total experimental areas were then marked and soil samples collected at 0 to 15, 15 to 30 and 30 to 60 cm depths. The farmers were asked not to apply fertilizer in the marked area for the rest of the crop cycle. Each experimental unit was 8 m long and six beds wide; the width of each bed was 80 cm. The harvest area was comprised of the center two beds and center 3 m, an area of 4.8 m^2. The only nutrient other than N that limits wheat yields in the Yaqui Valley is P, therefore, all experiments were fertilized with 20 kg P ha^{-1} as triple superphosphate (0–46–0). Except for the fertilizer application in the experimental area, the farmer was responsible for all other management decisions and operations.

All the experiments were planted within the optimum planting dates for the area (15/11 to 15/12). Four of the experiments were planted with the semi-dwarf durum wheat 'Altar C 84' and one was planted with the semi-dwarf bread genotype 'Rayon F 89.'

In general, the experiments were well managed. In a few instances, weeds were observed in some plots, but were removed manually before becoming a significant problem. At heading, twenty flag leaves were collected from each experimental unit, and three readings with a Minolta SPAD chlorophyll meter were taken along each. The flag-leaf samples were oven-dried (75°C, 48 h) and analyzed for total N. At physiological maturity, the harvest area was cut at ground level and bundled. A sub-sample of 100 spikes was collected at random from the harvest area and oven-dried as above. This sub-sample was used to determine yield components and moisture content of the bundle. The bundles were sun-dried and passed through a stationary thresher. Grain yields were weighed, and 40- to 60-g sub-samples collected and oven-dried at 105°C for 24 h to adjust total yield to zero moisture. A sub-sample of 100 stems was threshed separately and the straw and the grain saved and analyzed colorimetrically for %N (Technicon Auto Analyzer II, Tarrytown, NY, Industrial Method no. 154-71 W, February 1973). The dry weights of grain and non-grain biomass (total biomass – grain) were multiplied by their respective N concentrations to calculate above-ground total N. A sub-sample of 400 grains was taken from the grain-yield sample to determine the fraction of kernels with yellow berry.

3. RESULTS AND DISCUSSION

The combined analyses of variance for grain yield showed highly significant effects due to location and N treatment (Table III). On the other hand, the interaction between location and N

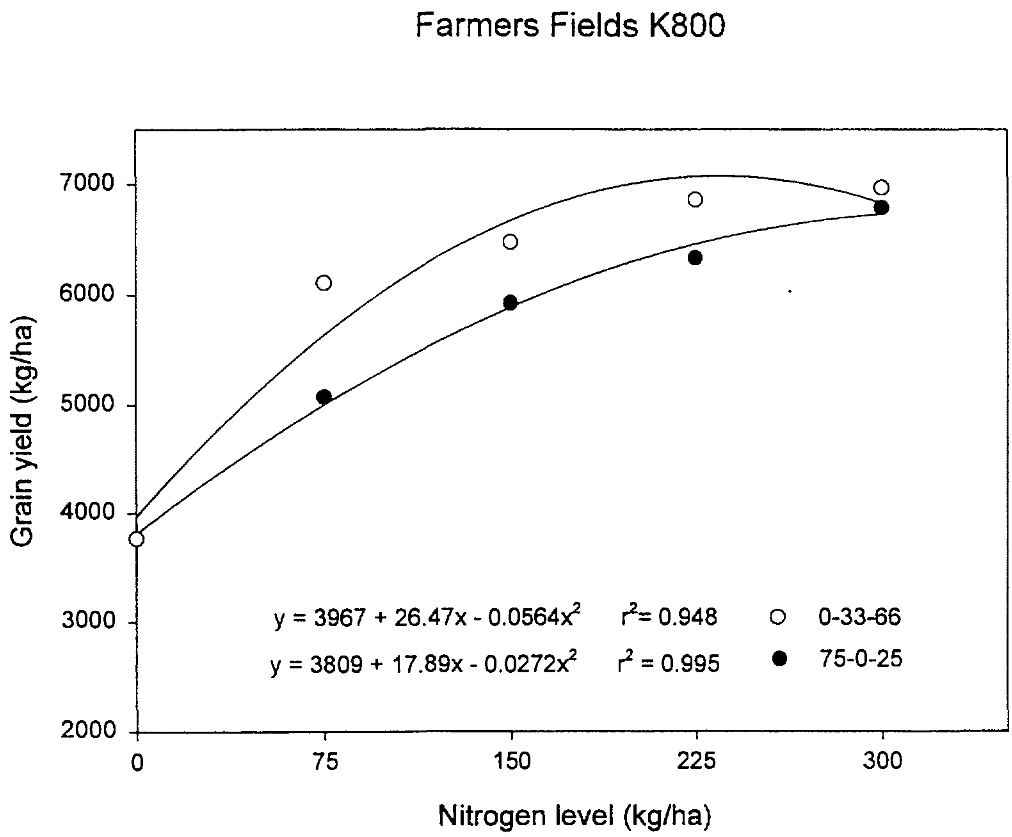

FIG. 1. Effect of five rates and two timings of N application on grain yield.

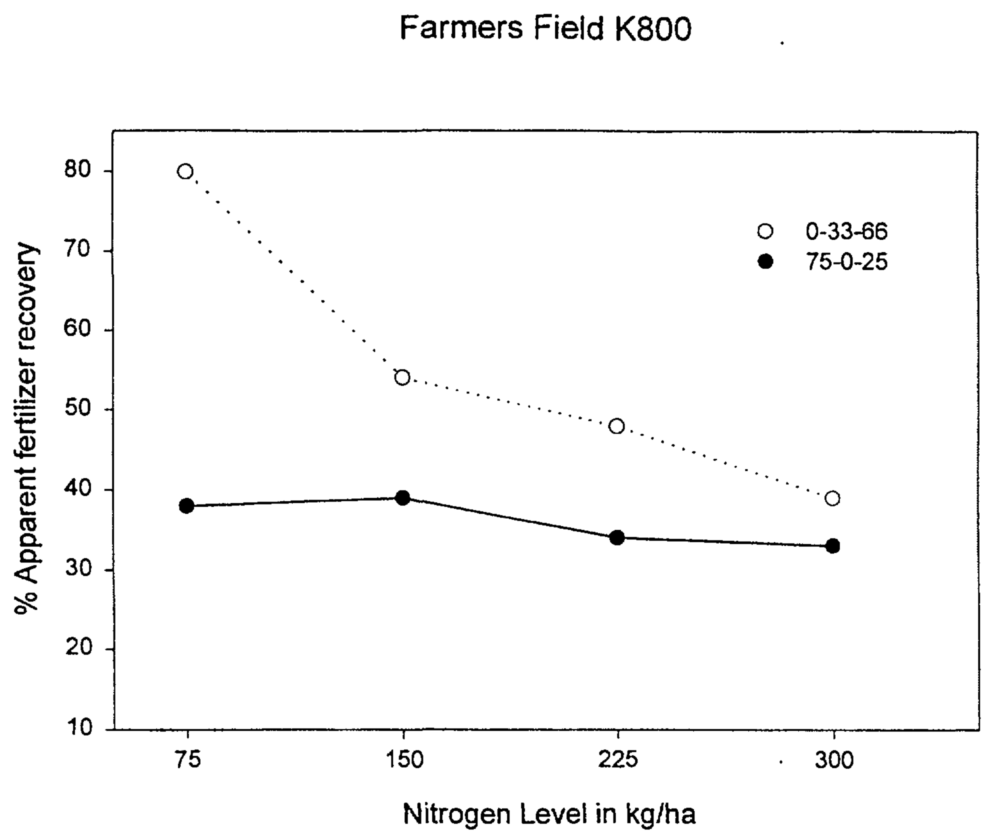

FIG. 2. Effect of five rates and two timings of N application on percent grain protein.

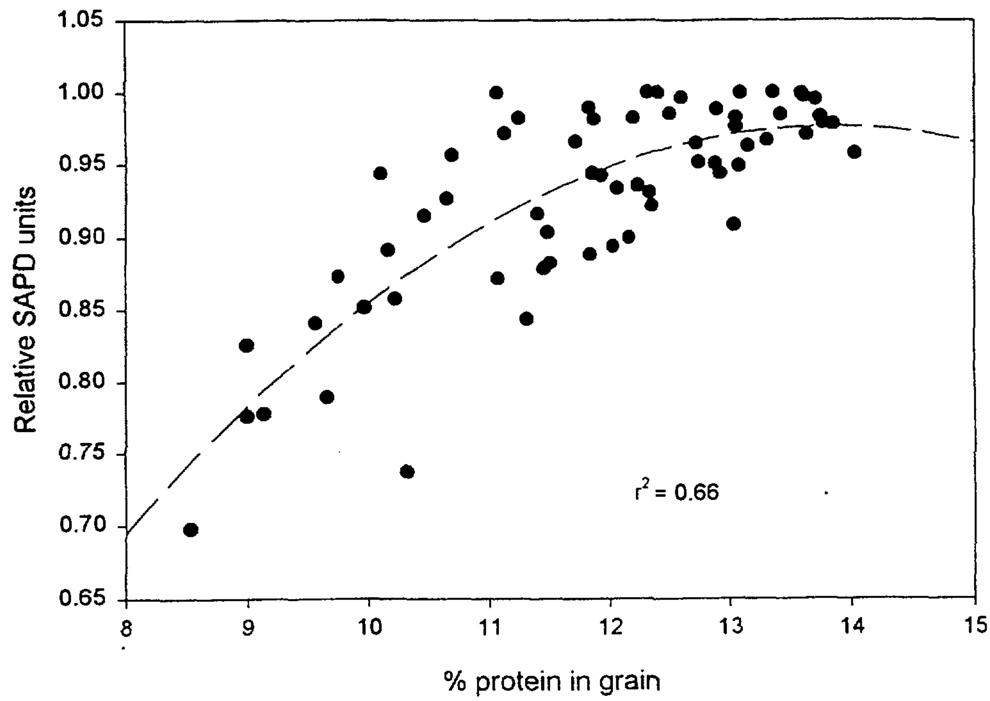

FIG. 3. Effect of five rates and two timings of N application on the percent apparent fertilizer recovery.

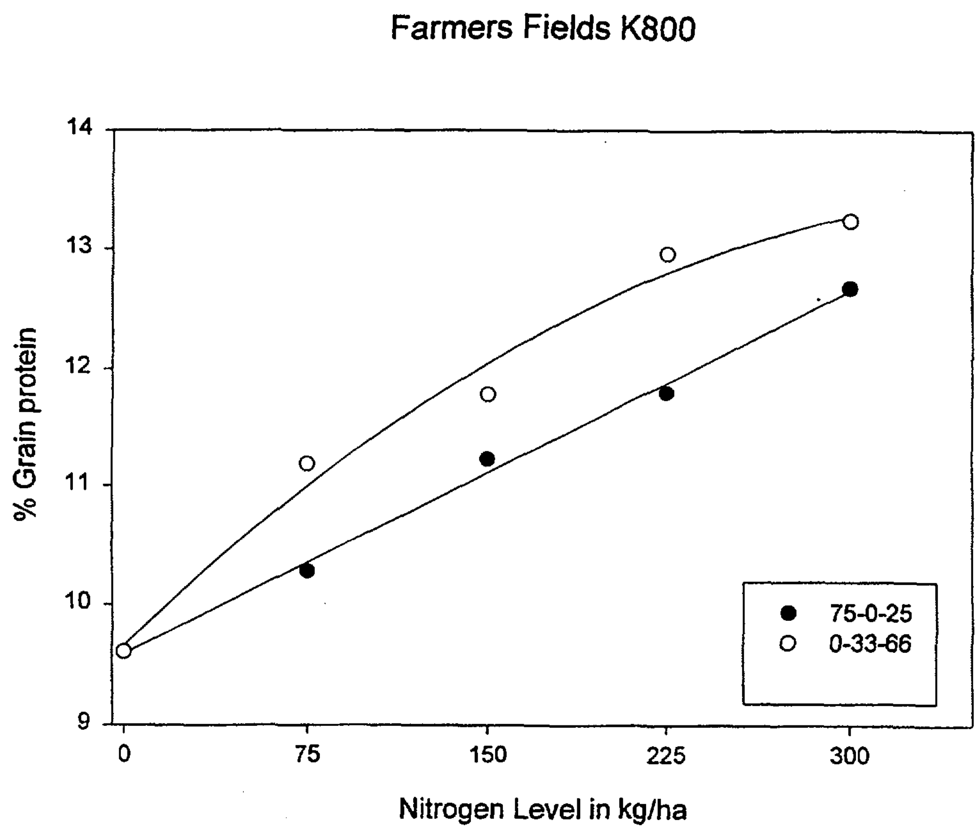

FIG. 4. Relationship between total aboveground nitrogen in the plant in plots without N fertilizer application and grain yield.

TABLE IV. TREATMENTS USED IN THE EXPERIMENTS ESTABLISHED IN FARMERS' FIELDS

Treatment[1]	Proportion & Timing[2]	Method[3]	Grain Yield	S. Dev.
1. 0 Control	0-0-0	broadcast	3765	920
2. 75	75-0-25	broadcast	5072	969
3. 150	75-0-25	broadcast	5918	707
4. 225	75-0-25	broadcast	6329	680
5. 300	75-0-25	broadcast	6782	757
6. 75	0-33-66	broadcast	6104	783
7. 150	0-33-66	broadcast	6471	474
8. 225	0-33-66	broadcast	6858	558
9. 300	0-33-66	broadcast	6963	654
10. 150	0-33-66	band	6591	766
11. 225	0-33-66	band	6967	594
12. 225	0-0-100	band	6648	643
13. Farmers'[4]			6720	674
Mean				6230
C.V.				9.66

1 The total rate of N applied in kg/ha.

2 The three figures represent the percentage of the total rate applied at three times; pre-plant, planting and 1st irrigation.

3 There were two methods of application as a broadcast over the field or as a band in the furrows.

4 This sample was collected from the farmers field in plots adjacent to the experiment.

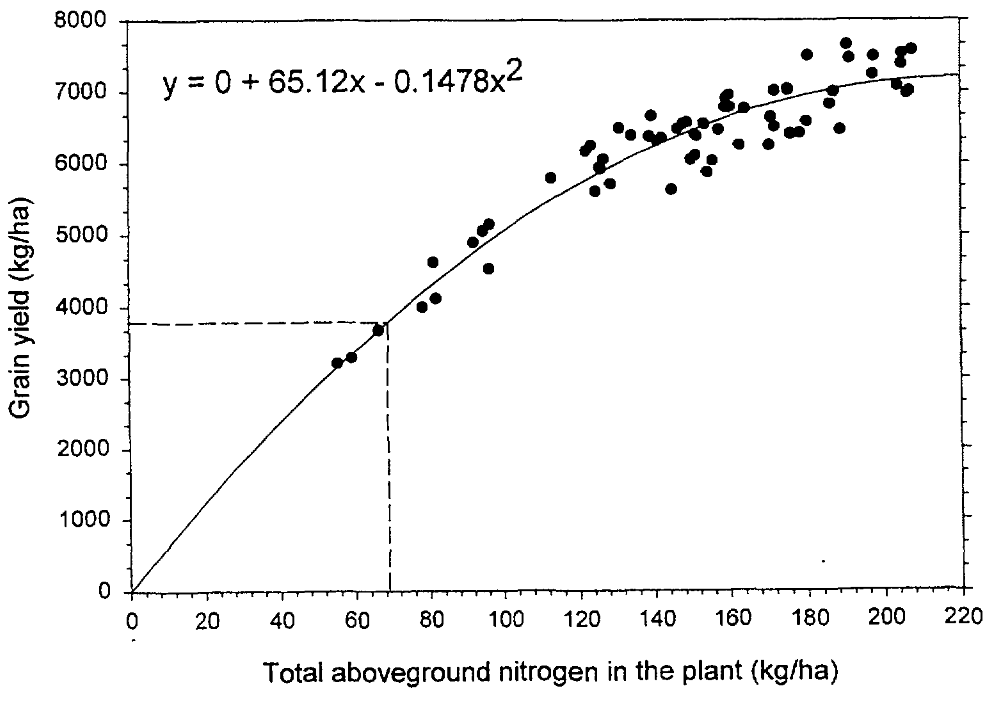

FIG. 5. Relationship between total aboveground nitrogen in the plant in plots without N fertilizer application and grain yield.

treatment was not significant. Therefore, discussion of the results focuses on the average of the N treatments across all five locations. In the farmers' practice, as well as in the new, the linear and the quadratic effects were highly significant, indicating the N responses with both approaches had linear and quadratic components (Fig. 1). The average effect across N rates was significantly higher with the new practice than with the farmers' (Table III).

Apparent fertilizer-N-uptake values were calculated for all fertilizer treatments. The new method showed higher recoveries than did the farmers' practice, particularly with the lower rate of N, which partially explains the higher yield obtained with 0–33–66 than with 75–0–25. The apparent recovery of N from 75 kg ha^{-1} in the 0–33–66 treatment was high at 79% [2]; the recovery values across N rates for the 75–0–25 treatment were lower and remarkably constant (Fig. 2), suggesting that large quantities of N were lost or made unavailable to the crop when the fertilizer was applied 3 weeks before planting. Normally, fractional N recovery decreases as N rate increases[2], as was observed in the 0–33–66 practice, whereas the low recoveries with 75–0–25 were not affected by the rate of N application. We found that losses of N as nitrous oxide and nitric oxide were cut by half with the 180 kg N ha^{-1}/0–33–66 practice compared to the farmers' 250 kg N ha^{-1}/75–0–25 [1]. However, this was not enough to account for the very large difference in recovery. We speculate that ammonia fixation may occur in these soils, immobilizing significant levels of N when it is applied well in advance; alternatively ammonia volatilization may explain some of these differences. This aspect requires more research.

The agronomic and economic optima were calculated for each of the response curves: the 0–33–66 practice resulted in savings of N fertilizer compared to 75–0–25. The agronomic optima were 329 and 234 kg N ha^{-1} for the 75–0–25 and the 0–33–66 practices, respectively. Economic optimum was calculated using a fertilizer:grain-price ratio of 3804/1350, i.e. 2.8 (10 pesos = US$1). The price of urea at the beginning of the crop cycle was 1,750 pesos t^{-1}, which was then divided by 0.46 to transform it to a unit-of-N bases. Some examples of the fertilizer:grain-price ratio of other countries are: India (2.1), Nepal (2.1), Egypt (2.1), Pakistan (2.5), USA (3.5), Turkey (3.6), Hungary (4.4), Brazil (4.6), Australia (5.5), Argentina (5.8) and Chile (8.8) [3], therefore, the ratio in the Yaqui Valley is relatively low. The optimum economic rate for the 0–33–66 practice was 210 kg N ha^{-1}, about 25% or 68 kg N less than with the 75–0–25 practice. This saving in fertilizer is similar to what we found previously [1].

Grain-protein concentration is a measure of quality for bread and durum wheat. The issue of wheat quality has become important in the Yaqui Valley, largely because most production is of durum for export. Therefore, a reliable diagnostic test is needed to give the farmer an indication of the final protein concentration at a time when it can still be modified. Foliar or soil application of N around the time of heading can have significant impact in grain protein [4–6]. It has been reported also that total N in the flag leaf at heading may be used to predict final protein concentration in the grain of wheat [7]. There was a significant correlation between chlorophyll reading and total N in the flag leaf at heading ($r = 0.74^{**}$, $n = 63$), suggesting that the SPAD meter is a useful estimator of total N. The correlation between percent protein in the grain and chlorophyll reading was high when calculated within each field, however, when run across all five locations, a quadratic model fit the data better, but with a low $r^2 = 0.32$. A relative chlorophyll value was calculated, based on the maximum reading from each location, to standardize the data. This adjustment improved the relationship between SPAD readings and percent grain protein to an $r^2 = 0.66$ (Fig. 3). We need to do additional calculations to determine the critical value.

It is often stated that there is a negative correlation between grain yield and grain-protein concentration. However, when the range in grain yields was associated with different rates of N, we observed a positive correlation, $r = 0.75^{**}$, $n = 65$. For grain protein concentration, the responses of the two management practices under the different N rates were somewhat different. The response of the 75–0–25 practice was linear, whereas that with 0–33–66 was slightly curvilinear, but significant (Table III, Fig. 4). The average protein concentration across rates was higher for the 0–33–66 practice. Yellow berry, also an important measure of quality, had a highly significant negative correlation with grain-protein concentration ($r = -0.88^{**}$). Therefore, 0–33–66 had a lower incidence of yellow berry than did 75–0–25.

Comparisons of treatments, 7 vs. 10 and 8 vs. 11, evaluated broadcast vs. band applications; there were no significant differences (Table IV), i.e. no effect due to placement of N under the conditions tested.

When we plotted grain yield vs. total above-ground N in the plant, a quadratic response was obtained that starts at the origin (Fig. 5). The average yield of the control plots from all locations was 3,765 kg ha^{-1}. Extrapolating this to the X-axis gives about 68 kg N ha^{-1}, the average amount of N supplied by the soil to the crop. Doing the same at the 1,000 kg ha^{-1} grain yield, the equivalent value on the X-axis is about 16 kg N ha^{-1}, i.e. the amount of N needed to produce 1 t of grain yield. However, due to the curvilinear nature of the response, the amount of N needed to produce 1 t of grain increases as the yield increases. For the highest average yield for the Valley, 6,000 kg ha^{-1}, the amount of N needed to produce it was 130 kg N ha^{-1}. By dividing that value by six to get the amount of N needed per ton of yield, the value is 22 kg N ha^{-1}, which is 37.5% more than at the 1-t yield level. It is possible that some fields and treatments had significant amounts of N available post-anthesis. Such N seldom has an effect on grain yield, however, if available, the plant absorbs and stores it in the grain and straw. In our conditions, it is common to find higher concentrations of N in the grain and straw at the higher levels of yield.

4. CONCLUSIONS

(1) Grain yield showed a curvilinear response to N rate under both the 75–0–25 and the 0–33–66 strategies.

(2) The new practice, 0–33–66, which supplies N in closer synchrony with the plant's needs, was more efficient than the farmers' 75–0–25 method, in the following respects:
- Grain yield response per unit of fertilizer applied,
- Percent apparent fertilizer recovery,
- Protein concentration in the grain and incidence of yellow berry.

(3) There were no differences in grain yield between the broadcast and the band methods of N application.

(4) Although the number of locations was relatively small, it gives a first indication about the amount of residual soil N in farmers' fields, i.e. 68 kg N ha^{-1}.

(5) The SPAD meter used at heading showed potential as a diagnostic tool to predict protein concentration in the grain at maturity.

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