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PAPER PRESENTED AT INTERNATIONAL WORKSHOP ON INCREASING WHEAT YIELD POTENTIAL, CIMMYT, OBREGON, MEXICO, 20–24 MARCH 2006

Reduced nitrogen and improved farm income for irrigated spring wheat in the Yaqui Valley, Mexico, using sensor based nitrogen management

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SUMMARY

Wheat nitrogen-use efficiency in the Yaqui Valley has been estimated at about 0·31. The nitrogen that is not recovered by the crop has important environmental costs that have regional and global consequences. In addition, these nitrogen losses represent an important reduction in farm income. The objective of the present work was to validate a technology that includes the use of N-rich strips together with the GreenSeeker™ sensor and a crop algorithm in farmers' fields with the ultimate goal of improving nitrogen-use efficiency through site-specific nitrogen management in irrigated spring wheat. During the wheat crop cycle 2002/03 and 2003/04, 13 validation experiments of *c.* 1 ha each were established in farmers' fields in the Yaqui Valley. After the validation phase, during the wheat crop cycle 2005/06, eight technology transfer trials were established in farmers' fields; these had on an average an area of 10 ha each. Both the validation and technology transfer trials compared the farmers' conventional nitrogen management use *v.* the use of the N-rich strip together with the Green Seeker™ sensor and a crop algorithm to derive N recommendations for each individual field. The results of the validation trials showed that on an average over all locations, farmers were able to save 69 kg N/ha, without any yield reduction. At the price of US$0.9 per unit of N in the valley when these experiments were established, this represented savings to the farmers of US$62/ha. The technology transfer trials demonstrated that, in large commercial areas with an average size of 10 ha, farmers could improve their farm income by US$50/ha, when using sensor based N management. The combination of the N-rich strip, together with the use of the sensor and a crop algorithm to interpret the results from the sensor, allowed farmers to obtain significant savings in N use and thus in farm profits. Farm income was increased by US$56/ha, when averaged over all trials in all years.

INTRODUCTION

Nitrogen-use efficiency in wheat in the Yaqui Valley has been estimated at about 0·31, similar to other reports for cereals around the world (Raun & Johnson 1999). The nitrogen that is not recovered by the wheat crop in the valley represents a reduction in farm income and results in losses to the atmosphere as nitrous oxide and nitric oxide (Matson *et al.* 1998), leaching below the root zone (Riley *et al.* 2001) and runoff to the surface waters of the Sea of Cortes, resulting in algae blooms (Beman *et al.* 2005). Two factors have shown great potential at increasing nitrogen-use efficiency in the valley: the timing and the rate of N applications (Ortiz-Monasterio 2002). In terms of timing, farmers currently apply three quarters of the total N rate (263 kg N/ha) *c.* 20 days before planting. Timing could be improved significantly by better matching of the N application with

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the time of highest demand by the crop, which is around the beginning of stem elongation, also known as Zadoks growth stage Z31 (Zadoks *et al.* 1974). Applying the correct rate could also result in substantial fertilizer savings. Research in the Yaqui Valley has shown that good diagnostics of residual soil N and climate forecasts can lead to a reduction of excess N fertilizer applications in the Yaqui Valley (Lobell *et al.* 2004), with subsequent benefits to farmer income and environmental quality (Matson *et al.* 1998; Riley *et al.* 2001; Lobell *et al.* 2004; Christensen *et al.* 2006). During the crop cycle 2005/06, the average cost of production for 1 ha of wheat in the Yaqui Valley was approximately US$900. Fertilizer represented 0·23 of those total costs.

There is a new technology based on the combined use of N-rich strips, sensors and crop algorithms that can help identify the optimum N rates for each individual field (Raun *et al.* 2005). This technology works by establishing an N-rich strip (an area of the field that receives a high enough N rate to guarantee that there will be no N deficiency in that area) in the farmer's field. The N in this strip has to be applied, at the latest, by the time of planting. The next step involves using a sensor, which sends a beam of light in the red and infrared bands in the electro-magnetic spectrum into the wheat canopy and collects reflectance data from the leaves in these two wavelengths in the N-rich area as well as in the farmer's field. These data are used to calculate the normalized difference vegetation index (NDVI), which is measured towards the end of tillering and the beginning of stem elongation in wheat (Z31). Lastly, through the use of a crop algorithm, this index predicts yield and calculates the need for any additional N (Raun *et al.* 2005).

The N-rich strip also allows a visual comparison with the farmer's N management. A farmer who is experienced in growing wheat can establish if there are differences between his field and the N-rich strip. If, by Z31, there are no noticeable differences for the trained eye between these two areas, this indicates that there is no need to apply additional N. This means that, for an experienced wheat farmer, the sensor is not really necessary when there is no difference between the N-rich strip and the rest of his field. However, the sensor becomes very useful when the area under the farmer's management shows a deficiency, as the sensor together with the crop algorithm will help identify the optimum N rate.

Farmers in the Yaqui Valley usually apply *c.* 180–200 kg N/ha pre-planting, irrigate, then plant wheat *c.* 20 days later. They make an additional application of *c.* 50–60 kg N/ha immediately before the first post-planting irrigation, which takes place 44–55 days after planting at Z31.

Most farmers in the Yaqui Valley belong to a farmers' union. These unions provide credit, farm inputs at lower than commercial rates, technical agronomic advice and help in marketing their farm products. The cost of these sensors is approximately US$3800, which could be considered expensive for individual farmers in developing countries. However, when the technical departments of these farmers' unions purchase the sensor and provide the service of N diagnostics to the farmers, this technology becomes affordable to farmers in the developing world.

The current blanket nitrogen recommendations fail to address the spatial and temporal variations in N supply and demand. This in turn results in over-fertilization in most farmers' fields. In the present study, the application of a new sensor-based technology that takes into account spatial variations in N supply and allows a site-specific management of nitrogen inputs is evaluated.

MATERIALS AND METHODS

The Yaqui Valley is located in northwestern Mexico, where the agroclimatic conditions are representative of areas in the developing world where 0·40 of the world's wheat is produced (Pingali & Rajaram 1999). Fields in the area average roughly 20 ha in size, with approximately 0·85 of the area planted to spring wheat during the winter (November–April). Temperatures during the wheat growing season average 9·8 and 27·1 °C for night- and daytime respectively. Soils in the valley are predominantly vertisols, with elevation varying from 0 in the western part next to the coast to 60 m asl on the eastern part of the valley. Almost all of the farmers plant wheat on ridges or beds using furrow irrigation. Since 1998, there has not been enough water in the reservoirs to allow the planting of a summer crop (except for the few farmers who have wells). Therefore, the main rotation since then has been wheat–wheat. Other crops that are grown in the area are: maize, safflower, chickpeas, vegetable crops, cotton and other minor crops.

Two types of trials were established in farmers' fields: (1) validation trials to test the robustness of the GreenSeeker™ (NTech Industries, Inc., Ukiah, CA) sensor based technology in areas of *c.* 1 ha under farmers' semi-commercial management, and (2) technology transfer trials in areas averaging 10 ha.

Validation trials

During the wheat crop cycles 2002/03 and 2003/04, 13 validation trials were established in farmers' fields in the Yaqui Valley. These experiments were composed of an N-rich strip 5–10 m wide and 150–300 m long, where all N was applied by planting (represented by the grey area in Fig. 1). In addition to the N-rich strip there was an adjacent area of *c.* 1 ha that received the basal (pre-planting and planting) N rate used by the

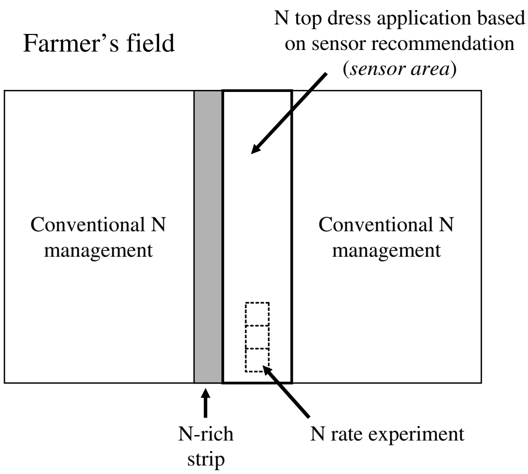

Fig 1. Field map of a typical validation trial showing the distribution of the N-rich strip, the conventional N management areas and the sensor area as well as the location of the N rate experiment within the sensor area.

farmer. In this area, the N application required at the beginning of stem elongation, Z31, was determined by the GreenSeeker™ sensor. Herein, this area is referred to as the *sensor area*. The rest of the area had conventional N management (Fig. 1). Within the sensor area, an N response experiment was established with six rates (0, 50, 100, 150, 200 and 250 kg N/ha) in 2002/2003 and five rates (0, 75, 150, 225 and 300 kg N/ha) in 2003/2004. In both cycles the experiments had three replications and were arranged as a randomized complete block design. The sensor area received the basal nitrogen rate used by the farmer (Table 1). All the nitrogen in the N rate experiment was applied just before planting time as urea, and incorporated with the planting operation. The plots were 5 m long and four beds wide. All farmers planted on beds 0·75–0·90 m wide, and only the central 3 m and the central two beds were harvested for yield evaluation. The experiment was established with two objectives: to verify if the N recommendation derived from the sensor was correct and to determine if more N was needed in addition to the basal rate applied at planting time. The N diagnostics in the sensor area were achieved by taking measurements along the centre of the beds. The NDVI was measured on 100 m, 50 m into the field and 50 m back, selecting a AQ1 different bed in each direction. The NDVI values generated by the sensor were entered in an optical sensor based algorithm for crop nitrogen fertilization (Raun *et al.* 2005) modified for spring wheat and using data for the Yaqui Valley to obtain the nitrogen recommendation (J. I. Ortiz-Monasterio, personal communication). In the algorithm, the maximum potential yield for wheat was set at 8000 kg/ha and the nitrogen-use efficiency at 0·35.

Technology transfer trials

The second set of trials, which are considered technology transfer trials, were established during the wheat crop cycle 2005/06. There were eight trials which were composed of (1) an N-rich strip, (2) an area managed by the sensor (*sensor area*) and (3) an area under conventional N management. The N-rich strip area was 8–16 beds wide (average bed size 0·75–0·90 m) and the full length of the field, which ranged from 200 to 400 m. The N rate applied in the N-rich strips ranged from 150 to 276 kg N/ha (Table 2). The average sensor area across all eight locations was 9 ha and the range of N rates applied in the sensor area varied from 75 to 180 kg N/ha (Table 2).

Yield was measured in the sensor area as well as in the conventional N management area, either by harvesting each of these areas with a commercial combine and sending wagons with all the grain to get weighed at the grain elevator or by taking cuts with a commercial combine and measuring yield in the field with a weighing wagon. Since these large technology transfer trials were not replicated within a farmer's field, the N-rich strip was also harvested to have an approximate measure of field variation, by comparing the area under farmer management and the N-rich strip. An economic analysis was performed on these plots; yield differences were assumed to be significant during the economic analysis. During the 2005/06 crop cycle in the valley, the wheat price that farmers received was US$0.191/kg, while the price of urea was US$0.82 kg/N and anhydrous ammonia was US$0.78 kg/N. The exchange rate used was that of May 2006 (11.0 Mexican pesos per US$1).

RESULTS

Validation trials

The results showed that the average N rate used by farmers following their conventional N management was 226 kg/N ha. In contrast, the average N rate used in the sensor area following the GreenSeeker™ recommendation was only 157 kg N/ha (Table 1). Yield was measured only in the area where N was managed conventionally using a combine and a weighing wagon. However, it was possible to establish whether N was limiting in the sensor area with the results of the N rate experiments that were established within this area. The results of the N experiments confirmed that although the sensor area received less nitrogen these lower rates were not limiting yield, since there was no response to N application, except in Pablos during 2002/2003 (Tables 3 and 4). In Pablos, the basal N rate used by the farmer was zero. The N rate experiment showed a strong response to N fertilizer application with an optimum agronomic rate of 242 kg N/ha and an optimum economic rate of

Table 1. *Thirteen on-farm validation trials showing the basal N rate utilized by farmers, the total amount of N applied in the N-Rich strip, the total N rate used in the area managed by the sensor, the total N rate used in the area where N was conventionally managed*

	Location	Basal N rate under conventional N management (kg N/ha)	N-rich strip (kg N/ha)	Total N rate sensor area (kg N/ha)	Total N rate conventional N management (kg N/ha)
1	Valenzuela	134	206	134	160
2	Amaya	92	276	92	230
3	Dabdoub	175	220	175	220
4	Castro	92	184	92	184
5	Pablos	0	207	198	207
6	Lopez de Lara	123	273	123	246
7	Felix	180	230	180	220
8	Arvizu	204	366	204	245
9	Dabdoub	189	275	219	275
10	Gallegos	160	344	160	252
11	Miranda	138	276	138	198
12	Perez	149	298	174	247
13	Nery	147	440	147	253
	Mean	137	277	157	226

Table 2. *Eight technology transfer trials showing the N rate used in the sensor areas, the area under farmer's management and the N-rich strip, the area planted of each of these plots*

	Block no.	Fertilizer rate (kg N/ha) Sensor	Fertilizer rate (kg N/ha) Farmer	Fertilizer rate (kg N/ha) N-rich strip	Planting area (ha) Sensor	Planting area (ha) Farmer	Planting area (ha) N-rich strip
1	B. 1003	138	220	230	12	12	1
2	B. 2128*	75	150	150	0·3	25	–
3	B. 1110	138	198	276	9·5	9·5	1
4	B. 909	115	197	230	5	5	1
5	B. 516	150	250	243	3	5	2
6	UCAH	92	184	276	0·9	?	1·8
7	B. 1924	160	197	217	15·5	4	0·5
8	B. 1107	148	230	241	12	12	1
	Mean	127	203	245	7·2	9	1·2

* In this field, the farmer management area was used as N-rich strip.

206 kg N/ha, using the price of urea in the valley (US$0.90/kg) and the price of wheat that farmers received in the valley (US$0.18/kg). The sensor recommended 198 kg N/ha, which is close to the optimum economic rate recommended by the N rate experiment. The results showed that on an average across trials, farmers were able to save 69 kg N/ha, without any yield reduction (Table 5). This was calculated comparing the difference between the total N rate applied in the sensor area with the total N rate under conventional N management. At the price of N at the time of the experiments (US$0.90/kg) in the valley, this represented US$62/ha of savings to the farmers.

Technology transfer trials

The results showed that the average N rate used by farmers under their conventional N management was 203 kg N/ha. In contrast, in the area managed by the sensor no additional top-dress N was recommend at Z31, which resulted in an average N rate of only 127 kg N/ha (Table 6). This represented 76 kg N/ha less applied in the sensor area. The yield differences between the farmer area and the sensor area were considered significant for the economic analysis. Often the sensor area yielded slightly less than the farmer area; however, after the economic analysis the sensor area was always more profitable because of

Table 3. *Mean yield (kg/ha) and ANOVA for the nitrogen rate experiments during crop cycle 2002/03*

N rate	D.F.	Valenzuela	Amaya	Dabdoub	Nery	Pablos	Lopez de Lara	Castro	Felix
0		5598	8465	4130	6817	3119	6946	7494	4834
50		5692	8438	4301	6554	4323	7034	7562	5463
100		5264	8647	4220	6711	5540	6942	7197	5262
150		5164	8218	3494	6651	6164	6982	7911	5239
200		5373	7897	4157	6752	6844	6879	7663	4980
250		5512	8965	4324	6779	6860	6963	7788	4756
Rep.	2	NS*	NS	NS	$P<0.05$	NS	NS	NS	NS
N rate	5	NS	NS	NS	NS	$P<0.01$	NS	NS	NS
Linear	1	NS	NS	NS	NS	$P<0.01$	NS	NS	NS
Quad	1	NS	NS	NS	NS	$P<0.05$	NS	NS	NS
Mean		5434	8438	4104	6711	5475	6958	7603	5134
S.E.D.	10	322	602	400	271	429	400	444	395
C.V.		7·25	8·76	11·93	4·94	9·58	7·03	7·14	9·42

* NS = non significant.

Table 4. *Mean yield (kg/ha) and ANOVA for the nitrogen rate experiments during crop cycle 2003/04*

N rate	D.F.	Dabdoub	Perez	Miranda	Nery	Gallegos	Arvizu
0		5287	5483	6378	4611	7244	5840
75		5625	5617	6613	4587	7320	6101
150		5576	5633	6614	4315	7316	5924
225		5790	5910	5813	4533	7168	5925
300		5578	6014	6128	4099	7210	6287
Rep.	2	NS*	NS	NS	NS	NS	NS
N rate	4	NS	NS	NS	NS	NS	NS
Linear	1	NS	NS	NS	NS	NS	NS
Quad	1	NS	NS	NS	NS	NS	NS
Mean		5571	5732	6310	4429	7252	6016
S.E.D.	8	208	389	803	228	188	264
C.V.		4·57	8·3	15·58	6·31	3·16	5·37

* NS = non significant.

the savings obtained by not applying the N top-dressing. The improvement in farm income by using the sensor when averaged over the eight locations was US$53/ha.

DISCUSSION

Validation trials

The results showed that the average N rate used by farmers following their conventional N management was 226 kg/N ha, which was somewhat lower than that reported in previous surveys (around 244–251 kg N/ha, Naylor *et al.* 2001). The sensor proved to be very reliable as a N diagnostic tool when there was no need to apply additional nitrogen. Unfortunately, there was only one field where there was a response to N above the basal N application; therefore, the performance of the sensor as a diagnostic tool to recommend additional N applications could only be tested in one location and under severe N deficiency. The results in that one location were very encouraging, since the N recommendation by the sensor was close to that observed in the N rate experiment. However, additional sites will be needed to verify the performance of the algorithm when additional N is required by the crop, particularly when the N deficiency is mild to intermediate. This is something that could not be assessed with this group of farmers.

Technology transfer trials

The average N rate used by farmers following their conventional management was 203 kg N/ha, significantly lower than the rate used in the validation trials

Table 5. *Thirteen on-farm validation trials showing grain yield of the area where N was managed conventionally, the N rate recommended by the sensor, the N rate recommended by the N response experiment and the total N rate applied in the area under conventional N management*

	Location	Grain yield (t/ha)*	Recommended top dress sensor area (kg N/ha)	Recommended top dress by the N response experiment†	Total N rate conventional N management (kg N/ha)
1	Valenzuela	5·7	0	0	160
2	Amaya	5·44	0	0	230
3	Dabdoub	3·86	0	0	220
4	Castro	6·97	0	0	184
5	Pablos	6·01	198	242	207
6	Lopez de Lara	6·95	0	0	246
7	Felix	5·32	0	0	220
8	Arvizu	5·6	0	0	245
9	Dabdoub	5·24	30	0	275
10	Gallegos	5·5	0	0	252
11	Miranda	6·3	0	0	198
12	Perez	–	25	0	247
13	Nery	4·8	0	0	253
	Mean	5·641			226

* Grain yield of the area with conventional N management.
† Optimum agronomic rate according to the N response experiment.

and also lower than that reported in previous surveys (around 244–251 kg N/ha, Naylor *et al.* 2001). This could be the result of a small sample size or the fact that farmers that participated in these validation and technology transfer trials did so because they were already trying to lower their N rates. The fact that none of the eight technology transfer trials required application of a top dress, according to the recommendations obtained, coincides with the results of the validation trials, where it was necessary to apply additional N in only one trial. This supports the idea that the soils in the Yaqui Valley have high amounts of residual soil N and/or that the N rates currently applied pre-planting and at planting are sufficient to high. In some of the fields the estimated savings are conservative. For instance, in field no. 3, the farmer originally intended to apply a top-dressing of 120 kg N/ha; however, when he was not able to perceive visually a difference between the N-rich strip and the rest of his field he decided to apply only half (60 kg N/ha) of what he had originally planned.

Agronomic implications

The N demand by the wheat crop is a function of yield potential; more N is needed by the crop when the yield potential is higher. In the Yaqui Valley, applying 20 kg N/ha limits yield to 1–5 t/ha. To achieve over 5 t/ha of wheat yield, 30 kg N/ha is required for each additional ton (Ortiz-Monasterio 2002). During the last 25 years the average wheat yield in the Yaqui Valley has ranged from 4·5 to 6·1 t/ha; these differences were mostly driven by climatic conditions (Lobell *et al.* 2005). The 2005/06 wheat cycle had the highest average yields in the history of the valley (6·1 t/ha), demonstrating that this technology worked even in the year with the highest N demand. As mentioned above, technically the sensor is not necessary when there are no visual differences between the N-rich strip and the farmer's field; however, farmers still collect the readings with the sensor. For them, collecting the data with the sensor when there are no visual differences is equivalent to getting a second opinion and reassures them in their decision making process. Trials looking at the amounts of residual soil nitrogen have shown that a significant number of farmers have relatively high amounts of residual soil N (J. I. Ortiz-Monasterio, personal communication). This suggests that if farmers in the Yaqui valley were willing to reduce the rate of N applied pre-plant or at planting, they could potentially benefit even more by adopting the use of the sensor as a diagnostic N tool.

Grain quality

It is possible that reductions in N application derived from the use of the sensor, which look to optimize only yield, may have an impact in wheat protein concentration. Currently, most farmers in the Yaqui Valley do not receive a premium price for high protein. However, farmers have a price penalty if their wheat has more than 0·12 yellow berry. There is a high negative correlation between grain protein and yellow berry. Therefore, this technology will eventually need to address issues related to wheat quality.

Table 6. *Eight technology transfer trials showing the N rate used in the sensor areas, the area under farmer's management and the N-rich strip, the area planted of each of these plots, the grain yield, fertilizer costs, income from wheat sales, amount of N saved using the sensor and improvement in farm income by using the sensor compared to the conventional farmer's management*

	Block no.	Fertilizer rate (kg/ha)	Grain yield (t/ha)	Fertilizer cost* (US$/ha)	Income from yield† (US$/ha)	N savings (US$/ha)	N savings (kg N/ha)	Improvement in farm income with sensor use (US$/ha)
1	B. 1003	138 Sensor	7·13	$113	$1362	$63	82	$20
		220 Farmer	7·36	$176	$1405			
		230 N-rich ztrip	7·43	$188				
2	B. 2128	75 Sensor	7·35	$61	$1403	$58	75	$56
		150 N-rich strip	7·36	$123	$1405			
3	B. 1110[1]	138 Sensor	6·97	$113	$1331	$46	60	$12
		198 Farmer	7·15	$159	$1366			
		276 N-rich strip	7·38	$226				
4	B. 909	115 Sensor	7·28	$94	$1390	$63	82	$26
		197 Farmer	7·48	$157	$1427			
		230 N-rich strip	7·73	$188	$1476			
5	B. 516	150 Sensor	8·05	$123	$1536	$77	100	$104
		250 Farmer	7·90	$200	$1509			
		243 N-rich strip	8·14	$199				
6	UCAH	92 Sensor	7·44	$75	$1421			
		92 Sensor	7·57	$75	$1444	$71	92	$71
		184 Farmer	7·57	$151	$1444			
		276 N-rich strip	7·29	$226				
7	B. 1924	160 Sensor	7·30	$131	$1394	$29	37	$86
		197 Farmer	7·00	$160	$1336			
		217 N-rich strip		$178				
8	B. 1107	148 Sensor	7·68	$121	$1466	$63	82	$45
		230 Farmer	7·77	$184	$1484			
		241 N-rich strip	7·82	$197				
Average								$53

AQ2

* Fertilizer cost on Jan 2006: urea US$0.82/kg N and Anhydrous ammonia US$0.78/kg N.
† Price of wheat per metric ton: US$191.
For all calculations, the exchange rate during May 2006 was used (1 US$ = 11 pesos).

In the meantime, with the use of this technology there are great opportunities in improving farm profits by reducing the cost of N application for a large number of farmers, particularly those with high amounts of residual soil N.

Environmental implications

Experiments looking at the implications of different N management practices on environmental impact in the Yaqui Valley have evaluated the combined effect of reducing N rates and changing timing of N application. These experiments have shown that when N rates are reduced from 250 to 180 kg N/ha together with a change in the timing of N application, losses to the environment can be reduced. The sensor technology that is currently being transferred to farmers is only addressing a reduction in N rates and not a change in timing of N application. However, other experiments have shown that by simply reducing the N rate, the N efficiency can be significantly improved (Ortiz-Monasterio 2002), resulting in less nitrogen that could potentially be lost to the environment as leaching to the ground water, volatilization to the atmosphere or run-off to the Sea of Cortes.

Technology transfer and policy

During the crop cycle 2006/07, a programme to extend the use of the sensor technology among farmers in the valley has been organized by the farmers' unions. The target of this programme is to incorporate 174 fields or approximately 3500 ha during the first year. An important component of this programme has been that it is cost-free to the farmer. Hopefully, as the farmers are convinced of the benefits of this technology, they will be willing to pay for it. If not, the farmer may need some type of incentive such as the use of this technology to qualify for government subsidies.

CONCLUSION

In 12 of the 13 locations of the validation trials and in all eight locations of the technology transfer trials, the sensor was evaluated only in fields with sufficient N (no N deficiency) and only in one field with severe N deficiency. Therefore, the sensor needs to be further tested under a wider range of situations, for instance where there are intermediate and low degrees of N deficiency. Nevertheless, within the range of degrees of soil N where the sensor has been tested (predominantly high amounts of residual soil N), performance has been good, resulting in average savings in N use of US$62, without any yield reduction in the validation trials, and an improvement in farm profit of US$52/ha in the technology transfer trials. The benefits to the environment should also be significant because a large proportion of the N that is applied in excess of the needs of the crop is lost to the environment as leaching to the ground water, volatilization to the atmosphere or run-off to the sea.

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