NITROGEN FERTILIZATION

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In 1997 we completed laboratory studies of N mineralization rates and N topdress efficiency. In addition we obtained data from field trials related to N mineralization rates and to Cu and Zn fertility.

Laboratory Studies of Nitrogen Mineralization

The series of laboratory experiments we conducted enabled us to determine the amount of nitrogen that can be mineralized by soil under different conditions and to determine how to better manage topdress nitrogen applications. We found that the straw additions can be beneficial to subsequent wild rice crop, especially if the straw has a relatively low ratio of carbon to nitrogen, and is added in large quantities, which is the case in wild rice cultivation when straw is not burned. Wild rice straw has a lower ratio of carbon to nitrogen than other small grains, and therefore is a more effective source of N. Also, N mineralization from straw is much more effective under flooded conditions compared to mineralization in well drained soils. The tie-up of N after straw incorporation that is often observed in well drained soils is, under most conditions, not seen in flooded soils. However, proper straw management is essential to maximize the benefits and avoid problems. The straw must be chopped and well incorporated into soil. Incorporation into wet cold soil in the fall can lead to organic acid toxicity and gas production that can cause floating peat.

Because of the legislated ban on straw burning in California, researchers there have been studying soil incorporation as an alternative to burning. They have found that with proper management, significant quantities of N can be added to the soil. This research has shown that how and when straw is incorporated into soils that are fall flooded is important in effective utilization of rice straw (J. Hill, University of California, Davis, personal communication).

Incorporation of wild rice straw soon after harvest ,when soils are quite dry and warm, allows for partial aerobic decomposition and will prevent the problems of organic acid toxicity and gas production. Potassium and phosphorus can be incorporated early with straw but nitrogen should not be added until latter, just before flooding in the fall. This partial aerobic decomposition is even more important if barley, oats, or wheat precedes wild rice. These high carbon to nitrogen ratio straws have an even greater capacity to produce of organic acids and gas than wild rice straw. The straw should be well chopped and well incorporated.

The data in our Table 1 show the quantities of N that can be produced by incorporation of wild rice straw. When properly incorporated into a neutral pH peat, wild rice straw can mineralize about 39 lb N ac^{-1} even at 43 °F, after 42 days of incubation (Table 1). From the time of wild rice seedling emergence in mid May to tillering/panicle initiation in late June, the soil temperature rises from about 40 °F to 68 °F (Grava and Koski, 1978). However, only 28 lb/ac of N would mineralize in a soil with pH of 5.

The data in Table 1 suggest that if wild rice straw is properly incorporated in the fall, over 90 lb/ac might be mineralized over the whole growing season in a soil with neutral pH. In an acid soil with a pH of 5 the quantity mineralized would be only about 40 lb/ac. The drained fallow data can be used to estimate the quantity of N needed following fallow. We did not include a treatment that is similar to the current practice of burning or burying straw using a moldboard plow, in wild rice following wild rice. However, the evidence from data from a flooded fallow treatment suggest that the N produced in the drained fallow treatment is less than we currently get from the soil in second and third year paddies. Reasonable estimates of soil supplied N are 15 lb/ac at pH 5 and 40 lb/ac at pH 7 following fallow and 35 lb/ac for pH 5 soils and 70 lb/ac for pH 7 for second and third year paddies with current management.

About 40 lb ac^{-1} nitrogen are needed for good growth up to panicle initiation (Grava and Raisanen, 1978), and mineralization has the potential in neutral pH soils to meet this need until the first topdress is applied early to mid boot stage, if straw is incorporated. However, under current management when no fall nitrogen is applied we have measured soil ammonium N in mid June of less than 30 lb/ac (Bloom and de Alwis, 1996). Field research is needed to ascertain how predictive laboratory results are for soils under field conditions.

Table 1. Nitrogen mineralization after 42 days of flooding for wild rice and drained fallow treatments with and without lime at different temperatures. (Calculated from mineralization data reported in Chapter 2 of the MS thesis of Deepa de Alwis, 1997)

Temp °F	Wild rice straw pH 5 lb/ac	Wild rice straw + lime, pH 7 lb/ac	Drained fallow pH 5 lb/ac	Drained fallow + lime, pH 7 lb/ac
43	22	39	7	23
54	31	53	9	21
64	38	60	11	31
75	47	97	15	44
86	72	119	40	78

We tried several legumes as green manure corps to supply organic N but growth was poor and the results were inconclusive. However, activated sewage sludge showed promise as a slow release nitrogen fertilizer, particularly in neutral soils. The addition 1072 lb/ac of dried sludge supplied an additional 45 lb N ac^{-1}. However, there are several drawbacks to using it. The high level of phosphorus (2%) in the sludge will lead to P build up in soils. High soil P is a potential hazard because it can increase the likelihood of algal blooms, and may become a regulatory problem for release of P in drainage water. Another compounding problem of using activated sewage sludge as a slow release N source is its poor performance at low pH as evident from our study. Many of the peats in Aitkin and Beltrami counties are quite acidic, and the addition of activated sewage sludge will not be very beneficial unless the soil is limed. In wild rice paddies with neutral pH, an organic fertilizer such as activated sewage sludge may be sufficient to supply all the nitrogen needed with only one fall application. Over fertilization with P is a problem, and a combination of activated sewage sludge and inorganic N fertilizer may work best for cultivated wild rice. Activated sewage sludge is a slow release fertilizer and with proper crop residue incorporation and fall flooding it has the potential to increase efficiency as there will be less losses during early crop growth. Therefore, more N will be available during the reproductive growth stages where the demand for N is the highest. The addition of minor nutrient elements such as zinc and copper are another positive aspect of using activated sewage sludge (Sartain, 1992). Copper and zinc may be limiting in some wild rice paddies.

Liming had a significant positive effect on nitrogen mineralization at all temperatures tested and two management practices used, drained fallow and wild rice straw addition. However, to obtain the level of mineralization reported in Table 1 from the pH 5 peat an equivalent of 9600 lb/a of lime was applied. This level of liming may not be financially feasible for most growers but waste ash products may provide for inexpensive alternatives to agricultural limestone.

The soil derived nitrogen will be less in an acid peat; therefore more fertilizer nitrogen has to be applied as topdress, especially during early reproductive stages. Increasing basal application would be less efficient as the loss potential is higher and high soil N early in the growth of wild rice can result in lodging.

Higher temperature and freezing also increases the amount of nitrogen mineralized. However, growers have no control over soil temperature or freezing. Northern Minnesota soils always freeze during the winter, hence the growers are assured of the greater quantity of nitrogen mineralized due to freezing, compared to the quantity without freezing. The low soil temperature during seedling emergence (Grava and Koski, 1978) however, hampers nitrogen mineralization. As the temperature rises in the summer the rate of mineralization also increases, providing more nitrogen to the growing crop.

Field Observations of the Difficulties Involved in Utilization of Straw

Two observations on a farm operated by Tom Godward near Aitkin illustrate some of difficulties that can be encountered with straw management. In one case organic acid toxicity was observed in wild rice following oats. In the other case various methods of straw incorporation were tried to determine the best method for incorporation of straw to produce the most N mineralization. Because of the wet and cool conditions in the fall, incorporation of wild rice straw resulted in decrease in early growth.

In the Aitkin area, the fall of 1996 was cool and wet which made fall operations difficult. On paddies grown to oats, oat straw was incorporated with two diskings into soil that soon after became very wet and cool because of the fall rains. This did not allow for much straw decomposition during the fall. The wild rice crop in the spring of 1997 showed very poor emergence and the plants that did emerge showed clear signs of toxicity. The young seedlings were very stunted even while nutrient resources in the seed were still available. Organic acids produced by straw decomposition in the spring apparently stunted plant growth. This problem is worse on acid soils like those in the Aitkin area, and has been observed in rice on acid soils in cooler climates like Japan. Acid pH both decreases the rate of straw decomposition and increases the toxicity of organic acids that can be produced during the early stages of straw decomposition in wet soils. The problem was worse on mineral soils than on nearby peats. The reason of this difference is not obvious but it might be due to the difference in the incorporation of straw in the peats. The water level was lowered to allow as much aeration as possible to the surface of the soil and some of the plants recovered. However, yields were very low.

The effect of different methods of managing straw were investigated in a paddy on the Godward farm. In the fall of 1996 treatments were initiated on a paddy after harvest of a first year crop. The treatments were a control, moldboard plow with incorporation of 30 lb/ac of urea N, plus several other treatments involving: 1) burning to remove residue, 2) chopping of residue, 3) a single heavy disking and 4) incorporation with 6 passes of a disk (see Table 2). The treatments were not replicated. Because of the wet weather the burning treatment was not complete and after the field operations were completed, the soils became very wet. The soils and plants were sampled on July 1 of 1997. Soil samples were taken for extractable N and plants were sampled for chlorophyll content with a SPAD meter and for tissue N. A few days before sampling, all plots were topdressed with 23 lb/ac of urea N.

The healthiest and most mature plants were in the moldboard plow plus fertilizer N treatment. These plants also had the highest tissue N concentrations. The poorest plants, both less mature and poorer stand, were in the chop and incorporation treatment. In this treatment we observed floating residue with gas bubbles with some indication of floating peat. The highest SPAD readings were also in the moldboard plow treatment. In these trials lower SPAD readings can reflect both lower tissue N and less mature plants. Readings on the SPAD meter increase with maturity. The soil, and plant N, and SPAD all indicated adequate values for the control treatment.

Table 2. Straw management study, sampled July 1, 1997

Treatment	Soil N lb/ac	Plant N %	SPAD
Control - Moldboard plow + 30 lb/ac N	36	3.08	35
Disk	11	2.30	29
Disk + 30 lb N	30	2.60	32
Disk and incorporation	36	2.98	31
Burn	13	2.85	31
Burn and incorporation	28	2.86	31
Chop	28	2.36	35
Chop and incorporation	45	2.95	33

Observations of early growth problems due to straw management problems were also made on the John Gunvalson farm. One of his paddies were too wet to till in the fall of 1996. In June of 1997 early growth was greatly inhibited by gassy decaying straw on the paddy surface.

The poor performance of the straw incorporation treatments with and without incorporation was probably due to the effect of organic acids and gas production from decaying residue. The incorporation of the residue into wet cold soil did not allow for decay of the residue. Moldboard plowing deposits most of the residue at a depth that is out of the rooting zone of young plants and the products of residue decay do not affect early growth. The high soil N in the chop plus incorporation treatment was expected because this treatment allows for the most complete decay of the straw and the greatest N mineralization. However, the poor stand means that plant uptake was minimal leaving more N in the soil.

The results of this trial demonstrates that straw burial is one of the reasons moldboard plowing gives consistently better results than other forms of tillage under current management schemes. Utilization of straw N from wild rice or other small grains, while avoiding the problems of floating peat and organic acid toxicity will require incorporation of the straw soon after harvest. A scheme that should be tried is spreading straw with a combine straw chopper and incorporation with disking soon after harvest. This can be followed by current management in the fall using moldboard plowing. The partial straw decay in drained soil in August and September should be sufficient to avoid the problems we observed if fall rainfall is not excessive.

Field Evaluation of Lime Applications.

In the fall of 1997 we attempted to initiate a field trial on a farm near Aitkin operated by Tom Godward to evaluate whether liming under field conditions would result in increased N mineralization and increased yield. Alternating strips were marked out in a first year paddy, in triplicate, with no lime, 2000 lb/ac and 5000 lb/ ac lime with no basal N. These plots were to be compared to another area in the field where a 30 lb/ac of basal N was applied. Unfortunately, because of very wet conditions, the lime was not applied until the spring and it was not incorporated. Nevertheless we did obtain data on plant and soil N in June of 1997. We found a greatly reduced stand in the limed strips with indications of floating peat (Table 3). Lime reaction with acid peat produces CO_2 gas which could cause problems if the lime is not well mixed in the soil and not allowed a period of reaction under drained conditions. All plants sampled had sufficient N for early growth. The highest concentration of soil N and plant N was found in the fall fertilized treatment. There was a tendency, however, for an increase in N with lime treatments compared to the control treatment but the trend was not statistically significant.

If and when funding is available we will sample these plots again to determine the long term effect of the liming. We also obtained permission for experimental use of wood ash for liming on wild rice paddies and will evaluate the effect of this material on N fertility in acid peats.

Table 3. Lime Study

Treatment	Soil N (lb/ac)	Plant N %	SPAD	Plant density plants/ft^2
no lime, n=5	22 ± 6	3.6 ± 0.3	33	8-10
2000 lb lime n = 3	31 ± 9	3.6 ± 0.4	34	4-7
5000 lb lime, n = 3	30 ± 3	3.5 ± 0.2	35	1-2
Fertilized (30 lb N) + 30 lb/N	45	3.8	34	-

Topdress Nitrogen

If the soil is depleted of N at the time of topdress, a wild rice crop can take up 80 lb/ac of topdressed nitrogen in little over a week with high efficiency (Bloom and de Alwis, 1997). In most wild rice paddies in Minnesota, soil N is depleted by late June (Bloom and de Alwis, 1996). Therefore, in most cases in the field, a large portion of the topdressed nitrogen can be taken up by the crop soon after application when plants are growing rapidly.

Before the present study, researchers did not take into account the root uptake when making nitrogen fertilizer recommendations. During early reproductive growth stages, about 45 lb N/ac were accumulated in the roots. As a crop matures some of this nitrogen may be translocated into the grain or other parts of the plants. However, the root system appears to maintain a total nitrogen concentration of at least 1.3 % even if the shoots are clearly deficient in nitrogen. The 45 lb/ac in the roots was about half of what the shoots accumulated at early flower (90 lb/ac). Therefore in calculating N requirements, the root nitrogen must be considered. We have a tentative nitrogen recommendations based on our experiment, which may be adjusted after field testing. These recommendations are based on extrapolation of nitrogen uptake during early flower stage to the harvest time. This was achieved by using the data from Grava and Raisanen (1978) for biomass addition and nitrogen uptake. The recommendations should be modified if no fall N is applied or flooding is late.

Table 4. Nitrogen fertilizer requirements for a good wild rice crop under current management of residue. The values given are approximate and may change depending on the stand density, temperature and other agronomic, climatic and soil conditions. The recommendations do not account for the stimulation of soil N mineralization by plant roots observed. In first year paddies following black fallow 20 lb/ac additional fertilizer N is needed. If wild rice straw is well incorporated 15 lb/ac less N is needed in acid peat and 30 lb/ac less N is needed in neutral pH peats

	Neutral pH	Acidic pH	Comments
	lb N ac^{-1}		
Wild Rice	**Nitrogen**	**Requirements**	
Total N requirements	145	145	100 shoots + 45 kg roots
Soil N	45	30	
N from Fertilizer	100	115	
Recommend	**Fertilizer**	**Application**	
Basal, Fall	30 - 40	30 -40	With immediate flooding*
Topdress, mid to late boot	60 - 70	60 - 70	
Topdress, mid to late flower	20-30	30 - 40	
Total fertilizer N	**110 -140**	**120 - 150**	

* If no fall nitrogen is applied or fall flooding was not possible, apply about 30 lb/ac during aerial leaf stage.

To fully understand the relationship between nitrogen mineralization and plant uptake, future researchers need to conduct field studies to determine the plant nitrogen uptake patterns during both vegetative and reproductive stages of the newer varieties currently used by growers. This information coupled with mineralization rates at the same temperatures should be compared to field testing. These recommendations are based on extrapolation of nitrogen uptake during early flower stage to the harvest time. This was achieved by using the data from Grava and Raisanen (1978) for biomass addition and nitrogen uptake. The recommendations should be modified if no fall N is applied or flooding is late.

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Field trials of Cu and Zn application

In some of the paddies in the Clearwater area we have seen low tissue Zn in the range where we would expect deficiency, along with quite low concentrations of tissue Cu. Our limited data from hydroponic studies suggests that Zn deficiency in wild rice produces reduced growth without distinctive symptoms. We sampled an area in a field that had been in wild rice since 1981, and over the last few years shown consistently low tissue Zn. The paddy had been fertilized on October 29 with 46 lb/ac N, and then flooded. The soil, when sampled on June 16 had 32 lb/ac of ammonium N. After this sampling, strips with 10 lb/ac Zn and 10 lb/ac Zn plus 5 lb/ac Cu were applied by air. A topdress of 46 lb/ac of N was also added. The soils and plants were sampled again on July 18.

The initial soil test suggests low Cu and adequate Zn(Table 4). The plant samples suggest possible low Zn and possible low Cu. The soils tests, however, were calibrated for upland grains and not for flooded soils and we expect drying of a soil before submission to soil testing increases the availability of Zn. Our previous research suggests a plant deficiency limit for Zn to be about 20 ppm. We know less about Cu but for most grains, tissue contents of less than 5 ppm are considered to be low. The data suggests additions of 10 lb/ac of Zn causes a small increase in tissue Zn. This was not sufficient, however, to visibly change plant growth. The 5 lb/ac of Cu was not sufficient to increase tissue Cu. This is expected because Cu binds very strongly to peats. We expected that at least 25 lb/ac of Cu would be needed to see a significant difference in tissue Cu but application of this quantity of Cu is very expensive. The SPAD and tissue N suggest possible N deficiency on July 18.

Table 5. Zn and Cu experiment

Treatment	Zn	Cu	N	SPAD	Sampling date
	ppm		%		
Initial (DTPA soil test)	3.3	0.7	-	-	June 16
Initial (plant)	21.9	4.5	3.12	-	June 16
Control	18.3	3.4	2.11	39	July 18
10 lb Zn	19.2	2.5	2.25	37	July 18
10 lb Zn, 5 lb Cu	22.2	2.3	2.21	38	July 18

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