

On the Road to Overcoming Soil Acidity in Upland Rice

SOIL ACIDITY is a major problem in most of the uplands in the humid forest zone, resulting in phosphorus deficiency in growing crops. WARDA is looking at the possibility of using a combination of tolerant rice varieties, rock-phosphate and nitrogen-fertilizer application to enable farmers to improve their rice production in the uplands.

Nearly 70% of the upland rice in West and Central Africa is grown in the humid forest zone. However, the productivity of rice in the uplands of the humid forest is probably the lowest among all the ecosystems in which rice is grown throughout West and Central Africa, averaging about one tonne per hectare. These upland soils are acidic and acid-soil-related infertility is the principal cause of the problem. The acidic components in the soil (aluminum and iron oxides) react with phosphorus and render it unavailable to plants. Since phosphorus is a vital element in plant growth, this effective deficiency in the soil has a direct impact on crop yield.

WARDA Soil Chemist, Kanwar Sahrawat, takes up the story: “if we look at a cross-section of soils in West Africa on a north–south axis, we find that the further south we travel, the higher the rainfall and the stronger the soil acidity. At the same time, we find a decrease in phosphorus in the soil, to the extent that phosphorus-deficiency becomes the most serious soil nutrient problem for growing crops in the humid forest zone.” Acidity is a problem in its own right, in that rice varieties that are not tolerant of soil acidity give no yield at all. Farmers’ varieties (commonly known as ‘landraces’) are acid-tolerant because they have been selected over many generations in

acid soils. Improved upland varieties are also tolerant of soil acidity, since the breeders have built on the work the farmers started, and the plants are then specifically selected in acidic uplands. It is well known among agricultural researchers and many farmers that nitrogen is almost always a limiting factor in crop production, but in the humid forest of West and Central Africa the soil phosphorus level is so low that the crops cannot respond to the addition of nitrogen fertilizer alone. However, once the phosphorus deficiency is overcome, the crop will respond well to nitrogen fertilizer, which should never be far away from the crop-manager’s armory.

“Phosphorus deficiency was known to be a problem in tropical acid soils by the early 1970s,” explains Sahrawat. “However, acid soils are also often deficient in other nutrients—calcium and magnesium.” In one early experiment, therefore, WARDA investigated the effects of applying these nutrients (along with nitrogen) in various combinations to see what role they play in alleviating the acidity-related infertility of the soil. The results were conclusive: the addition of phosphorus alone or in combination with calcium, magnesium, or both, increased both grain and straw yields of upland rice; however, application of calcium, magnesium, or both, without phosphorus did

not increase yields (Table 1). In fact, the addition of the calcium and magnesium to the suite of fertilizers had no greater effect on yields than the application of phosphorus alone.

Other nutrient problems may arise, however, in the longer term. WARDA Soil Physicist Sitapha Diatta explains: “since 1997, we have been studying the effects of long-term rice cropping on soil nutrient reserves. This has confirmed that nitrogen and phosphorus are deficient in the acidic uplands of the humid forest zone. In addition, latest results indicate that potassium may also become deficient in the third season of cropping. In traditional slash-and-burn farming, this wouldn’t be a problem, but as farmers are forced to crop the same land for more seasons, and to return to land after shorter and shorter fallow periods, potassium may become a serious limiting factor.”

It is important for subsistence-oriented farmers to know if they need to add fertilizer to their soils and, if so, how much. A next step was, therefore, to assess the relationship between the availability of phosphorus in the soil and the yield of the rice crop. The experiment was conducted on a soil that had received phosphorus fertiliza-



Compare same rice variety receiving Mali rock-phosphate (left) with control receiving no P fertilizer (right) on acidic upland soil. Note reduced tillering (more soil is visible between plants) and fewer panicles of unfertilized plants

tion (in the form of commercially available triple superphosphate) in the preceding season. For each experimental plot, available phosphorus was determined in the laboratory. Owing to the vagaries of acid soils, plots fertilized in the previous season had widely differing levels of phosphorus that was available to growing plants (known

Table 1. Effects of calcium, magnesium and phosphorus fertilization on yield (t/ha) of rice variety WAB 56-50, Ultisol, Man, Côte d’Ivoire, 1994.

Treatment†	Grain yield	Straw yield
Control‡	2.02	2.14
P	3.14	2.99
Ca	2.11	2.43
Mg	2.28	2.86
P + Mg	2.87	2.72
P + Ca	2.79	2.79
Ca + Mg	2.12	2.28
P + Ca + Mg	2.98	2.81
LSD (0.05)	0.364	0.712

† All treatments received 100 kg N and 80 kg K per hectare.

‡ No P, Ca or Mg added.

as ‘available phosphorus’). This, however, was a positive aspect and enabled us to calibrate grain yield (in the form of relative grain yield—a percentage of maximum yield achieved) against available phosphorus. The results established a ‘critical limit’ of available phosphorus (for the varieties tested) at 12.5 to 15 mg of phosphorus per kilogram of soil. If a soil test gives a reading for available phosphorus below this critical limit, the farmer needs to apply phosphorus fertilizer.

“Another indicator for grain yield—and a potentially more accurate one—is the amount of phosphorus actually accumulated by the rice plants,” explains Sahrawat. “Therefore, we conducted a series of experiments to relate plant phosphorus content to final grain yield and to measure available phosphorus in the soil.” For the plant test, whole plant tops (that is, all of the plant above the ground) were collected at maximum tillering stage, that is when the plants have maximum vegetative growth just before they put out spikes to bear flowers and grains. Like the soil, plants were tested for phosphorus content in the laboratory. Again, results were positive, demonstrating a linear relationship between phosphorus taken up by the

crop (as measured at maximum tillering) and final grain yield, and also between plant phosphorus uptake and available phosphorus in the soil (Figure 3). Thus, a relationship was established from available phosphorus in the soil, not just to relative yield, but (through plant uptake) to actual grain yield. This means that the soil test can act as a direct indicator of likely crop yield, and phosphorus-fertilizer requirement.

Towards affordable phosphorus

A serious problem with all this need for phosphorus, however, is the cost of commercial phosphorus fertilizer (triple superphosphate, TSP). The experiment that confirmed phosphorus as the limiting nutrient used some 50 kg of phosphorus per hectare, and other experiments gave even better response with higher rates of fertilization (e.g. 90 kg P/ha). Fertilizer is sold by the sack, each sack containing 50 kg of fertilizer, in this case TSP, but TSP is only 20% phosphorus, so 50 kg of phosphorus would be five sacks of TSP! Each sack of TSP may cost about 10,500 FCFA—that is simply too much investment for subsistence farmers!

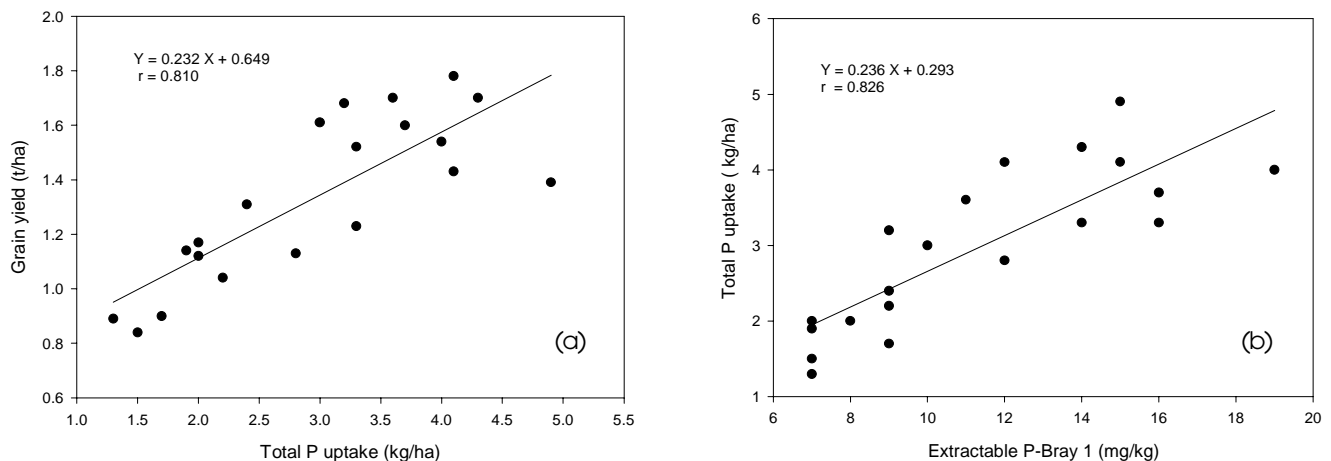
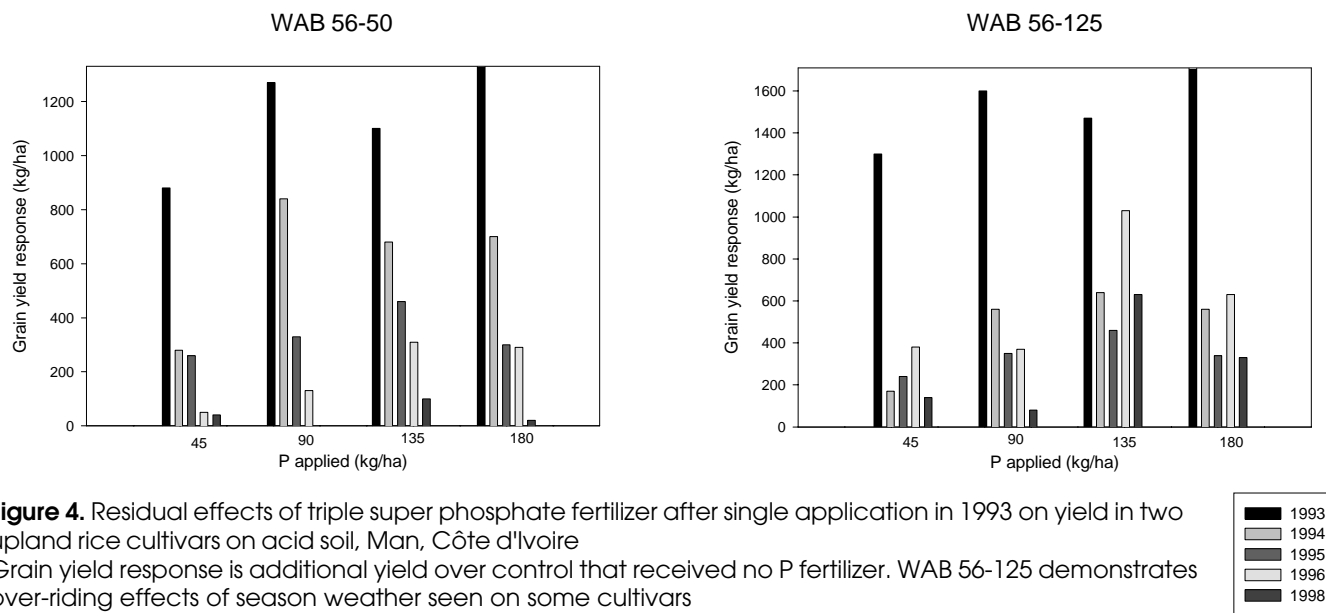


Figure 3. Relationship between grain yield and plant total P uptake (a), and plant total P uptake and extractable P in the soil (b) of four upland rice varieties

“To compound the problem of cost,” explains Sahrawat, “there is the fact that TSP is only really effective in the soil for one or two seasons. Our experiments on the soil test for phosphorus availability demonstrated a significant yield response to TSP applied in the first year by the second-year crop, but only as a fraction of the ‘immediate’ response.” By the fourth year, residual effect of applied TSP is negligible, except for plots that received very high doses of TSP (Figure 4). “With these facts in mind,” Sahrawat continues, “we started looking for alternative, and potentially affordable, sources of phosphate for use on this rice crop.”

Diatta takes up the story again: “we were aware of work on phosphorus-demanding crops in the humid forest, savanna and Sahel zones—groundnut, maize, millet and sorghum—involving the use of local rock-phosphate. These crops give a good response to rock-phosphate applied as a fertilizer.” Much of this ground-breaking work had been conducted by the International Fertilizer Development Corporation (IFDC), which is headquar-

tered in Alabama, USA, with an Africa Division based in Lomé, Togo. Rock-phosphate occurs naturally throughout the dry savanna and Sahel zones of West Africa, and IFDC had characterized many of these for their reactivity and solubility in acid soils. In 1997, WARDA established trials to compare the effects on rice yield of rock-phosphate from six sources—Burkina Faso, Mali, Niger, Senegal (two sources) and Togo—with that of TSP. “Plots receiving TSP significantly out-yielded those receiving rock-phosphate,” explains Sahrawat. “However, among the rock-phosphate sources, that from Mali gave good results and showed potential as a substitute for expensive TSP.” The following year (1998), a trial was established at Man, Côte d’Ivoire, to compare residual effects of a single application of rock-phosphate with that of annual application of TSP. That year, the Mali rock-phosphate treatment performed as well as the TSP treatment (Figure 5). In the second year of the experiment (1999), all rock-phosphate treatments gave significantly higher rice yield responses than in the first year—a clearly demonstrated ‘residual effect.’



What we are building on—the work of IFDC

The International Fertilizer Development Corporation (IFDC) has a mandate for detailed research and development in soil fertility management. Its headquarters are in Alabama, USA, and there is an Africa Division based in Lomé, Togo.

IFDC has a database containing characteristics of rock-phosphate sources throughout the world, including many from West and Central Africa. Particularly important qualities of rock-phosphate are how easily it reacts with acidic soils, and how soluble it is in such soils. These are used as measures of the appropriateness of rock-phosphate from a particular source being used as a direct-application fertilizer. These data were used earlier in IFDC tests on the use of rock-phosphate fertilizer in drier-zone crops of West Africa, such as groundnut, millet and sorghum. The Mali rock-phosphate that appears promising in WARDA trials has an IFDC designation of 'medium reactive' and, as such, was potentially the most useful source of those tested. "The IFDC ground-work enabled us to target our own research and resources," explains Sahrawat, "but we are working on a crop and environment combination [upland rice in the humid forest zone] that had not been researched by IFDC. Rice reacts very differently to soils and phosphate fertilization than dry-area crops. Compared to the dry-area crops tested by IFDC, rice is acid-soil tolerant and less demanding of fertilizer phosphate; however, it is still responsive to applied phosphate, especially in acid soils."

Sitapha Diatta explains: "rock-phosphate is relatively insoluble, so we are not surprised that, generally, in the first year yields from rock-phosphate fertilized plots fail to match those from plots fertilized with soluble TSP. However, the solubility of TSP works against its potential residual effect, as it can be progressively immobilized by the aluminum and iron oxides that are so common in the acidic soils."

"Chemical reactions are not one-way events," explains Sahrawat, "but rather reactions occur until a state of equilibrium is reached." Thus, in the absence of soluble phosphorus, the acid elements are free to react with the rock-phosphate, slowly but continuously releasing phosphorus. Some phosphorus therefore becomes available for plant nutrition in the seasons following rock-phosphate application. Thus, rock-phosphate looks increasingly like a viable alternative to TSP for rice fertilization in the humid uplands.

Improving acidity tolerance in rice varieties

Alongside the fertilizer management trials, breeders are trying to improve the acidity tolerance of available varieties. Three of the four varieties used in the soil- and plant-test diagnostic trials were WARDA-bred materials, which are more acid-tolerant than the local traditional variety IDSA 6. These improved rices have formed the basis for assessing the performance of WARDA interspecific hybrid progenies (recently dubbed NERICA for *New Rice for Africa*). "The interspecific hybridization project was initially established to develop new plant types for the uplands," explains upland-rice breeder and Rainfed Rice Program Leader Monty Jones, "so we should not be surprised to find the

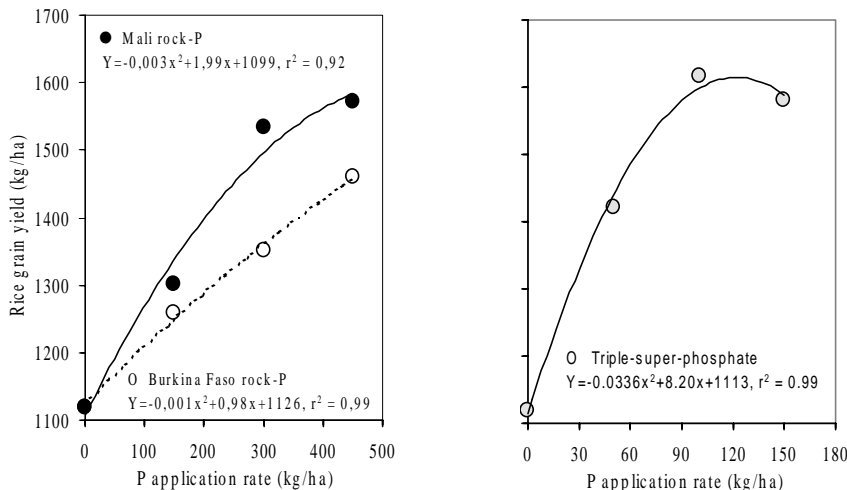


Figure 5. Rice response to rock-P from Mali and Burkina Faso (left) and to triple super phosphate (right) in an acid Ultisol

NERICAs doing well on acidic, phosphorus-deficient soils in the humid forest zone.” At the acidic Man site in Côte d’Ivoire, 15 NERICAs gave an average yield of 1.16 tonnes per hectare without phosphorus fertilizer, compared to 0.89 t/ha for the best *Oryza sativa* variety. In fact, the best NERICA gave a staggering 2.9 t/ha *without application of phosphorus!* In 1999, two NERICAs gave grain yields in excess of 3 t/ha in unfertilized soil at Man. One of these is scheduled to be one of the first NERICAs to be officially released in the region—NERICA 1 [= WAB 450-I-B-P38-HB] in Côte d’Ivoire in 2000.

“What we really want is to encourage farmers down the road of development,” explains Monty Jones. “First, we need an acidity- and low-phosphorus-tolerant variety that will increase farmers’ yields, and therefore their incomes. But then we want to encourage them to take the next step—applying fertilizer. Thus, we want varieties that perform well under no inputs, but then respond positively to inputs when the financial status of the farmer allows their use.” Accordingly, WARDA is also testing the response of the acidity-tolerant NERICAs to applied phosphorus. In 1999, again at Man, four NERICAs were tested for their response to phosphorus application in the form of both TSP and Mali rock-phosphate. And the good news—all four NERICAs responded positively to rock-phosphate application, one of them even giving a linear response to application of up to 450 kg P/ha (Figure 6). What’s more, the yields of these NERICAs were higher than those of the traditional check at all levels from 0 to 450 kg P/ha.

Outstanding questions

So, it can be seen that we are developing a three-pronged approach to the soil-acidity related infertility problem in upland rice in the humid forest zone. We are developing varieties that are tolerant to both soil acidity and phosphorus deficiency, but that are also responsive to the addition of phosphorus once farmers can afford to buy it. Then we are working towards a long-term phosphorus-fertilizer

strategy involving local rock-phosphate, possibly with the use of TSP in the first year of rice cropping. After that, we may be in a position to refine nitrogen-fertilizer recommendations to improve the benefit–cost ratio of upland rice farming further.

“We are well along the road,” Sahrawat cheerfully explains, “but we still have a long way to go. So far all this research has been an academic exercise to examine the possibilities, but we are still a few years off from making concrete recommendations to farmers.” Results from ongoing trials—which may be available as soon as the end of 2000—should determine once and for all the agronomic viability of rock-phosphate as a fertilizer for upland rice, then we will have to seriously look into the socio-economic aspects. Rock-phosphate is available in large quantities in the northern Sahel and dry savanna zones of the region, but it is needed in the southern humid forest. To date, Mali rock-phosphate has not been commercially exploited as a fertilizer, so there are outstanding questions of logistics. Can the rock-phosphate be formulated where it is mined into a product that is both easily transportable and immediately usable on the farm?

The only rock-phosphate available commercially in Côte d’Ivoire comes from Senegal, and is distributed by a company in Abidjan—a fortunately suitable center for distribution to the humid forest zone. The other rock-phosphates used in the WARDA experiments were carried in from their sources. “In our experiments,” explains Diatta, “we used powdered rock-phosphate. However, this has several disadvantages. First, it is bulky and difficult to transport. Second, and perhaps more importantly, it is labor-intensive to apply—application by hand results in the farmer being covered with white dust, so it is better if the powder is first mixed with humid soil and then applied. It can take a whole day to fertilize one hectare, but then again, we are not talking about an annual event! We believe that it should be possible to formulate the rock-phosphate as granules.” These would be both easier to transport and easier to apply.

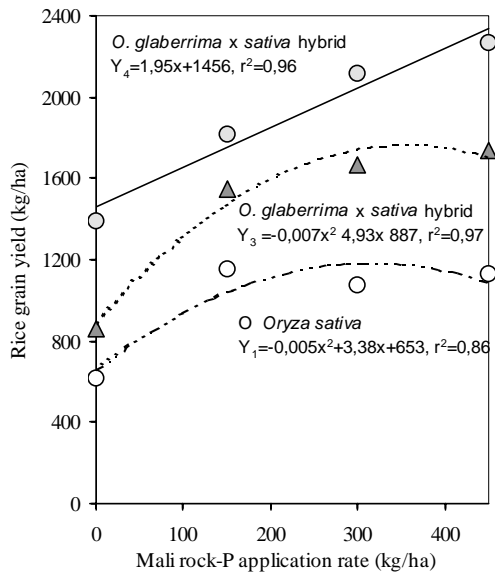


Figure 6. Response of two NERICA rice varieties and control to Mali rock-phosphate in humid forest acid soil

Once we have a suitable formulation, transport costs will then determine the viability of using the product as proposed. If transport costs are too high, farmers in the humid forest will not be able to afford the rock-phosphate, and therefore will not use it. We believe that rock-phosphate fertilizer made and distributed within the region will be much cheaper than imported fertilizers like TSP. But TSP is so expensive, that it remains to be seen whether a mechanism can be found to make the rock-phosphate product available at a cost affordable to resource-poor farmers.

Future avenues

“Our studies are far from complete,” says Diatta. “One thing we need to do is to study plant uptake of phosphorus from fertilizer rock-phosphate in much the same way as we calibrated yield to plant uptake with TSP. A further avenue is the possibility of P-32 isotope analysis to determine the rate of immobilization of soil phosphorus fixation by the action of aluminum and iron oxides.” WARDA does not have the facilities for this work, but Diatta has contacts in France with whom he hopes to collaborate on this work.

The first on-farm trials with rock-phosphate will take place at three sites in Côte d’Ivoire (humid forest and savanna zones) in 2000. These will be an addition to the ongoing participatory varietal selection program (see ‘New Rice for Africa... with a Little Help from our Friends’ in this Report) and will involve 25 farmers at each site.

Another potential avenue for the future is to combine our agronomic work on fallow-replacement legumes into the ‘package.’ Using legumes in place of natural (weed) fallow has the double benefit of reducing the weed population and not depleting the nitrogen reserves of the soil. In fact, if a cover-crop legume is used and the whole crop plowed back into the soil, the legumes actually replenish the soil’s nitrogen, reducing the need for nitrogen fertilizers (see *WARDA Annual Report 1998*, pages 36–37). “Even what nitrogen is held in the leaves can improve soil nitrogen status,” explains Diatta. So, he is looking into the possibility of starting rotation trials with cowpea—the seeds of which can be harvested for food—in the 2001 season.