AGRICULTURAL USE OF INDIGENOUS PHOSPHATE ROCKS IN SUB-SAHARAN AFRICA

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ABSTRACT

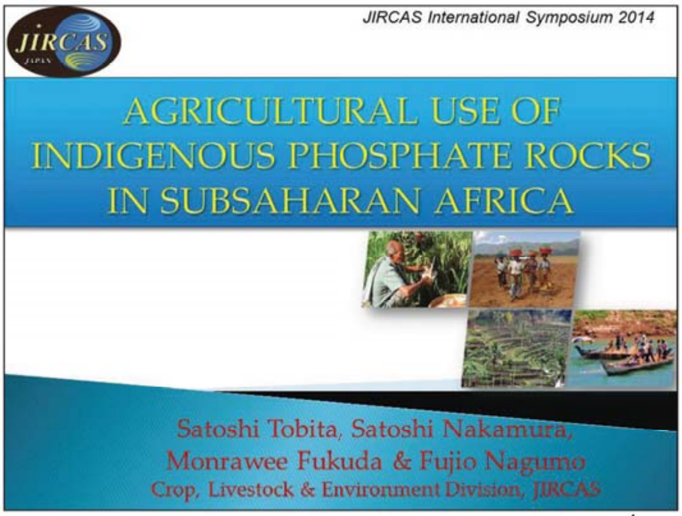
Phosphorus (P) is an essential nutrient for crop growth and production. In Sub-Saharan Africa (SSA), deficit of soil P is one of the most serious constraints to crop yield. This shortfall has resulted from the high P fixation capacities of highly weathered acidic soils in SSA, spreading throughout a range of agricultural lands, from upland to lowland fields. To cope with the P deficiency, however, resource-poor farmers in SSA cannot apply commercial water-soluble P fertilizers because of their very limited accessibility and affordability.

As its deposits are found in several places in SSA, indigenous phosphate rock (PR) should be recognized as a cheaper alternative source of P for local agricultural production. Hence, it is important to develop appropriate methods for effective utilization of local PRs after knowing their chemical and physical properties. PRs mined in SSA, with lower water-solubility, are generally considered to have less effectiveness when they are directly applied onto the fields. Even so, it is worth to evaluate the effectiveness of PRs on agricultural systems which are differed in crops and environmental (soil and climate) conditions in SSA.

The JIRCAS Team, collaborating with colleagues in West Africa, has shown a positive effect of the directly-applied PR from Burkina Faso (BPR) on the growth and yield of lowland rice in ecologies of Equatorial (Ghana) and Savanna Zones (Ghana and Burkina Faso). BPR could also be utilized as a delayed-release P fertilizer as it demonstrated a significant residual effect in the same ecologies.

For the sake of increase in solubility of BPR, several processing technologies have been examined in consideration of farmers and/or community-based feasibility, e.g., low-temperature calcination during charring and biological acidulation during composting.

KEYWORDS
Indigenous resource; Infertile soil; Phosphate rock; Phosphorus nutrition; Rice, Sub-saharan Africa;



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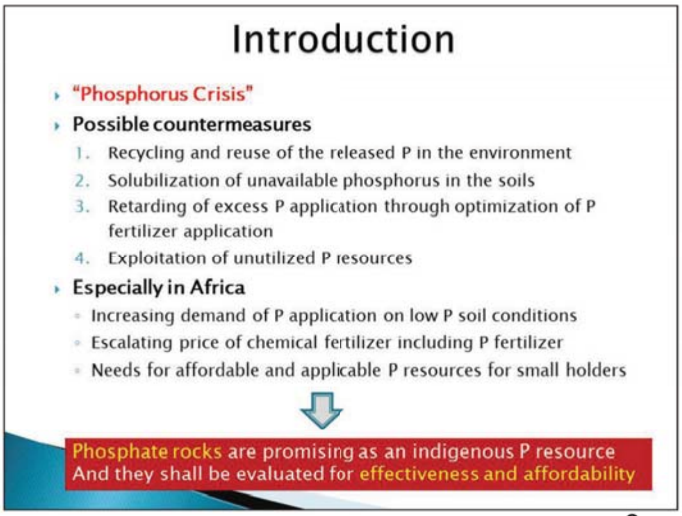

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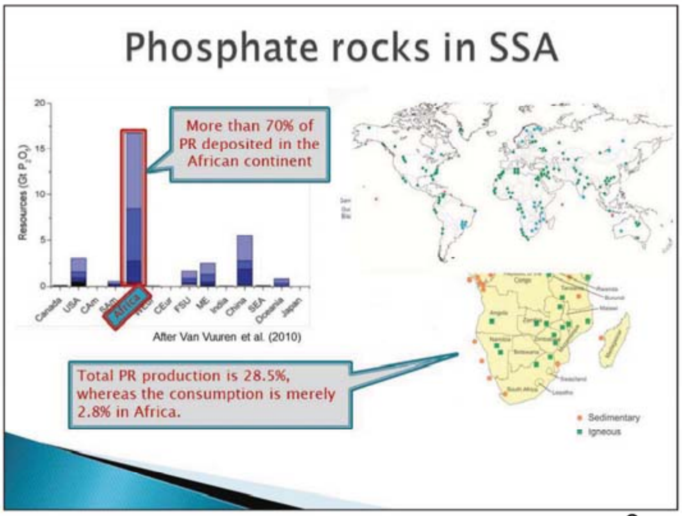

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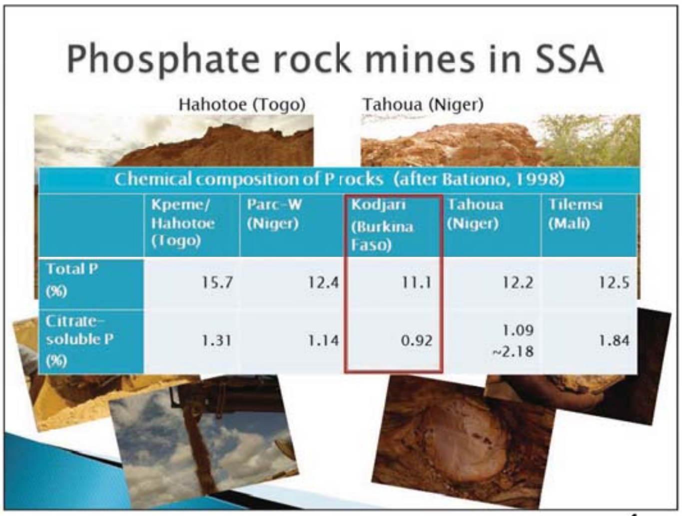

	Kpeme/ Hahotoe (Togo)	Parc-W (Niger)	Kodjari (Burkina Faso)	Tahoua (Niger)	Tilemsi (Mali)
Total P (%)	15.7	12.4	11.1	12.2	12.5
Citrate-soluble P (%)	1.31	1.14	0.92	1.09 ~2.18	1.84

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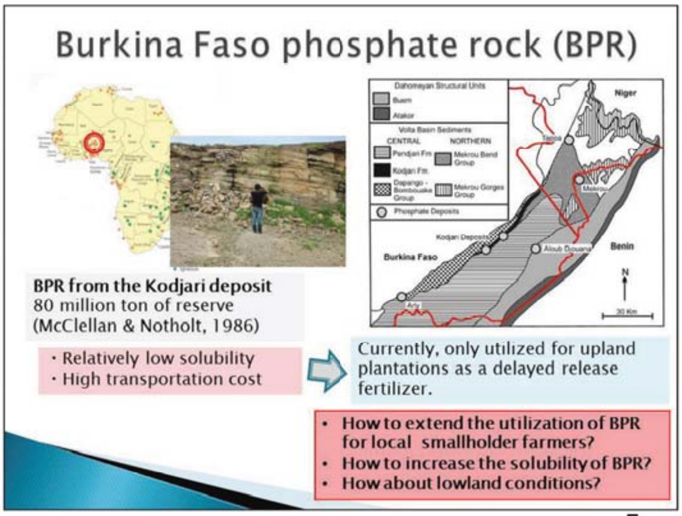

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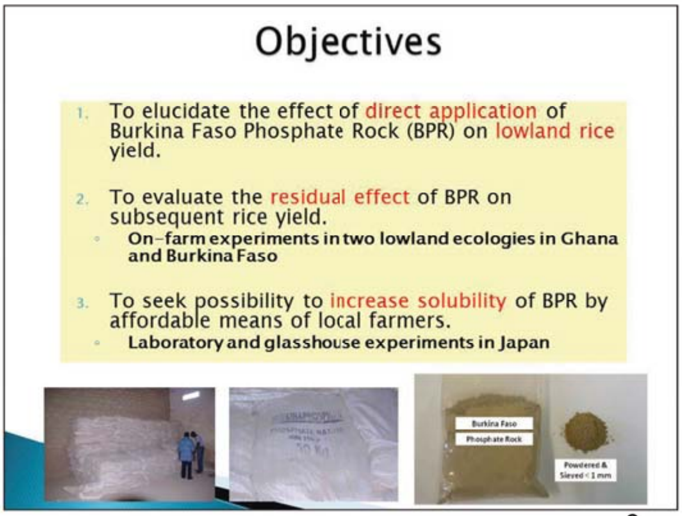

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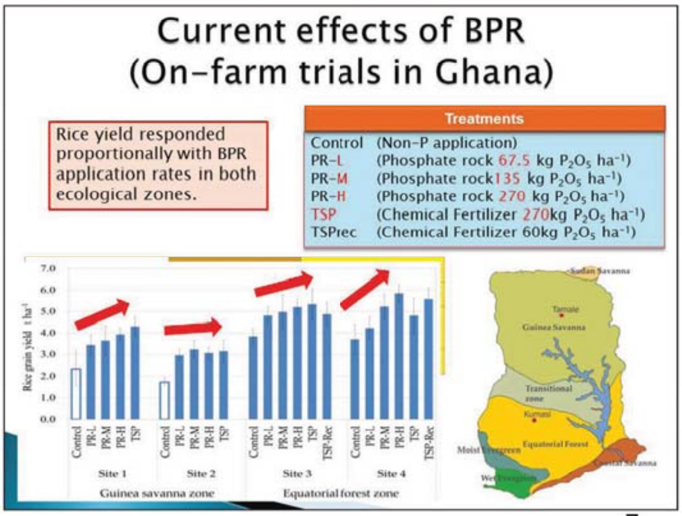
Current effects of BPR
(On-farm trials in Ghana)
Rice yield responded proportionally with BPR application rates in both ecological zones.
Treatments
Control (Non-P application)
PR-L (Phosphate rock 67.5 kg P2O5 ha-1)
PR-M (Phosphate rock 135 kg P2O5 ha-1)
PR-H (Phosphate rock 270 kg P2O5 ha-1)
TSP (Chemical Fertilizer 270kg P2O5 ha-1)
TSPrec (Chemical Fertilizer 60kg P2O5 ha-1)
Rice grain yield t ha-1
Site 1
Site 2
Site 3
Site 4
Guinea savanna zone
Equatorial forest zone
Sudan Savanna
Tamale
Guinea Savanna
Transitional zone
Kumasi
Equatorial Forest
Moist Evergreen
Wet Evergreen

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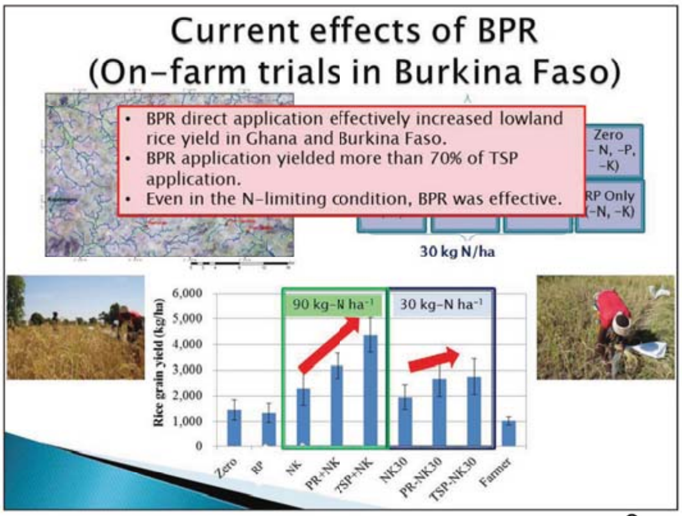
Current effects of BPR
(On-farm trials in Burkina Faso)
BPR direct application effectively increased lowland rice yield in Ghana and Burkina Faso.
BPR application yielded more than 70% of TSP application.
Even in the N-limiting condition, BPR was effective.
Zero -N, -P, -K)
RP Only (-N, -K)
30 kg N/ha
Rice grain yield (kg/ha)
90 kg-N ha-1
30 kg-N ha-1
Zero
RP
NK
PR+NK
TSP+NK
NK30
PR-NK30
TSP-NK30
Farmer

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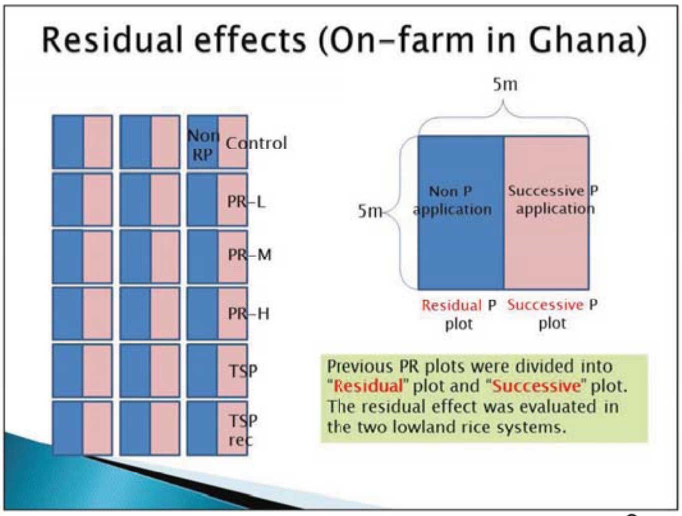
Residual effects (On-farm in Ghana)
Non RP
Control
PR-L
PR-M
PR-H
TSP
TSP rec
5m
5m
Non P application
Successive P application
Residual P plot
Successive P plot
Previous PR plots were divided into "Residual" plot and "Successive" plot. The residual effect was evaluated in the two lowland rice systems.

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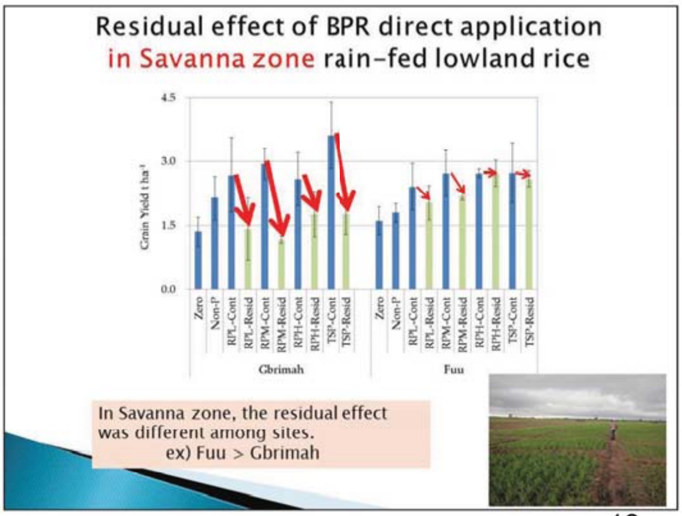
Residual effect of BPR direct application
in Savanna zone rain-fed lowland rice
Grain Yield t ha-1
Gbrimah
Fuu
In Savanna zone, the residual effect was different among sites.
ex) Fuu > Gbrimah

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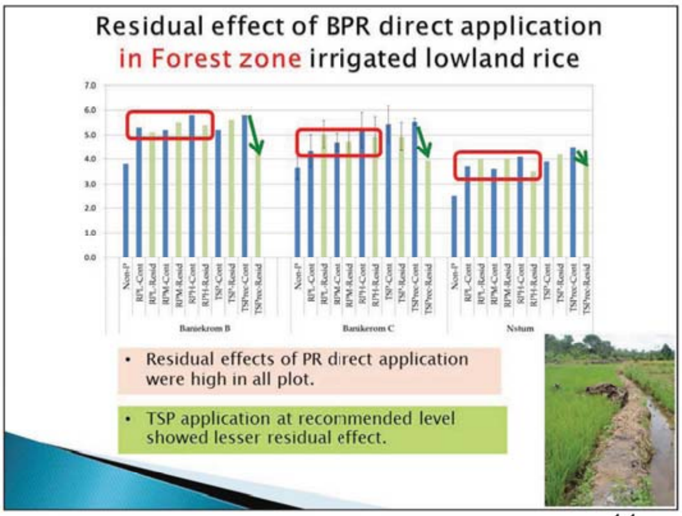
Residual effect of BPR direct application
in Forest zone irrigated lowland rice
Baniekrom B
Baniekrom C
Nstum
Residual effects of PR direct application were high in all plot.
TSP application at recommended level showed lesser residual effect.

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Socio-economics of BPR
Participatory studies in Ghana on farmers' view
Accessibility: 0%
Acceptability: 100%
Most of farmers want to use BPR if available
Handling problem as BPR is too fine powder: new technologies shall be developed, ex., pelleting + α
BPR costs ¼ against TSP at Burkina Faso
Worth to utilize if the effect is the same or higher

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Discussions

- Direct application of Burkina Faso phosphate rock (BPR) was generally effective on lowland rice yield in Ghana and Burkina Faso.
- Residual effect of BPR was also observed, but it may be affected by the soil/water conditions.
- Thus, BPR direct application was not always superior to water-soluble fertilizers, depending on environmental and socio-economic conditions.

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- Technologies shall be developed to increase the solubility of PR under diverse conditions, which are also applicable for small-holder farmers.

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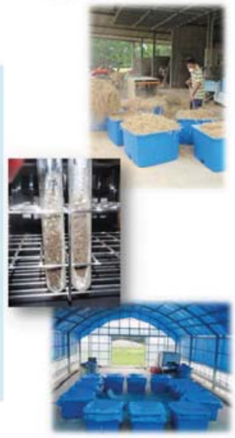
PR solubilization technology 1. Composting process

- Principle:
  - PR would be dissolved by organic acids and heat produced by microorganisms growing during the composting process.
- Method:
  - BPR was put into the rice straw composting process.
  - As a PR-dissolving fungus, *Aspergillus niger*, was inoculated and evaluated.
  - Water content was maintained at app. 60%.
  - Temperature of the compost was recorded.
  - Effectiveness of rice straw composting was estimated at 56 DAS by available-P in the compost, extracted by water and 0.1 M NaOH solution.



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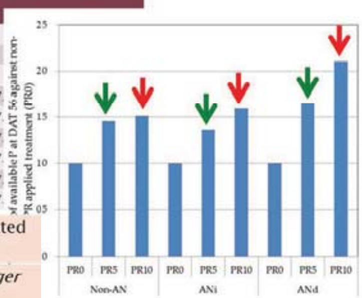
PR solubilization technology 1. Composting process

Treatment	Rice straw	BPR	A. niger inoculant	Inoculation timing	Initial P content
		g DW			
RS	7,500	0			
RS+BPR 5	7,500	375			
RS+BPR10	7,500	750			
RS +Ani	7,500	0	187.		
RS+BPR 5+Ani	7,500	375	187.		
RS+BPR10+Ani	7,500	750	187.		
RS +And	7,500	0	187.		
RS+BPR 5+And	7,500	375	187.		
RS+BPR10+And	7,500	750	187.		



- Composting process accelerated the PR solubilization.
- Inoculation of *Aspergillus niger* seemed to promote the PR solubilization in the composting process

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PR solubilization technology 2. Low temperature calcination

- Principle:
  - High temperature calcination of PRs around 1300°C is an industrial process of water-soluble P-fertilizer.
  - PR would be partially solubilized by lower temperature calcination locally achievable.
- Method:
  - BPR was calcinated at 100 to 500°C for several hours with use of a muffle furnace.
  - The calcinated BPR was analyzed for water-solubility and 2% citric acid (CA) extractability.

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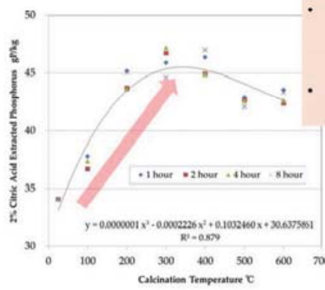
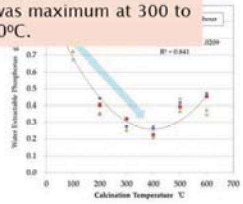
PR solubilization technology 2. Low temperature calcination



- Low temperature calcination significantly increased the solubility of PR to citric acid.
- It was maximum at 300 to 400°C.



Water solubility of PR was decreased by low temperature calcination.

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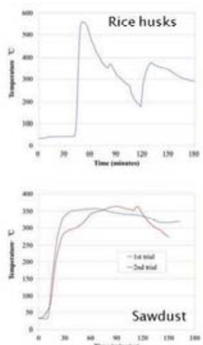
PR solubilization technology 2. Low temperature calcination

- The "Kuntan" technology (or carbonization of plant residues, like rice husks and sawdust) is applicable for local communities.
- Temperatures of 300 to 400°C is achievable in the "Kuntan" process.

By mixing with PR into the Kuntan material, low temperature calcination would be possible.



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Conclusions

- Burkina Faso phosphate rock (BPR) can be locally used as P-fertilizer, especially for lowland rice systems.
  - Direct application: comparable to chemical P-fertilizer (ex. TSP)
  - Residual effect: depending on conditions, superior to TSP in some sites = slow-release fertilizer
- Solubility of BPR could be increased by community-based technologies.
  - Composting process:
  - "Kuntan" process: low-temperature calcination
- These findings show possibility of the agricultural use of other indigenous phosphate rocks in Africa, mostly not yet utilized.

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- JIRCAS
  - Dr. Satoshi Nakamura, Dr. Monrawee Fukuda, Mr. Junji Koide, Dr. Fujio Nagumo
  - Dr. Osamu Ito, Dr. Kazunobu Toriyama, Dr. Ryoichi Matsunaga
- MAFF, Japan

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Thank you for your attention!

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Chair Matsumoto: Next speaker is Dr. Satoshi Tobita. He holds a doctoral degree in Agriculture from Tokyo University of Agriculture and Technology and is currently Director of the Crop, Livestock and Environment Division in JIRCAS. His expertise is in the area of Crop Physiology and Nutrition. He had worked at ICRISAT, India, as a Post-Doc, followed by JIRCAS Tropical Agriculture Research Front at Ishigaki. As a JIRCAS scientist, he has experiences to collaborate with several institutions in Sub-Saharan Africa. His presentation title is “Agricultural Use of Indigenous Phosphate Rocks in Sub-Saharan Africa.” Dr. Tobita, please.

Dr. Satoshi Tobita: Thank you, Chairman, Dr. Matsumoto-san, and sorry for make you alone. Today, I’ll speak about phosphate rocks in Sub-Saharan Africa.

Previous speakers mentioned about phosphorus crisis, but we have several possible countermeasures, like recycling and reuse of the released P in the environment; and second, solubilization of unavailable phosphorus in the soils; and third, retarding of excess P application through optimization of P fertilizer application; and exploitation of unutilized P resources. But especially in Africa, there’re several big characteristics in this situation, one is increasing demand of P application on low P soil conditions and second is the price of the chemical fertilizer is escalating including P fertilizer, need for affordable and applicable phosphorus resources for smallholders. Phosphate rocks are promising as an indigenous P resource and they shall be evaluated for effectiveness and affordability.

We take a look at the phosphate rocks in the Sub-Saharan Africa. There’re many, many phosphate rock mines in the world, but there is more than 70% of rock deposits in the African continent. These are the map of the deposits in the African continent. Total phosphate rock production is 28.5% in Africa, but the consumption in Africa is only 2.8%.

This is some pictures in the rock mines in Sub-Saharan Africa. The left one is in Togo that is very big scale production of rock phosphates. The right one is from Niger, the name is Tahoua, is a small-scale rock mine. I’ll show some examples of the chemical composition of phosphate rocks in West Africa. There’re several variation in characteristics, but the total P is around 10% to 15% and its citrate solubility is around 1% to 2%.

Now we started studies about rock phosphates with use of Kodjari, Burkina Faso rock phosphates. So, this is about this rock phosphate. It’s 80 million tons of reserve, but this phosphate rocks have relatively low solubility and high transportation cost so that’s why currently this rock phosphate is only utilized for upland plantations as a delayed release fertilizer. So, we’ll have some questions and challenges. How to extend the utilization of rock phosphates for local smallholder farmers? How to increase the solubility of rock phosphates? How about the lowland conditions?

This is the objectives of this study. The first is to elucidate the effect of direct application of Burkina Faso phosphate rock on lowland rice yield and secondly is to evaluate the residual effect of Burkina Faso rock phosphate on subsequent rice yield. So these two objectives are studied in the on-farm experiments in two lowland ecologies in Ghana and Burkina Faso. Thirdly, we seek the possibility to increase the solubility of rock phosphate by affordable means of local farmers. So, this experiment is implemented in the laboratory at glasshouse level in Japan.

First, I’ll talk about the results of the effects of BPR in the on-farm trials in Ghana. In Ghana, there’re two ecological zones: one is Guinea Savanna and another one is Equatorial Forest. So each ecological zone has the corresponding rice systems like rainfed lowlands and irrigated lowlands respectively. So, we did experiments in the two regions and the treatments is one is control and phosphate rock applications with low, medium and high rates as well as TSP that is water-soluble chemical fertilizer. So, this is the result in terms of the rice grain yield. In the Guinea Savanna zone that is rainfed lowland ecologies, so rice yield responded very well to the rock phosphate application in the two sites. Also, in the Equatorial Forest zone, this irrigated rice ecologies, it also have a good response to rock phosphate application. So that means that rice yield responded proportionally with BPR application rates in both ecological zones.

This is about the on-farm trials in Burkina Faso. In Burkina Faso, we have eight villages, eight sites for the on-farm trials. And this is the result. So only the application of rock phosphate has no effect on the rice yield as compared with zero application. But if we put nitrogen and potassium fertilizer in the optimum levels, so rice yield responded to rock phosphate, as in this graph, and also responded to TSP. And this tendency was also observed in the low level of nitrogen application. So, the BPR direct application effectively increased lowland rice yield in Ghana and Burkina Faso. And rock phosphate application yielded more than 70% of TSP that's a chemical fertilizer application. And even in the nitrogen-limiting condition, phosphate rock was effective.

Next we will see the residual effects. That is also from the on-farm experiments in Ghana. The previous PR plots were divided into two. So, one is residual, which is no more application of P in this current season, and another one is successive plot that is applied to the PR in this current season. The residual effect was evaluated in the two lowland rice ecosystems.

This is the results in the Savanna zone, rainfed lowland rice. In the one village, so named Fuu, it has a good residual effect we can observe. So, we should compare the blue bar and the green bar that is corresponding, the one is residual and the one is successive. But in another village, named Gbrimah, it has there is no residual effect in terms of the grain yield of rice. In Savanna zone, the residual effect was different among sites.

This is the results in the forest zone in the irrigated lowland rice. As seen in these figures, all of the sites, we have good residual effects of PR direct application were high in all plots. But in the TSP application, there is lesser residual effect that means the effect was not continued to the successive seasons.

We had small surveys on the socio-economics on the BPR. We had participatory studies in Ghana on farmers' view to the rock phosphates. As a result, the accessibility was 0% because in Ghana there was no BPR commercialized so 0%, but from the farmers' view there was this 100% acceptability. This means most of farmers want to use BPR if available. Through the interviews, there some problem of the BPR is observed. BPR costs one-fourth against TSP chemical fertilizer at Burkina Faso. So, it's worth to utilize if the effect is the same or higher.

The small discussions, as seen before, the direct application of Burkina Faso phosphate rock was generally effective on lowland rice. And just observed residual effect, but it depends on the soil and water conditions. Therefore, rock phosphate direct application was not always superior to water-soluble fertilizers; it depends on the environmental and socio-economic conditions. We should develop some technologies which shall increase the solubility of rock phosphate under diverse conditions, which are also applicable for smallholder farmers.

First, we tested the composting process as a solubilization technology. Phosphate rock would be dissolved by organic acids and heat produced by microorganisms growing during the composting process. We'll put the BPR into the rice straw composting process. We test the PR-dissolving fungus, Aspergillus niger, was inoculated and evaluated. And that is the normal process of the composting. We will evaluate the solubility – available-P in the compost.

The result is here. Composting process accelerated the rock phosphate solubilization. If fungi are inoculated, the solubilization is promoted in the composting process.

Next we see the low temperature calcination as solubilization technology, because the high temperature calcination of PRs around 1300-degree C is an industrial process of water-soluble P-fertilizer. But if the temperature is lower, we can have some partial solubilization to which the temperature is locally achievable. So, the BPR was calcinated at 100 to 500-degree C for several hours with use of a muffle furnace. This is experiment done in Japan. The solubility was evaluated with water and also the 2% citric acid extractability.

This is the result. Unexpectedly, the water solubility of phosphate rock was decreased by low temperature calcination. But as evaluated by the 2% citric acid extraction, the solubility was increased, as in this graph, and it was the maximum at 300 to 400-degree C.

How to achieve this temperature? We look at the "Kuntan" that is carbonization of plant residues, "Kuntan" process. In this process, we'll have several hundred degree C in the "Kuntan" process, so it can be achievable. By mixing with phosphate rocks into the Kuntan material, calcination would be possible.

Conclusions: Burkina Faso phosphate rock can be locally used as P-fertilizer, especially for lowland rice systems. One is direct application: comparable to chemical P-fertilizer, like TSP; and secondly, we see through the residual effect, it depends on the conditions, superior to TSP in some sites. So that's why BPR can be used as a slow-release fertilizer. Solubility of rock phosphate could be increased by community-based technologies like composting or "Kuntan" process. So, these findings show possibility of the agricultural use of other indigenous phosphate rocks in Africa, mostly not yet utilized.

Thank you very much and we thank to our collaborators in Ghana and Burkina Faso, and of course our colleagues in JIRCAS. This study is funded by MAFF, Japan. So, I address that I have acknowledgements…

Thank you very much for your attention.

Chair Matsumoto: Thank you, Dr. Tobita. His group tried the phosphate rock application in African part and demonstrated that phosphate rock is useful. He showed us the development of technology increased phosphate's efficiency of the phosphate rock is applicable for farmers. Now, we have few minutes. Then, do you have any question and comments from – yeah? Please.

Male Questioner: Thank you very much for your presentation. I would like to ask about the residual effect. It depends on the location you mentioned and the reason you mentioned water condition, but any effect of the fixation by the aluminum in Africa soils?

Dr. Satoshi Tobita: Yeah, of course, we should consider about the difference in the soil itself. Some soils have some higher P absorption capacity or/and some is low so that kind of difference can affect to the residual effect.

Chair Matsumoto: Another question and comments?

Dr. Kazuki Saito: Thank you very much. I just would like to know the expected price for the phosphate rocks, because farmers mentioned they want to use if available, but it actually depends on the price.

Dr. Satoshi Tobita: Yeah, I know only information about the price is one-fourth of the chemical fertilizer. Exact price it can be reached, but I don't know now. So, let me tell you later if possible.

Chair Matsumoto: Or one question? It's okay? Okay. Thank you, Dr. Tobita.