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Pongamia Seed Cake as a Valuable Source of Plant Nutrients for Sustainable Agriculture

***Pongamia** a multipurpose leguminous tree containing non-edible oil grows widely in India. Oil extracted from the seeds of Pongamia is used as energy source as well as in tanneries while the cake (a by-product after extracting oil) was found to be rich in all plant nutrients in general and nitrogen (4.28%) and sulphur (0.19%) in particular. Both nitrogen and sulphur were found to be deficient in 100% and 80% soil samples from farmers' fields in Powerguda village of Adilabad district, respectively. Use of Pongamia seed cake as a source of plant nutrients for maize, soybean and cotton was found beneficial in participatory research and development (PR&D) trials on farmers' fields. Further, application of critically deficient micronutrients such as zinc and boron and secondary nutrient sulphur increased crop yields by 16.7% and 19% in soybean and cotton, respectively. Additional B:C ratios of 5.03, 1.81 and 2.04 were obtained for soybean, maize and cotton, respectively with use of cake as a source of N, however it needed higher initial investment.*

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Continued escalating oil prices, declining fossil fuel reserves and global warming associated with release of CO_2– C in the atmosphere have triggered research in the area of biofuels globally. In USA and Europe edible oils such as soybean, canola, palm oil, etc., are used for production of biodiesel. However, developing countries like India having shortages of edible oils for food needs cannot afford the use of edible oils for biodiesel production (28). There are number of non-edible oilseed trees and plants grown in the tropics which can be commercially exploited for preparing biodiesel in India. *Pongamia pinnata* (Karanj) and *Jatropha curcas* (Ratanjot) are evaluated as potential candidate trees for producing biodiesel in India (7).

Pongamia pinnata a leguminous N_2-fixing tree is native to India and is commonly grown as avenue plantation as well as on field boundaries. This tree is found naturally growing along riverbanks and also on village common lands. *Pongamia* seeds are rich source of oil (28 to 42%) (29) and is successfully used for preparing biodiesel. In remote tribal hamlets, straight vegetable oil (SVO) is used for running generators to supply electricity (5) and oilseed cake (75% of seed weight) a by-product after extracting oil is locally available. In a decentralised model of oil extraction at village level and to add value to a by-product (28) oilseed cake was evaluated as a source of plant nutrients for sustaining productivity of rainfed crops, as large degraded areas are planted with *Pongamia* in addition to large number of existing trees in forests. This will result in increased availability of oilseed cake too. Earlier researchers have evaluated *Pongamia* oilseed cake as a nitrification inhibitator in soil to improve fertiliser N use efficiency (23, 17, 18). The study was undertaken to assess the economic value of *Pongamia* seed cake and its suitability as sustainable source of plant nutrients and to reduce dependence on external input.

MATERIALS AND METHODS

Watershed Locations and Site Description

On-farm trials were conducted in watersheds during rainy season (*Kharif*) of 2004 and 2005 in Powerguda village, Jainoor Mandal and Kistapur village, Neradigonda Mandal of Adilabad district in Andhra Pradesh. Powerguda is spread over 423 ha, of which agricultural area in watershed covers 222 ha and forests 201 ha. The hamlet is located at 78° 52' to 78° 35' E and 19°22' to 19°25' N. The average annual rainfall is 1100 mm, the maximum temperature is 47° C (May) and the minimum temperature is 9° C (December). Kistapur is spread over 600 ha of which agricultural area in watershed covers 68 ha and forest (519 ha). The average annual rainfall is about 1140 mm and 93% of the rainfall occurs from June to October. The main crops grown are cotton, soybean, sesame, blackgram, wheat and groundnut. These watersheds fall under the semi-arid agro-ecological sub-region of southern India. The soils of the sites are mostly Vertisols and are low in fertility, especially total nitrogen and boron.

Soil Sampling and Analysis

Composite soil samples from individual farmer's field, about 8 to 10 cores of samples from the soil surface (0-15 cm depth) layer were collected for assessing the fertility status before imposing the treatments and analyzed using standard methods **(Table 1)**. The soil samples were air dried and powdered with wooden hammer and passed through a 2 mm sieve. For total nitrogen, the soil samples were finely powdered to pass through a 0.25 mm sieve.

The processed soil samples were analyzed in the ICRISAT Analytical Services Laboratory. The soil pH was measured by a glass electrode using a soil to water ratio of 1:2; electrical conductivity (EC) was determined by an EC meter using a soil to water ratio of 1:2. Total nitrogen

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Table 1 – Status of macro and micronutrients in Powerguda village, Adilabad district and normal values, medium range and critical limits for different parameters

	pH	EC (dS/m)	Total N (mg kg^{-1} soil)	P (mg kg^{-1} soil)	K (mg kg^{-1} soil)	S (mg kg^{-1} soil)	Zn (mg kg^{-1} soil)	B (mg kg^{-1} soil)
Mean	7.94	0.21	6.34	7.36	246	8.32	0.69	0.27
Range	7.4-8.3	0.1-0.4	317-978	0.6-19	135-359	5.5-15.1	0.5-0.9	0.1-0.5
Critical limits			<1200	<5	<50	8-10	0.75	0.58
Per cent of farmers' fields deficient			100	40	0	80	60	100

was determined by segment flow analyzer (8), available P was analyzed by Olsen method (13), exchangeable K was determined by atomic absorption spectrophotometer (27), available S was measured using 0.15% calcium chloride ($CaCl_2$) solution as an extractant (26), available Zn was extracted by DTPA reagent (12) and available B was extracted by hot water (10).

Detailed nutrient composition of the *Pongamia* cake from the Powerguda village oil extraction unit operated by women self help groups (SHGs) was analyzed by sulphuric acid-selenium digestion method (19) and chemical composition is given in **Table 2**.

On-farm Trials

On-farm trials were laid out during *Kharif* (rainy season) of 2004 and 2005 in Powerguda and Kistapur villages taking number of farmers as replications.

Table 2 – Chemical composition of *Pongamia* cake used for the study

Nutrients	Content
Nitrogen (%)	4.28
Phosphorous (%)	0.40
Potassium (%)	0.74
Calcium (%)	0.25
Magnesium (%)	0.17
Zinc (ppm)	59
Iron (ppm)	1000
Copper (ppm)	22
Manganese (ppm)	74
Boron (ppm)	19
Sulphur (ppm)	1894

Soybean, maize and cotton were test crops for this study. During 2004, five farmers each conducted trials with soybean and maize crops. During 2005, soybean and cotton farmers were four each.

On-farm trials for soybean 20 kg N & 50 kg P_2O_5 ha^{-1}, 90 kg N and 50 kg P_2O_5 ha^{-1} for maize and 130 kg N and 90 kg P_2O_5 ha^{-1} for cotton as recommended N and P were applied. Four treatments were, 100% N through *Pongamia* cake (PC), 50% N through *Pongamia* cake + 50% N through fertiliser, 100% N through fertiliser (RDF) and the fourth was farmer's practice (FP). Cake was applied based on N equivalent during all the years. The entire P requirement was met by application of single super phosphate. In 2005, one more treatment of micronutrient was added changing the design from randomized block in 2004 to split plot in 2005. Two main treatments comprised of supplementation of secondary (S)+ micronutrients (Zn and B) and control (without S, Zn and B) while the four sub-treatments remained as that of 2004. Sulphur (30 kg ha^{-1}) was applied in the form of gypsum @ 200 kg ha^{-1}, zinc (10 kg ha^{-1}) as zinc sulphate @ 50kg ha^{-1} while boron (0.5 kg ha^{-1}) as borax @ 5kg ha^{-1} as basal dressing.

Crop Yields

Crops were sown in 200 m^2 plots each with the on-set of monsoon. Necessary agronomic package of practices were followed to keep the crop free from pest and diseases. Growth parameters were recorded at pod initiation stage in 2005. For harvesting the crops, plant samples were collected from 3 spots in each treatment. For each spot, harvested area was 4 m^2. Thus in each trial, crop plants covering a total area of about 12 m^2 was harvested, and the harvested plants were pooled. Economic parts of the plants were separated from the vegetative parts and weighed separately. Grain/cotton yield and stover or stalk weights were taken and brought to the ICRISAT center at Patancheru (India). The plant samples were dried at 60^0 C for 48 hrs and dry weights of grain/cotton and straw samples were computed.

Statistical Analysis

Crops yields obtained were converted to kg ha^{-1} and tabulated according to the crop and treatments. The data was subjected to statistical analysis using the GENSTAT (Statistical Package, Rothemsted University, UK) 7th edition package.

Results

The analysis of soil samples from the participating farmers indicated a hundred per cent deficiency of N, while P was found to be deficient in 40% of the fields and excess in 30%. No deficiency of K was noticed in all the fields. In case of sulphur, zinc and boron, 80%, 60% and 100% fields were found to be below the critical limit respectively **(Table 1)**. The analytical data of field samples suggest a need of both macro and micronutrients application for realizing higher crop yields.

Pongamia cake used for application contained essential nutrients required for plant growth, particularly nitrogen (4.28%), phosphorus (0.4%) and sulphur (1894 mg kg^{-1}), iron (1000 mg kg^{-1}) that are important nutrients for crop production **(Table 2)** in addition to organic carbon content.

In the first year of on-farm experimentation (2004), it was observed that application of seed cake increased yields in case of sole or mixed source of nitrogen along with mineral source (**Table 3**). Detailed results revealed that soybean grain yield was increased by 49.0% over the farmer's practice although, N supplied by the cake was 25% lower than through mineral N (12 kg vs.16 kg N ha^{-1}). The highest soybean grain yield (1650 kg ha^{-1}) amongst the treatments was recorded in case of mixed N treatment which was higher by (83.0%) over farmers' practice and 61% over the treatment which received 23 kg N ha^{-1} (**Table 3**). Increased yields in spite of lower N supplied in case of seed cake treatments as against the mineral N treatments could be due to supply of other nutrients through the cake (**Table 2**) as well as addition of organic carbon also.

Table 4 – Plant height, cotton yield, total income, additional cost over farmers' practice and N-fertiliser equivalent in farmers' fields, (Powerguda, rainy season, 2005)

Treatment	N applied (kg ha^{-1})	N fertiliser equivalent using FP as control	Cotton yield (kg ha^{-1})	Total income (Rs ha^{-1})	Additional cost over farmer's practice (Rs ha^{-1})	Additional income Rs. ha^{-1}	Additional BCR
Farmer's practice (FP)	80	-	890	16990	-	-	-
Pongamia Seed Cake (PC) 3000 kg ha^{-1}	128	160	1790 (101)	34070	8390	17080	2.04
PC 1500 kg ha^{-1} + 100 kg DAP + 100 kg Urea ha^{-1}	128	104	1160 (29.5)	22000	5275	5010	0.95
Mineral fertiliser 200 kg DAP + 200 kg Urea ha^{-1}	128	95	1065 (19)	20235	2160	3245	1.50
SE±	-	-	124.8	-	-	-	-

Note: Figures in parentheses indicate percent increase in yield over farmer's practice

Similarly, in case of maize and cotton crops, which are non-legumes, requiring higher N application also showed increased crop yields due to *Pongamia* cake application over the mineral N treatments. In case of maize and cotton also maximum yields were observed in case of N supplied through combined sources (mineral and organic). Secondly, in the case of maize with only 70 kg N through seed cake yielded on-par grain yield of the mineral N treatment with 90 kg N (**Table 3**). Similarly, in case of cotton, significantly ($P \leq 0.05$) higher yield of 1790 kg ha^{-1} (60%) in case of oilseed cake N treatment (128 kg ha^{-1}) as compared to 1065 kg ha^{-1} in case of mineral N (128 kg ha^{-1}) was recorded (**Table 4**).

Oilseed cake as a source of N for crop growth was evaluated economically. Nitrogenous fertilisers are subsidized and such subsidy mechanism is not available for organic sources of plant nutrients. As indicated in **Table 3**, supply of N through seed cake was quite costly (Rs. 125 kg^{-1} N as against Rs 55 kg^{-1} N through DAP and Rs. 11 kg^{-1} N through urea). Relative economics of use of *Pongamia* cake found beneficial for the farmers, however, higher investment was needed. For example, farmers would need an investment of Rs. 1500 ha^{-1} towards use of *Pongamia* cake in production of soybeans, which is almost four folds higher as against Rs. 450 ha^{-1} using mineral fertiliser in FPs. Resource-poor farmers will be constrained to invest more in organic N source and to encourage them for increased use of organic manures suitable policy mechanisms are needed. There is a clear impact of use of *Pongamia* cake on profitability of crops reflecting higher additional B:C Ratio viz., 5.03 and 8.57 in case of use of cake and cake + fertiliser, respectively in production of soybean while 1.81 and 1.75 in case of maize.

Table 3 – Effect of *Pongamia* cake application on accruing additional benefit-cost ratios in production of soybean and maize - 2004

Crop	Treatment	N applied (kg ha^{-1})	Yield (kg ha^{-1})	Income (Rs.ha^{-1})	Cost of nutrients (Rs/ha)	Effect of cake use on crop income		
						Additional benefit (Rs. ha^{-1})	Additional cost (Rs. ha^{-1})	Additional 1 B.C. ratio
Soybean	Farmers, Practice	16	900	10800	450	-	-	-
	Pongamia cake (PC)	12	1340	16080	1500	5280	1050	5.03
	Fertiliser + PC	17	1650	19800	1500	9000	1050	8.57
Maize	Farmers Practice	40	1200	6000	1125	-	-	-
	Pongamia cake (PC)	71	2240	11200	4000	5200	2875	1.81
	Fertiliser + PC	81	2560	12800	5000	6800	3875	1.75

Effect of Micronutrients and Oilseed Cake on Soybean Growth Parameters

The impact of micronutrients on plant growth parameters at pod formation stage was found to be significant and application of micronutrients resulted in higher values of all the growth parameters (plant height (11.6%), leaf area (18.7%), number of pods (31.1%) and pod weight (34%)) as compared to control, without secondary (S) and micronutrients (Zn and B) (**Table 5**). These results demonstrated the benefits and mechanisms through which application of micro and secondary nutrients increased crop yields by overcoming hidden hunger of the crops grown in tropical farmers' fields. Similarly, the impact of sub-treatments on growth parameters and treatments receiving *Pongamia* cake was significant and had higher values over two other treatments (RDF and farmers' practice).

Total dry matter (16.5%), seed yield (16.6%) and numbers of pods (6.3%) per plant were significantly (P d"0.05) higher with application of micronutrients. The increase in seed yield of soybean was 260 kg ha^{-1} with application of micronutrient over control while total drymatter was 440 kg ha^{-1} **(Table 6)**. The effect of sub-treatments on seed yield was significant and treatments receiving nitrogen through *Pongamia* cake had higher values, which could be due to slow release of N and its availability over a prolonged period as observed by Patro and Sahu (14) in case of rice.

Table 5 – Plant growth parameters of soybean at pod formation stage as influenced by application of secondary and micronutrients in 2005

Treatments	Plant height (cm)	Leaf area (cm²/plant)	Shoot weight (g/plant)	No. of pods/ plant	Pod weight (g/plant)
Main plot: Applied Micronutrients					
(S, Zn &B)	30.8	431	5.7	19.4	3.35
Not applied (Control)	27.6	363	4.00	14.8	2.5
Sub-plot: Nutrient management					
Pongamia cake (100%)	30.13	466	6.82	19.8	3.29
Pongamia cake (50%) + RDF (50%)	30.88	388	5.02	16.8	3.07
RDF (100%)	28.00	383	4.03	16.8	2.73
Farmer's practice	27.75	352	3.50	14.9	2.57
General mean	29.19	397	4.83	17.1	2.92
SEM±					
Main plot	0.21	15.1	0.19	0.40	0.19
Sub plot	0.58	28.9	0.18	0.92	0.24
Interaction	0.82	40.9	0.25	1.30	0.34
CD at 0.05					
Main plot	0.95	67.6	0.85	1.79	0.86
Sub plot	1.73	86.1	0.53	2.74	0.71
Interaction	2.44	121.8	0.75	3.87	1.00

Soybean Yield

A comparison of yield data of two seasons indicated a similar trend. The highest yield obtained was with INM module of meeting nitrogen through both organic and inorganic source and the increase was to the extent of 34.2% over control (farmer's practice) followed by recommended dose of fertiliser (18.9%). Substituting hundred percent N with *Pongamia* cake also gave higher yield over farmer's practice **(Table 7)**.

Cotton Yield with Different N Sources

In case of cotton, application of Zn, B and S increased cotton yield by 19 per cent, however, results were not statistically significant. Application of *Pongamia* cake @ 3000 kg ha^{-1} supplying 128 kg N ha^{-1} yielded highest cotton yield of 1790 kg ha^{-1} which was significantly ($P \leq 0.05$) higher by 100% over the farmers' practice control **(Table 4)**. Application of 1500 kg PC + 64 kg N ha^{-1} through mineral fertiliser also produced higher yield (29.5%) than the farmers' practice treatment. Similarly, application of full-recommended N (128 kg) through mineral fertiliser had no significant effect on cotton yield over the farmer's practice treatment of 80 kg N ha^{-1} through mineral fertiliser **(Figure 1)**.

N Fertiliser Equivalent with *Pongamia* Seed Cake

The results of N-fertiliser equivalent **(Table 4)** showed that in case of full N through *Pongamia* cake although 128 kg N ha^{-1} was applied, the yield benefits were equivalent to 160 kg N ha^{-1} using FP as control. The additional benefits in case of PC (*Pongamia* cake) treatment could be due to supply of other nutrients **(Table 2)** and organic carbon, which play vital role in nutrient cycling and water retention in the soil. It may be noted that in case of

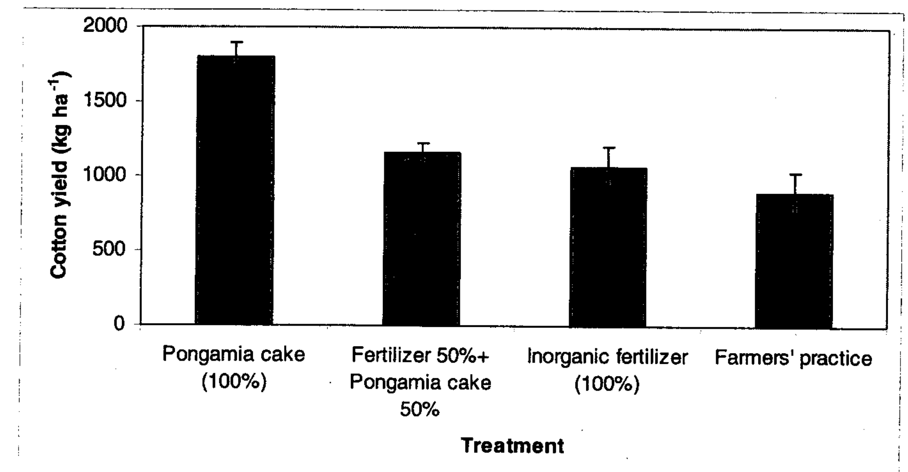

Figure 1 – Cotton yield as influenced by application of *Pongamia* cake in 2005

Table 6 – Dry matter and seed yield of soybean as influenced by application of secondary, micronutrients and *Pongamia* cake at harvest in 2005

Treatments	Dry matter (kg ha^{-1})	Seed yield (kg ha^{-1})	Total drymatter (kg ha^{-1})	No. of pods/plant	Test weight (g)
Main plot: Micronutrients					
Applied (S, Zn & B)	1280	1830	3110	17	12.0
Not applied (Control)	1100	1570	2670	16	11.6
Sub-plot: Nutrient management					
Pongamia cake (100%)	1060	1730	2670	16	11.6
Pongamia cake (50%) + RDF (50%)	1320	1850	3150	18	12.1
RDF (100%)	1200	1620	2930	16	11.9
Farmer's practice	1180	1590	2800	15	11.7
General mean	1190	1700	2887	16.5	11.8
SEM±					
Main plot	2.44	2.85	1.34	0.23	0.12
Sub-plot	2.05	3.87	1.91	0.13	0.18
Interaction	3.0	5.48	2.71	0.19	0.26
CD at 0.05					
Main plot	11.0	12.8	6.01	1.03	NS
Sub-plot	6.1	11.5	5.68	0.39	NS
Interaction	8.6	NS	8.04	0.55	0.77

PC, N release would be slower than the mineral fertilisers and absolute N recovery could be far less, however, yield benefits are several folds due to non-N benefits from the *Pongamia* cake.

P Fertiliser Equivalent Yield

P-fertiliser equivalent values were also calculated using FP wherein 57.5 kg P_2O_5 was applied. In case of PC applied @ 3000 kg ha^{-1} only 27.6 kg P_2O_5 ha^{-1} was applied and the yield was equivalent to 115.3 kg P_2O_5 ha^{-1} using FP as control. Similar was the case in case of PC @ 1500 kg ha^{-1}, 100 kg DAP and 100 kg urea ha^{-1}, total P applied was 60 kg P_2O_5 ha^{-1}, however yield benefits were higher with 74.5 kg P_2O_5 ha^{-1} equivalent. In case of mineral fertiliser treatment with 92 kg P_2O_5 ha^{-1} with the yield benefits of 68.5 kg P_2O_5 ha^{-1} equivalent were observed.

Discussion

Results indicate a widespread deficiency of macro and micronutrients in farmers' fields in the semi-arid regions of India, due to low organic matter additions (6) and depletion under continuous cropping without application of these plant nutrients (15). Use of *Pongamia* cake has provided essential plant nutrients for crop production in addition to organic carbon content (5, 1, 22, 25).

Analysis of income and investment revealed that to accrue an additional income of Rs. 17080 ha^{-1} over FP, the treatment 3000 kg PC ha^{-1} needed additional investment of Rs. 8390 ha^{-1} in production of cotton **(Table 4)**. The additional B:C ratio in case of *Pongamia* cake treatment in production of this crop was 2.04. Considering these results for soybean, maize and cotton, it indicated an urgent need for enabling policies to promote use of organic sources of nutrients.

Use of *Pongamia* seed cake as a source of plant nutrient for soybean, maize and cotton is a environment-friendly and sustainable fertility management option. Although, use of *Pongamia* cake is an economically viable proposition, it needs considerable additional investment by the farmers @ Rs. 8390 ha^{-1} in case of cotton, Rs. 1050 ha^{-1} in soybean and Rs. 2875 ha^{-1} in maize production, which will be difficult for the resource poor farmers in the semi-arid tropics. Use of organic fertilisers would not only benefit the environment but also provide better resilience and coping ability to short drought spells during the crop growing period (2, 9, 11, 4). As large wasteland areas are planted with *Pongamia* for biodiesel production in the country, provision of subsidies for use of seed oil cake as source of plant nutrient will be a win-win proposition for the farmers, for the oilseed cake producers, and also for environment (21).

Application of micro and secondary nutrients increased crop yields by overcoming hidden hunger of the crops grown in farmers' fields (15, 24, 20). Yields of soybean, maize and cotton were significant and treatments receiving nitrogen through *Pongamia* cake had higher values, which could be due to slow release of N and its availability over a prolonged period (16, 17, 18) and also

Table 7 – Grain yield of soybean as influenced with sources of nitrogen 2004 and 2005

Treatment	Yield (kg ha^{-1})			% increase over FP
	Kharif 2004	*Kharif* 2005	Mean	
Pongamia cake (100%)	1530	1730	1630	18.5
Pongamia cake (50%) + RDF (50%)	1845	1850	1845	34.2
RDF (100%)	1650	1620	1635	18.9
Farmer's practice (FP)	1160	1590	1375	-
SEM±	82.0	39.1	-	-
CD at 0.05	262.3	114.0	-	-

observed by Patro and Sahu (14) in case of rice.

Based on the studies, it can be inferred that the *Pongamia* cake, which is available locally and in large quantities with increasingly larger area under cultivation of *Pongamia* for biodiesel production can serve as one of the alternative sources of plant nutrients.

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