Vol. 14, No. 1, pp. 10-21 (2014)
Journal of Agricultural Physics
ISSN 0973-032X
http://www.agrophysics.in

Research Article

Use of Paper Mill Sludge as an Alternative Liming Material and its Impacts on Light Interception, Radiation Utilization Efficiency of Groundnut in Acid Soils of Eastern India

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ABSTRACT

Acid soils affect the productivity and radiation interception in crops directly or indirectly by influencing the availability of plant nutrients, crop growth and biomass. Thus, the maintenance and management of acid soils are very much important to obtain higher productivity of the crop on sustainable basis. In this study, possibility of using low cost liming materials like paper mill sludge (PMS) to ameliorate acid soil was investigated and its impacts on productivity, light interception, radiation utilization efficiency of groundnut were assessed under tropical monsoon climate of eastern India. The PMS used in this study contained 32.5% calcium carbonate which was applied at different rates *viz*., 20, 30, 40, 50 and 60% of lime requirements (LR), 4-5 weeks before sowing of the crop. Results were compared with control (no lime treatment, 0% LR). The PMS enhanced soil pH, nutrient availability, biomass, leaf area and yield and in turn, it increased light interception, radiation use efficiency significantly when applied up to 50% LR. No significant effect on crop growth, water productivity, light interception were observed when it was applied at 60% LR.

Key words: Paper mill sludge, Lime requirements, Light interception, Acid soil, Groundnut

Introduction

Productivity of groundnut on acid soils is low (850 kg ha^{-1}) due to low pH, cation exchange capacity and available nutrients. Acidic soil (pH < 6.5) affects plant growth by influencing availability of nutrients, particularly phosphorus, Ca, Mg and micronutrients like Mo, B and Zn, reducing microbial activity and creating toxicity of Fe and Mn (Sumner *et al.,* 1991; Sumner and Noble, 2003). The maintenance and management of these soils are important to obtain higher resource use efficiency and productivity of the crop on sustainable basis (Bolan *et al.,* 2003; Anetor and Ezekiel, 2007; Brown *et al.,* 2008; Caires *et al.,* 2008). Limestone is the most common liming material used to ameliorate acid soils. However, small and marginal farmers of eastern India can not afford to purchase lime as pure $CaCO_3$ (or $MgCO_3$) because of high cost. Alternative cheap sources of liming materials like paper mill sludge (PMS), as bi-products of paper mill that contains $CaCO_3$, can be used (Torkashvand *et al.,* 2010; Kar *et al.,* 2010) but the quantity of required PMS depends on the paper manufacturing processes, soil type, crop species and cultivars (Noble and Hurney, 2000; Caires *et al.,* 2005).

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Growth and yield of a crop under a particular management system are largely determined by nutrient availability in soils as well as by PAR interception, efficiency of conversion of intercepted radiation into dry matter and partitioning of dry matter to grain yield (Figuerola and Berlinger, 2006; Kar *et al.,* 2014). Acid soils create nutrient stress in plant, reduce crop growth and thus reduce radiation interception, its conversion efficiency and partitioning of dry matter into grain (Quangi *et al.,* 2008). Hence, the objective of this study was set to evaluate the impacts of different application rates of PMS on soil properties, water productivity, radiation interception and its utilization efficiency of rainfed groundnut on upland acid soil.

Materials and Methods

Study area

On-farm trial was carried out during 2007 to 2009 rainy seasons in a representative acid soil of eastern India: Bhimda, Badasahi block, Mayurbhanj district, Orissa (Longitude: 86°44′; Latitude: 21°57′). About 80% of the farm families of the area are marginal/small with an average land holding <2 ha. The climate of the study area is hot-humid and of tropical monsoon type. The mean maximum temperature of 42 °C occurs in the month of May and minimum temperature occurs in December (8 °C). The mean annual rainfall is 1590 mm, 80% of which occurs due to south-west monsoon (June to September). During this time, farmers of the region grow groundnut on rainfed upland which are acidic in nature (pH ranged from 4.9 to 5.1), although productivity is very low.

Treatments and crop management

The groundnut crop cv. "TMV-2" was sown in 3 years on 28th June 2007, 25th June, 2008 and 1st July 2009 keeping the plant to plant distance of 15 cm and row spacing of 30 cm following standard package of practices. Nitrogen, phosphorus and potassium were applied @ 20, 50, 50 kg ha^{-1} in the form of urea, single super phosphate and muriate of potash, respectively. Six treatments *viz*., no paper mill sludge (0% LR); PMS @ 20% LR (20% LR); PMS @ 30% LR (30% LR); PMS @ 40% LR (40% LR); PMS @ 50% LR (50% LR); PMS @ 60% LR (60% LR) were imposed in randomized block design with 3 replications. The individual plot size was 4 m × 3 m. The PMS was applied every year in ploughed layer, 4-5 weeks before sowing of groundnut. Observations like date of occurrence of important phenological stages, biomass, leaf area index, yield and yield components, as influenced by different rates of PMS were recorded.

Five plants were collected at important phenological stages for leaf area index and biomass analysis. A developmental stage was recorded when 50% of the plants in a given plot were reached at that stage. Harvesting was done from the central rows for analysis of pod and grain yield.

The leaf area was measured using the following relationships.

$$\text{Leaf area index (LAI)} = \frac{\text{Sum of area of all leaves}}{\text{Field area where the leaves were collected}}$$

Soil sampling and analysis

Initial soil properties (at 0-0.15, 0.15-0.30 and 0.30-0.45 m soil depths) of experimental field before starting of experiment are mentioned in Table 1. Soil samples at 0-0.20 m depth were also collected before harvesting of the crop in each season to assess the change in soil properties after application of PMS. Samples were air-dried and ground to pass through 2 mm sieve for analysis. The bulk density and saturated hydraulic conductivity were estimated using core sampling methods. Chemical properties like soil organic carbon, available macro-nutrients (N, P and K), pH, EC were estimated using standard procedure (Jackson, 1973). Particle size distribution (clay, silt and sand content) was determined by hydrometer method. The pH (soil:water=1:2.5) was determined with digital pH meter (Jackson, 1973) and cation exchange capacity (CEC) was determined by the neutral 1N ammonium acetate method. Organic carbon and available nitrogen was determined using Walkley and Black (1934)

Table 1. Initial properties of the soil of the experimental field at different depths

Soil parameters	Soil profile depth (m)		
	0-0.15	0.15-0.30	0.30-0.45
Permanent wilting point (m^3m^{-3})	0.095	0.098	0.108
Field capacity (m^3m^{-3})	0.281	0.295	0.281
Available water capacity (m^3m^{-3})	0.156	0.170	0.163
Hydraulic conductivity (cm h^{-1})	24.5	13.2	7.80
Bulk density (Mg m^{-3})	1.42	1.44	1.46
Organic carbon (g kg^{-1})	5.7	4.8	4.6
Clay (%)	23.8	26.3	27.3
Silt (%)	13.4	15.6	18.9
Sand (%)	62.8	58.1	53.8
pH in water	4.9	5.0	5.1
Ca (meq 100 g^{-1} of soil)	2.15	2.19	2.25
Mg (meq 100 g^{-1} of soil)	0.85	0.87	0.88
Na (meq 100 g^{-1} of soil)	0.12	0.14	0.16
Al^{3+} (meq 100 g^{-1} of soil)	1.25	1.20	1.22
CEC (meq 100 g^{-1} of soil)	6.95	7.05	7.18
Base saturation (%)	42.9	41.3	44.5
Exchangeable acidity (%)	43.6	44.6	44.9

and alkaline potassium permanganate method, respectively. The lime requirement of surface soils (0-0.20 m) was determined using Shoemaker *et al*. (1961). The chemical and physical properties of the applied paper mill sludge (PMS) were also analyzed using standard procedures (Jackson, 1973). The PMS in this study had pH (1:2.5) of 8.23; EC of 0.20 dS m^{-1}; average Ca and Mg of 7.2 meq100g^{-1} soil, $CaCO_3$ equivalent of 30%, organic C of 25%; total N of 0.87%, P_2O_5 of 0.20%, K of 0.14% and Na (water extract) of 0.10%.

Intercepted photosynthetically active radiation (IPAR) and radiation utilization efficiency (RUE)

The percentage light interception or IPAR (400-700 nm) was derived by measuring the incident radiation above the canopy and that transmitted to the ground below the canopy by a 1-m long quantum light bar (light transmission meter, EMS-7) as per the following relationship.

$$I_i = I_o - I_{rc} - I_t + I_{rg} \quad \ldots(1)$$

I_i (%) by the canopy= ($I_i/I_o \times 100$)

I_i = Intercepted PAR (IPAR) by the canopy

I_o = Incident PAR on the canopy

I_{rc} = Reflected PAR by the canopy

I_t =Transmitted PAR through the canopy

I_{rg} = Reflected PAR from the ground

Measurements of radiation at ground level were taken by placing the linear sensor diagonally across the inter-row space with the ends of the sensor coinciding with the centre-line of the rows. All measurements were performed at 10 to 14 h in a clear day at intervals of 7–14 days depending on weather conditions.

The rate of increase of biomass density, B (g m^{-2}), is proportional to the absorbed photosynthetically active radiation, APAR (MJ m^{-2} d^{-1}) (Monteith, 1977).

$$\frac{dB}{DT} = \varepsilon \text{ APAR} \quad \ldots(2)$$

Where ε is the radiation use efficiency (RUE) (g MJ^{-1}) (Pitman, 2000).

In this study, the dry biomass at different stages were measured and corresponding accumulated IPAR were computed to estimate the RUE using the following relationship:

$$\varepsilon\ (g\,MJ^{-1}) = \frac{\text{Cumulative biomass}\,(g\,m^{-2})}{\text{Cumulative IPAR}\,(MJ\,m^{-2})} \qquad \ldots(3)$$

Daily intercepted solar radiation (MJ m^{-2}) by the crops was obtained as the product of daily incident solar radiation, measured at the agro-meteorological station and the percentage of mid-day light interception. The mean daily values of IPAR were calculated by multiplying daily intercepted solar radiation with 0.48 following Monteith (1972).

Crop water requirements and water productivity

Under unlimited water supply, crop water requirements for a given crop, i (CWR_i) is equal to the potential evapotranspiration ($PETc_{i)}$ of that crop , Thus,

$$CWR_i(mm) = PET_{C_i}(mm) = \sum_{t=1}^{m}\left(ET_{0t} \times K_{ct}\right)mm \qquad \ldots(4)$$

ET_{0t} is the reference crop evapotranspiration (ET) of the location for the day t (mm)

K_{ct} is the crop coefficient for the day t

The ET_0 was determined using FAO Penman-Moteith method and K_c at various stages of the crop was taken from Irrigation and Drainage Paper No. 56.

Crop water productivity in terms of seasonal crop water use (SCWU) under different PMS management practices was computed as:

$$WP_{SCWU}(kg\,m^{-3}) = \frac{Crop\ yield\,(kg)}{SCWU\,(m^{-3})} \qquad \ldots(5)$$

Since effective rainfall was more than that of crop water requirements, it was assumed that seasonal crop water use was equal to potential evapotranspiration (PET_c) or crop water requirement (CWR).

Statistical analysis

All data were statistically analyzed by standard analysis of variance (ANOVA) technique as per the procedure suggested by Gomez and Gomez (1984). Wherever treatments were found significant based on F-test, least square differences (LSDs) were calculated using SAS (statistical analysis system) software (v 9.2).

Results and Discussion

Initial basic properties of the soil profile

Soils within the experimental area were largely homogeneous. The texture was sandy loam with clay content varied from 23.8 (0-0.15 m) to 27.3% (0.30-0.45 m) (Table 1). The bulk density was 1.42 Mg m^{-3} at 0-0.15 m depth and at 0.30-0.45 m depth, it became 1.46 Mg m^{-3}. The soil pH was slight to moderately acidic (pH 4.9 to 5.1) and no salt was detected. The soil organic C content ranged from 5.7 (0-0.15 m) to 4.8 (0.15-0.30 m) g kg^{-1}. The CEC was 6.95 to 7.18 meq 100 g^{-1} soil at different depths. Percentage base saturation was low (41.3-44.5%).

Impact of PMS on dry biomass, leaf area index and grain yield

The effects of PMS on grain weight, pod weight, haulm weight and total biomass are presented in Fig. 1 (a,b). Dry matter yield increased significantly ($P<0.05$) in PMS-treated plots from 0 to 50% LR. Total biomass (pod yield+haulm yield) was 4076, 4269, 4523, 4850, 5359 and 5455 kg ha^{-1} under 0, 20, 30, 40, 50 and 60% LR, respectively. Application of 60% LR produced greater total biomass but not significantly different from 50% LR. No difference in biomass was observed between first two years but in 3rd year, biomass was significantly higher. Peak LAI values of 3.61, 3.80, 4.32, 4.61, 4.83 and 5.06 were recorded under 0, 20, 30, 40, 50, and 60% LR, respectively (Fig. 2a). The years had no significant effect on peak LAI (Fig. 2b).

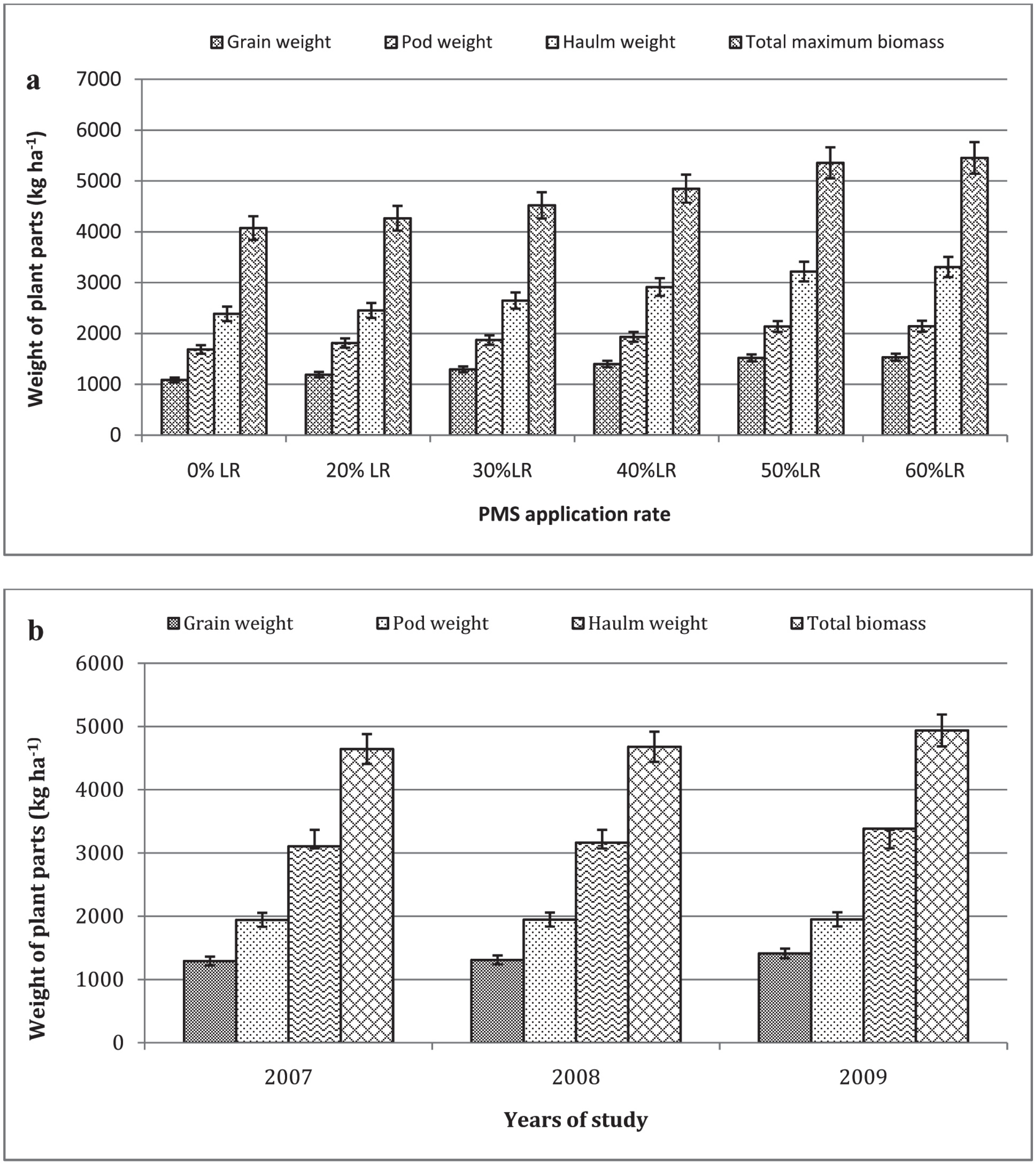

Fig. 1. Grain, pod, and haulm and weight and maximum biomass production under different (a) PMS application rates and (b) study years

No significant effect of different doses of PMS on yield and yield attributes of groundnut was recorded. Average over years, the lowest grain yield (1063 to 1126 kg ha^{-1}) was obtained under 0% LR whereas, the highest grain yield of 1493 to 1618 kg ha^{-1} was obtained under 60% LR, which was at par with yield under 50% LR (Table 2). Application of PMS @ 20% LR increased grain yield by 10.1-18.1%. The yield increase with 60% LR was 47.1, 58.1 and 67.2% over 0% LR in the 1st, 2nd and 3rd year, respectively; no significant difference was observed between 50 and 60% LR in either of the years.

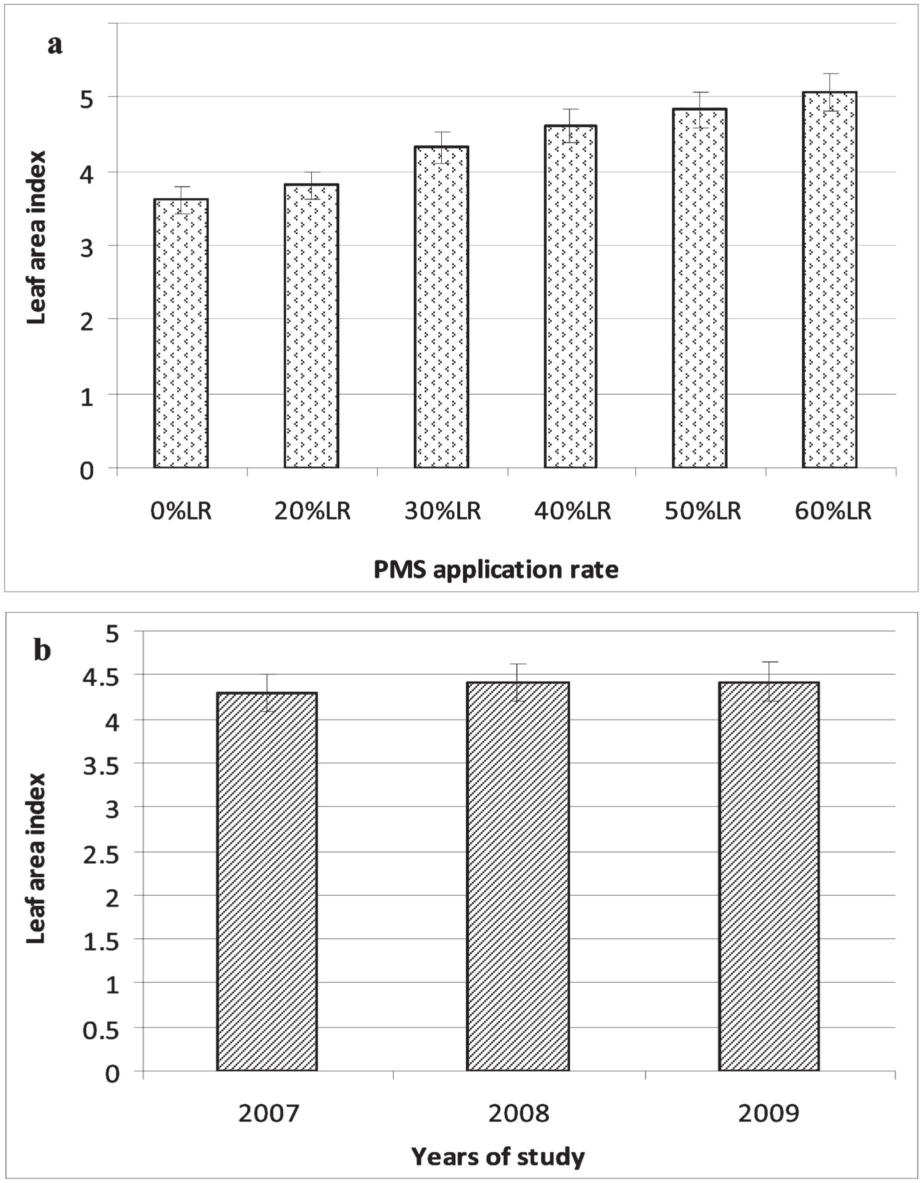

Fig. 2. Peak leaf area index as influenced by (a) paper mill sludge (PMS) application rates and (b) study years

Light interception and radiation utilization efficiency

Peak values of IPAR were influenced by PMS application rates and years of study (Fig. 3 a&b, respectively). The peak IPAR was the lowest (66.6%, average of 3 years) when no PMS was applied. Peak IPAR values were 77, 81, 85, 88, and 89% under 0, 20, 40, 50 and 60% LR treatments. Values are not significantly different between 50 and 60% LR. The increase in IPAR with higher levels of PMS was due to better crop growth, which was evidenced by maximum plant height, LAI and total dry matter. The IPAR was more closely related with LAI ($R^2 = 0.718$) than biomass ($R^2 = 0.68$) (Fig. 4 and 5).

The radiation utilization efficiency has linear relationships with biomass and accumulated IPAR (Fig. 6) with R^2 of 0.82. The RUE (in terms of total biomass) at different growth stages under different PMS application rate is presented in Fig. 7. The RUE was progressively higher up to beginning of seed filling stage, and became lower

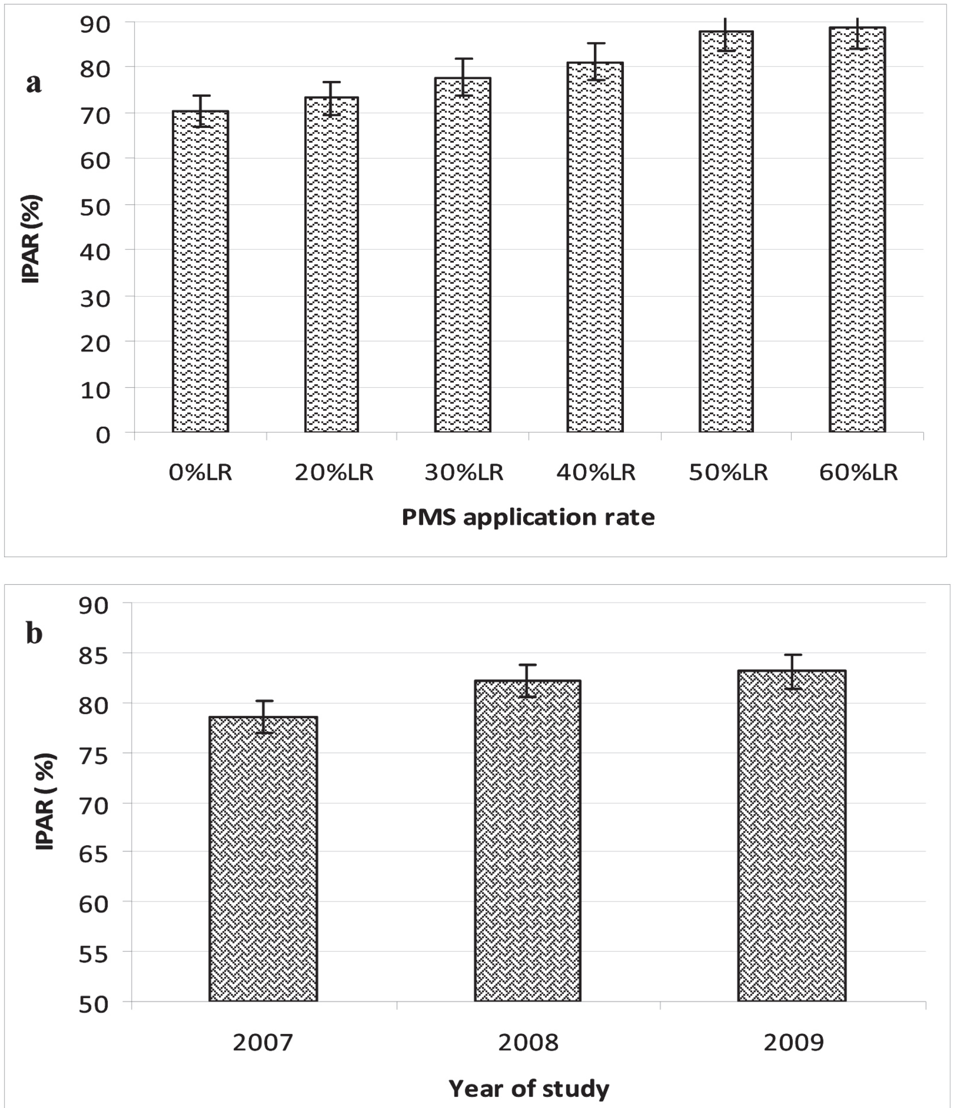

Fig. 3. Peak IPAR as influenced by (a) paper mill sludge (PMS) aplication rate (b) study years

during seed filling. The highest RUE (1.58 g MJ^{-1}) was obtained in 60% LR, but not significantly different from 50% LR (1.56 g MJ^{-1}). The peak RUE was less when no or lower dose of PMS were applied. Averaged over application rates, RUE of 1.30, 1.32 and 1.38 g MJ^{-1} were recorded in 2007, 2008 and 2009, respectively. Similar observation was also made by Gallo *et al*., 1993 who found that the improved RUE appeared to be mainly due to the changes in LAI and accumulation of dry matter before anthesis in PMS treated plots.

Working on wheat, Fang *et al.* (2006) found that after anthesis, yield capacity is mainly determined by photosynthesis of the green flag leaves and spikes and PAR does not seem to be a limiting factor. Therefore, the improved ability of these plant parts to transform light energy into dry matter might be very important for increased dry matter production (Monteith, 1977; Sinclair and Muchow, 1999).

Impacts of PMS on water productivity

The water productivity was also enhanced when the soil was ameliorated with PMS. Lowest productivity of 0.262 to 0.283 kg m^{-3} was achieved when no PMS was applied. The highest productivity of 0.369 to 0.407 kg m^{-3} was seen

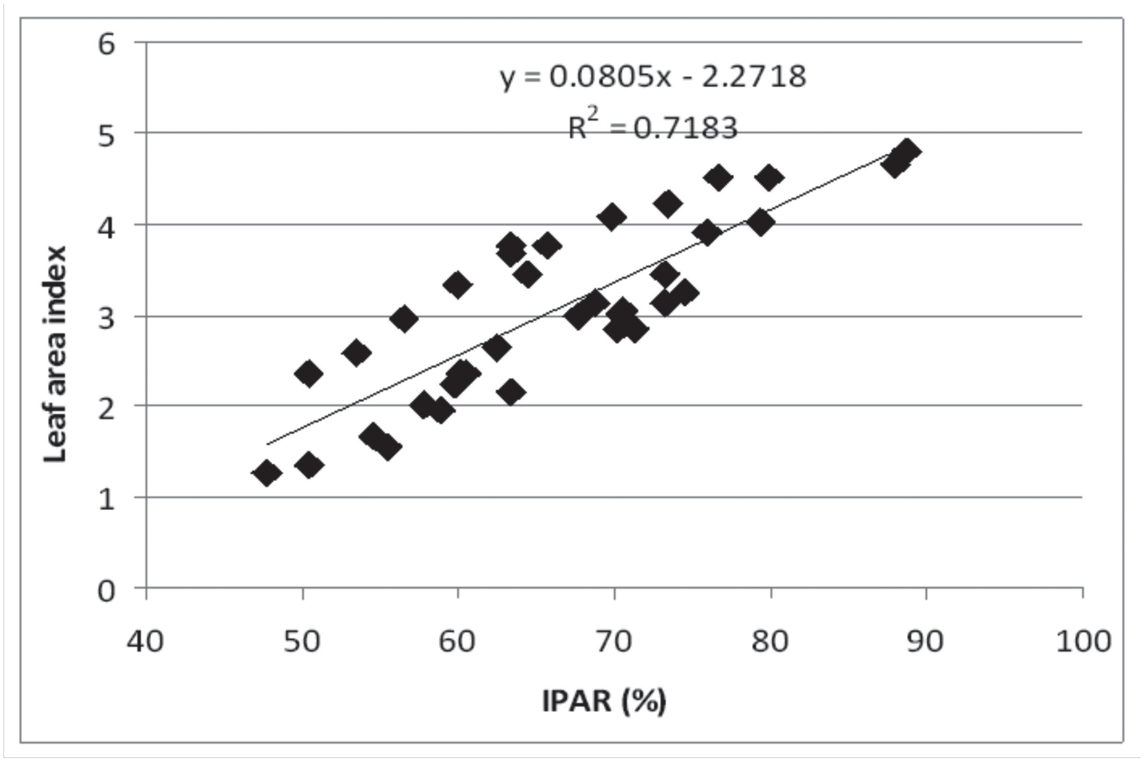

Fig. 4. Relationship between leaf area index and IPAR

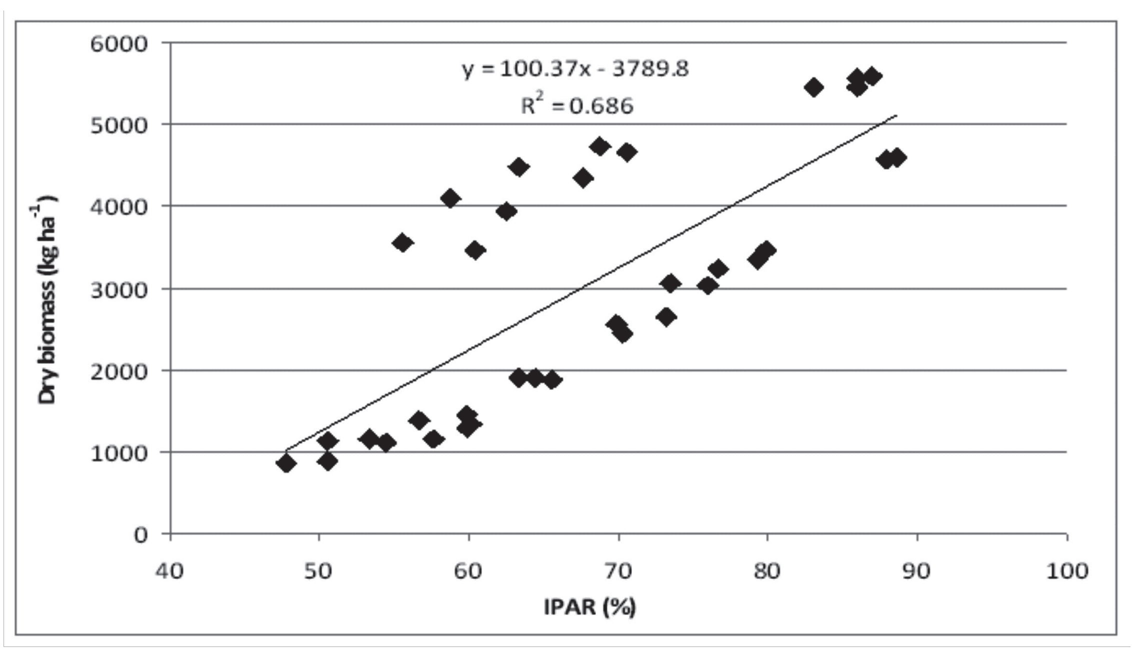

Fig. 5. Relationship between dry biomass and IPAR

under 60% LR treatment, at par with 50% LR (Table 2). The increase of water productivity in PMS treated plots was attributed to mainly increased grain yield of the crop. This suggests that the water productivity of a crop to a large extent is influenced by agricultural management rather than by the agro-climate under which the crop is grown. This provides an opportunity to improve yield and water productivity through different improved agro-management practices.

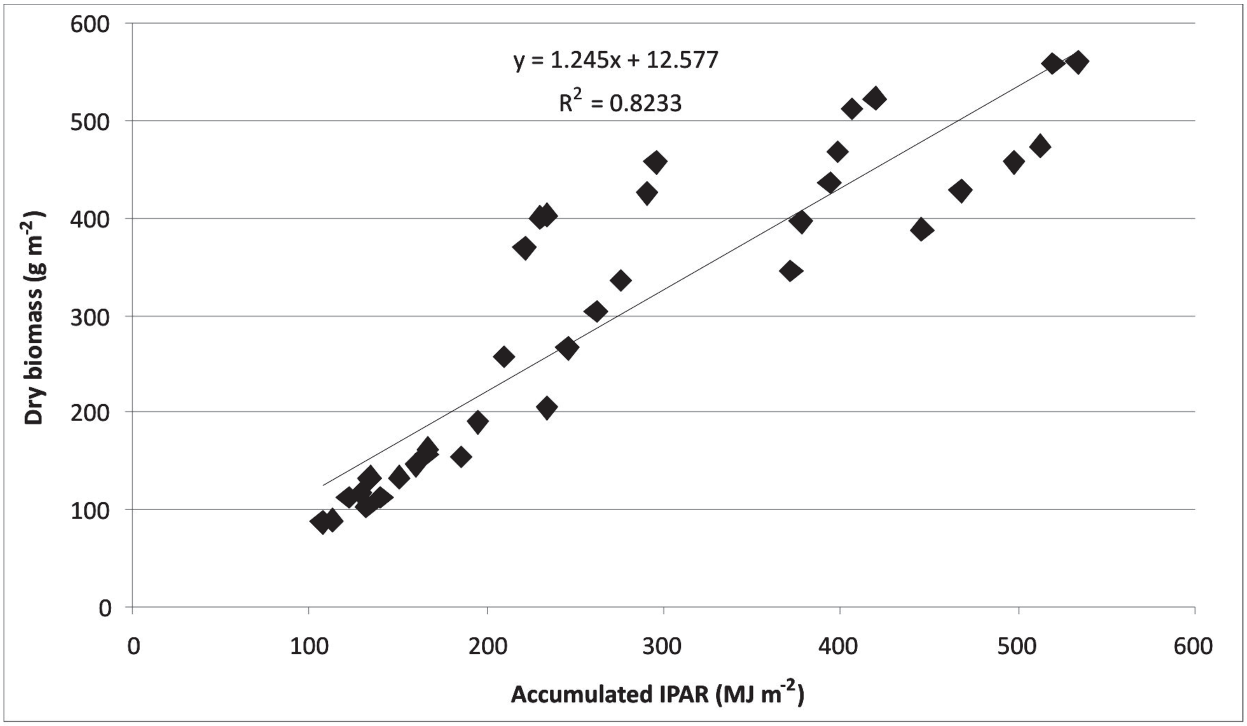

Fig. 6. Relationship between dry biomass and accumulated IPAR

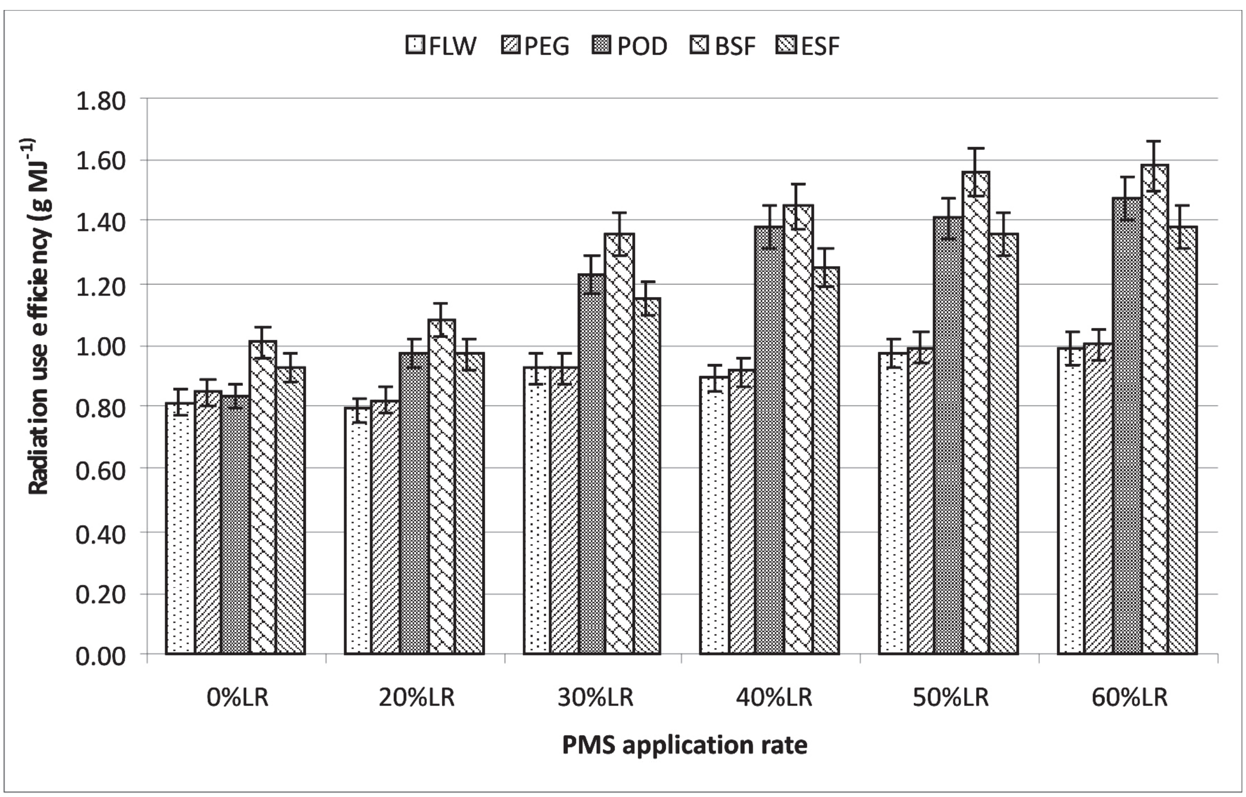

Fig. 7. Radiation use efficiency as influenced by paper mill sludge application rate

Impact of PMS on soil pH

The crop growth and productivity were enhanced through PMS which might be attributed to improvement in soil physico-chemical properties (Fig. 8a). Increase in pH was recorded from 4.9 (control) to 6.2 (60% LR treatments) at 0-0.15m depth. Increase in pH was proportional to the rates up to 50% LR. No significant difference was seen between 1st and 2nd year, but in 3rd year, pH was significantly higher (Fig. 8 b).

Conclusions

Results indicate that PMS can be used as a cheap source of liming material. However, further

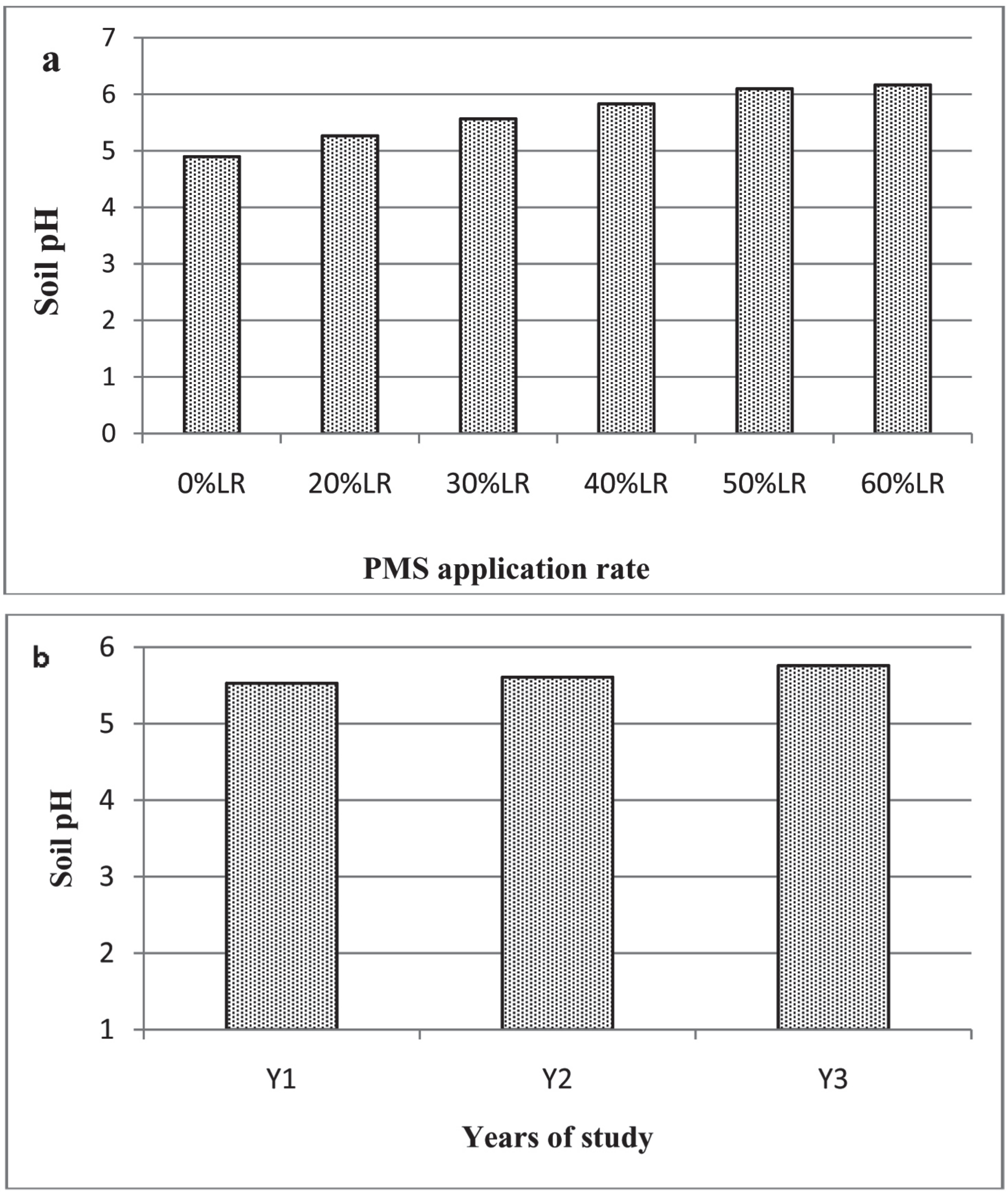

Fig. 8. Variation of soil pH (a) due to application of dfferent doses of PMS and (b) in different study years (Y1, Y2 and Y3 are year 2007, 2008 and 2009)

Table 2. Grain yield and water productivity of groundnut as affected by paper mill sludge doses in different years

Paper mill sludge	Yield ($kg\ ha^{-1}$)	CWR (mm)	WP_{CWR} ($kg\ m^{-3}$)
	1st year		
0% LR	^{E}1063	405	^{E}0.262
20% LR	^{D}1166	405	^{D}0.288
30% LR	^{C}1238	405	^{C}0.306
40% LR	^{B}1317	405	^{B}0.325
50% LR	^{A}1483	405	^{A}0.366
60% LR	^{A}1493	405	^{A}0.369
Mean	1293	405	0.319
CV (%)	17.35		
	2nd year		
0% LR	^{E}1073	410	^{E}0.262
20% LR	^{D}1163	410	^{D}0.284
30% LR	^{C}288	410	^{C}0.070
40% LR	^{B}1367	410	^{B}0.333
50% LR	^{A}1479	410	^{A}0.361
60% LR	^{A}1496	410	^{A}0.365
Mean	1311	410	0.320
CV (%)	16.37		
	3rd year		
0% LR	^{E}1126	398	^{E}0.283
20% LR	^{D}1246	398	^{D}0.313
30% LR	^{C}1362	398	^{C}0.342
40% LR	^{B}1522	398	^{B}0.382
50% LR	^{A}1603	398	^{A}0.403
60% LR	^{A}1618	398	^{A}0.407
Mean	1413	398	0.355
CV (%)	17.68		

CWR = Crop water requirements, WP_{CWR}= Water productivity in terms of crop water requirements; Values in the column followed by same letters are not significant at 5% probability as per the Duncan's Multiple Range Test (DMRT).

Significance for yield and water productivity: PMS = **; YEAR = *; PMS * YEAR = NS (** and * Significant at 5 and 1% probability level, respectively, NS- Non significant)

studies are required to establish the optimum rates under different crops and also to study the residual and environmental impact of its application to soils.

References

Anetor, M.O. and Ezekiel, A.A. 2007. Lime effectiveness of some fertilizers in a tropical acid alfisol. University of Ibadan, Ibadan, Nigeria.

Bolan, N., Adriano, D.C. and Curtin, D. 2003. Soil acidification and liming interactions with nutrient and heavy metal transformation and bioavailability. *Adv. Agron.***78**: 215-272.

Brown, T., Koenig, R., Huggins, D., Harsh, J. and Rossi, R. 2008. Lime effects on soil acidity, crop yield and aluminum chemistry in inland Pacific Northwest direct-seed cropping systems. *Soil Sci. Soc. Am. J.* **72**: 634-640.

Caires, E.F., Alleoni, L.R.F., Cambri, M.A. and Barth, G. 2005. Surface application of lime for crop grain production under a no-till system. *Agron. J.* **97**: 791-798.

Caires, E.F., Pereira Filho, P.R.S., Zardo Filho, R. and Feldhaus, I.C. 2008. Soil acidity and aluminium toxicity as affected by surface liming and cover oat residues under a no-till system. *Soil Use Manage.* **24**: 302-309

Fang, Q.X., Chen, Y.H., Li, Q.Q., Yu, S.Z., Luo, Y., Yu, Q. and Ouyang, Z. 2006. Effects of soil moisture on radiation utilization during late growth stages and water use efficiency of winter wheat. *Acta Agron. Sinica* **32**: 861-866.

Figuerola, P.I. and Berlinger, P.R. 2006. Characterization of the surface layer above a row crop in the presence of local advection. *Atmosfera* **19**: 75-108.

Gallo, K.P., Daughtry, C.S.T. and Wiegand, C.L. 1993. Errors in measuring absorbed radiation and computing crop radiation use efficiency. *Agron. J.* **85**: 1222-1228.

Gomez, K.A. and Gomez, A.A. 1984. Statistical Procedures for Agricultural Research with Spatial Emphasis on Rice. International Rice research Institute, Philippines.

Jackson, M.L. 1973. Soil Chemical Analysis. Prentice-Hall, New Delhi.

Kar, G., Sahoo, N. and Kumar, A. 2010. Integrated approach of crop diversification, soil and rainwater management for enhancing agricultural productivity of rainfed acidic land. Res. Bull. No. 47, Directorate of Water Management, Bhubaneswar, Odisha. pp. 40.

Kar, G., Kumar, A., Sahoo, N. and Mohapatra, S. 2014. Radiation utilization efficiency, latent heat flux, and crop growth simulation in irrigated rice during post-flood period in east coast of India. *Paddy Water Environ.***12**: 285-297.

Monteith, J.L. 1972. Solar radiation and productivity in tropical ecosystems. *J. Appl. Ecol.* **9**: 747-766.

Monteith, J.L. 1977. Climate and efficiency of crop production in Britain. *Phil. Trans. Royal Soc., London* **281**: 277-94.

Noble, A.D. and Hurney, A.P. 2000. Long-term effects of lime additions on sugarcane yield and soil chemical properties in North Queensland. *Expt. Agric.***36**: 397-413.

Pitman, J.I. 2000. Absorption of photosynthetically active radiation, radiation use efficiency & spectral reflectance of Bracken [*Pteridium aquilinum* (L.) Kuhn] canopies. *Annals Bot.* **85** (Supplement B): 101-111.

Quangi, L., Yuhai, C., Mengyu, L., Xunbo, Z., Songlie, Y. and Baodi, D. 2008. Effects of irrigation and planting patterns on radiation use efficiency and yield of winter wheat in north China. *Agric. Water Manage.* **95**: 469-476.

Shoemaker, H.E., McLean, E.O. and Pratt, P.F. 1961. Buffer methods of determining lime requirements of soils with appreciable amounts of extractable aluminum. *Soil Sci. Soc. Amer. Proc.***25**: 274-277.

Sinclair, T.R. and Muchow, R.C. 1999. Radiation use efficiency. *Adv. Agron.* **65**: 215-265.

Sumner, M.E., Fey, M.V. and Noble, A.D. 1991. Nutrient status and toxicity problems in acid soils. In: Ulrich, B., Sumner, M.E. (Ed.), Soil Acidity, Springer, New York. pp. 149-182.

Sumner, M.E. and Noble, A.D. 2003. Soil acidication: The world story. In: Rengel Z. (Ed.), Handbook of soil acidity, Marcel Dekker, New York. pp. 1-28.

Torkashvand, A.M., Haghighat, N. and Shadparvar, V. 2010. Effect of paper mill lime sludge as an acid soil amendment. *Sci. Res. Essays* **5**: 1302-1306.

Walkley, A. and Black, I.A. 1934. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci.* **37**: 29-38.

Received: 18 February 2014; Accepted: 21 June 2014