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# Seasonal variations in organic carbon and nutrient availability in arid zone agroforestry systems

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**Abstract:** Investigations were carried out on the temporal variations in organic carbon and nutrient availability in arid zone agroforestry systems. Organic carbon, extractable P, $NO_3$-N and $NH_4$-N were determined in top 20 cm soil layer under three year old agroforestry systems comprising *Emblica officinalis* Gaertn., *Hardwickia binata* Roxb. and *Colophospermum mopane* (Kirk ex Benth.) Kirk ex J. Leonard tree species with *Vigna radiata* (L.) as intercrop and a control. The temporal variations in soil organic carbon (SOC) ($P<0.01$), extractable P ($P<0.01$) and soil available N ($P<0.01$) were significant. Increased SOC coincide with the periods of litter production and the harvest of agricultural crop. The levels of $PO_4$-P, $NO_3$-N and $NH_4$-N increased during summer. However, the increase in the concentration of some nutrients was also observed in winter months which may be attributed to either plant senescence or change in the soil biological processes. Higher availability of $NH_4$-N in soil under *E. officinalis* indicated relatively lower rate of nitrogen mineralization than under the legume species *H. binata* and *C. mopane* soil. Approximately two to three fold higher concentration of $NH_4$-N was observed during monsoon (cropping period) and which probably was due to utilisation of nitrate by the agricultural crops and/or due to nitrogen fixation by *V. radiata* and moisture controlled net-nitrifications.

**Resumen:** Se llevaron a cabo investigaciones sobre las variaciones temporales en el carbono orgánico y la disponibilidad de nutrientes en sistemas agroforestales de zonas áridas. El carbono orgánico, P extraíble, $NO_3$-N y $NH_4$-N, fueron determinados a 20 cm de la capa del suelo bajo sistemas agroforestales de tres años de edad que tenían las especies arbóreas *Emblica officinalis* Gaertn., *Hardwickia binata* Roxb. y *Colophosperum mopane* (Kirk ex Benth.) Kirk ex J. Leonard con *Vigna radiata* (L:) como intercultivo y un control. Las variaciones temporales en el carbono orgánico del suelo (COS) ($P<0.01$), P extraíble ($P<0.01$) y N disponible del suelo ($P<0.01$), fueron significantivas. El incremento en el COS coincide con los períodos de producción de hojarasca y la cosecha del cultivo. Los niveles de $PO_4$-P, $NO_3$-N y $NH_4$-N incrementaron durante el verano. Sin embargo, el incremento en la concentración de algunos nutrientes se observó también en los meses de invierno, lo cual puede atribuirse y sea a la senscencia de la planta o a los cambios en los procesos biológicos del suelo. La alta disponibilidad de $NH_4$-N en el suelo bajo *E. officinalis*, indicó una relativamente baja tasa de mineralización del nitrógeno que en el suelo bajo las leguminosas *H. binata* y *C. mopane*. Se observó una concentración más alta de $NH_4$-N aproximadamente de dos a tres veces mayor durante el monzón (período de cosecha), y el cual probablemente se debió a la utilización de nitratos y por los cultivos y/o debido a la fijación de nitrógeno por *V. radiata* y a las controladas nitrificaciones netas con humedad.

**Resumo:** Este estudo foi efectuado para avaliar as variações temporais do carbono orgânico e a disponibilidade em nutrientes em sistemas agroflorestais na zona árida. O carbono orgânico, o P extractável, $NO_3$-N e $NH_4$-N foram determinados na camada superior dos 20 cm de solo de sistemas agroflorestais compreendendo as espécies arbóreas *Embelica officianalis* Gaertn., *Hardwickia binata* Roxb. e *Colophospermum mopane* (Kisk ex Benth) Kirk ex J. Leonard com *Vigna radiata* (L.) como cultura associada e um controle. As variações temporais no carbono orgânico do solo (SOC) (P<0,01), no P extractável (P<0,01) e no N disponível no solo foram significativas. Um aumento no SOC coincide com os períodos de produção de folhada e de colheita da cultura agrícola. Os níveis de $PO_4$-P, $NO_3$-N e $NH_4$-N aumentaram durante o verão. Verificou-se, contudo, também, um aumento no teor de alguns nutrientes nos meses de inverno, o que pode ser atribuído quer à senescência das plantas quer a mudanças nos processos biológicos com sede no solo. Uma maior disponibilidade de $NH_4$-N no solo sob cultura de *E. officinalis* indicou uma menor taxa relativa de mineralização do azoto do que a verificada em solos com expécies leguminosas como a *H. binata* e *C. mopane*. Observou-se duas a três vezes maior concentração de $NH_4$-N durante a estação da monção (período de cultura) o que foi devido, provavelmente, à utilização dos nitratos por parte da cultura agrícola e/ou devido à fixação do azoto pela *V. radiata* e nitrificação líquida controlada pela humidade.

**Key words:** Agroforestry, arid region, seasonal variations, soil nutrients.

## Introduction

The practice of growing tree on cultivated land is quiet common in arid areas. The trees are deliberately and consciously planted and promoted on farmlands along with agricultural crops to enhance the long term sustainability and productivity. These trees provide an assurance to the farmers towards sustainable crop production in normal rainfall year, while in drought and famines years, they provide top feed for livestock (Saxena 1994). Besides yielding food, fodder, fuel, fruit and timber and providing shade for crops and animals, trees enhance soil fertility of agroforestry farms. The tree based agricultural systems are considered more efficient in nutrient cycling than many herbaceous systems because of the extensive and deeper root system of trees than the herbaceous species (Nair 1995). Soil fertility is maintained through decomposition of roots of trees and agricultural crops and litterfall which in turn increase organic matter and biological activity of the soil (Szott *et al.* 1991), enhancing soil nutrient status. Thus agroforestry systems promote closed nutrient cycling by taking up soil nutrients through tree roots and recycling them as litter, including root residue and helping to synchronize nutrient release with crop requirements by controlling the quality, timing and manner of addition of plant residue (Young 1991). Thus agroforestry has important effect on soil physical and chemical characteristics, rate of soil mineral cycling and the role of soil in long term storage of C and N. These processes are regulated by various parameters such as physical and chemical properties of litter, soil properties, climate and decomposer communities consisting of microorganisms and soil invertebrates (Upadhyay & Singh 1989). There are reports on litter production and nutrient cycling in agroforestry systems in himalayan region of India (Sharma *et al.* 1997). However, information on seasonal variations in available nutrients in arid soils is lacking. The present study was carried out to generate data on seasonal and temporal variations in available nutrients under different agroforestry systems in arid climate, so that the field operations could be so devised as to synchronize nutrient release and plant uptake in an agroforestry system.

*Hardwickia binata* Roxb., *Colophospermum mopane* (Kirk ex Benth.) Kirk ex J. Leonard and *Emblica officinalis* Gaertn. based agroforestry systems were selected for study. In these systems *H. binata* and *C. mopane* are the fodder yielder whereas *E. officinalis* produces fruit, a rich source of Vitamin C. The seasonal changes observed in the level of $NH_4$-N, $NO_3$-N, $PO_4$-P and organic matter under different agroforestry systems are compared and discussed.

## Materials and methods

### *Study area*

The study was conducted in an arid area of Rajasthan, India, at the experimental field of AFRI, Jodhpur, located at 72° 03 E longitude and 26° 45 N latitude. Soil of the experimental site is coarse loamy, mixed, hyperthermic family of camborthids according to US soil taxonomy. Soil pH in top 20 cm soil layer, ranged from 8.02 to 8.29 in the planted area and from 8.38 to 8.45 in unplanted area. The bulk density of the soil was lower in planted area being 1.58 under *E. officinalis*, 1.61 under *H. binata* and 1.60 under *C. mopane*. It was higher (1.65) in unplanted area (control).

The climate of the area is dry tropical type with the mean annual rainfall 433 mm (nine years average from 1988 to 1996) falling mostly between July and September with very high (65%) coefficient of variation (Pant & Hingane 1988). Mean annual pan evaporation (1988-1996) was 2794 mm showing high water deficit. The mean monthly minimum temperature varied from 9.0°C to 29°C and the mean monthly maximum temperature from 23.8°C to 42.6°C during the experimental period.

### *Experimental design and soil sampling*

The study was started in December 1996, after the crop harvest and continued upto December 1997 in a two and half year old agroforestry plantation (initiated in July, 1994). The experiment comprised of three tree species forming different agroforestry systems with three replications. Each plot was of 20 m x 30 m in size with twenty four experimental plants at a spacing of 5 x 5 m. Different time period (sampling in different months) and the three species plus a control (unplanted area) comprising four plots, were taken as the main factors.

*Vigna radiata* was taken as the intercrop during July to October 1997. In each sub plot, one tree was randomly selected for sampling purposes. Soil samples from 0-20 cm soil depth were collected at 30 cm distance from each of the selected tree, using an auger of 50 mm diameter. Soil samples were also collected from control without plants to compare the changes in soil nutrient status in different tree based agroforestry systems. Soil samples were collected for one year during December 1996 to November 1997 so as to cover seasonal variability.

### *Sample preparation and analysis*

Air dried soil samples were sieved through a 2 mm mesh sieve and analysed for soil organic matter, $NO_3$-N, $NH_4$-N and extractable P following standard procedures (Jackson 1973). For analysis of available N ($NO_3$-N and $NH_4$-N), 10 g of dry soil was shaken with 50 ml of 2 M KCl for 30 minutes and then filtered with Whatmann filter paper. For estimating available soil P, 5 g dry soil was extracted with 0.5 M $NaHCO_3$ solution (Olsen's extraction) and filtered. Available $NO_3$-N, $NH_4$-N and $PO_4$-P were determined colorimetrically using Teacator model Enviroflow 5012 autoanalyser. Soil organic carbon (SOC) was determined by the partial oxidation method using potassium dichromate. Soil pH and electrical conductivity (EC) were determined in 1:2 soil : water suspension. Soil moisture was determined gravimetrically by oven drying method. Data were analysed using SPSS programme. Differences in soil parameters among the months were analysed using two way ANOVA with mean soil parameters as the dependent variables and the months and different plots as the main effect. Variations among the plots were tested as the error terms (Lindman 1992).

## Results and discussion

### *Soil organic carbon*

SOC varied significantly ($P<0.01$) with highest being in autumn (October) and lowest in summer. Accumulation of organic matter during autumn winter period has been observed in two Canadian soils (Darmaar *et al.* 1984). The decrease in organic carbon during cropping and late spring to summer resulted probably due to decomposition of organic matter owing to enhanced tillage activity, moisture availability and increased microbial population (Venkateswarulu & Aggrawal 1980) during monsoon. Decrease in SOC during summer (June) could be due to increased soil temperature (Raich 1983). Considering the plots, SOC was greatest under *C.mopane* (0.211%) followed by *H. binata* (0.204%), whereas, it was significantly ($P<0.01$) low in control (0.156%). Significantly higher SOC ($P<0.01$) in planted area (Shankarnarayan 1984) coincides with the periods of litter production from the tree species and soon after the crop harvest. Higher SOC in planted area than control could be attributed to addition of decomposable roots and litter from plants and root stubbles and leaves from agricultural crops (Shankarnarayan 1984).

### *Extractable phosphorous*

Extractable P was significantly ($P<0.01$) higher (13.54, ranged from 21.82 to 4.41 mg $kg^{-1}$) in planted area than the control (10.16 mg $kg^{-1}$) and was probably due to application of diammonium phosphate in 1996 crop season. The variations in available P between months and plots was significant. Ross *et al.* (1995) reported an increase in the availability of extractable P in fertilized plot. Pooled extractable P (three species and one control) was the highest in soil of *H. binata* followed by the soil of *E. officinalis*. Available P showed significant temporal variation ($P<0.01$) with maximum in summer and minimum in monsoon (crop period). Decline in available P during the cropping period might be attributed to its uptake by crop. Such type of variations were also observed in the dry tropical forests, where the size of the nutrient pool increased towards the end of the dry season, as plants senescence and show a decline in P content during the wet growing seasons (Singh *et al.* 1989). The winter increase in concentration of P has also been observed in a fertile pasture soil (Perrott *et al.* 1990) and in unfertilized plots (Ross *et al.* 1995). The decline in P during late autumn and spring is indicative of the autumn and spring flushes of plants growth (Searle *et al.* 1991). Low availability of P (Mean of all) in *H. binata* and *C. mopane* soil was believed to be due to higher P requirement of these species compared to *E. officinalis* (Sprent 1988). Low available P in control (unplanted) was probably due to the presence of *Tephrosia purpurea*, a nitrogen fixing species (Rao *et al.* 1998) showing luxuriant growth during the monsoon period and drying out during summer.

### *Nitrate-nitrogen*

Available nitrogen showed significant ($P<0.05$) seasonal variations. The data are in agreement with an earlier report on a dry tropical forest with a long dry season showing strong seasonal pattern in pool size of N and P (Roy & Singh 1995). It was believed to be controlled by changes in soil water content. Thus, the length and severity of the dry season play a critical role in soil nutrient recycling. $NO_3$-N varied significantly between plots and months (Table 2). In plots, it ranged from 1.71 to 8.25 mg $kg^{-1}$ soil in *E. officinalis*, 2.40 to 18.76 mg $kg^{-1}$ soil in *H. binata* and 1.83 to 16.38 mg $kg^{-1}$ soil in *C. mopane* compared to 1.43 to 6.55 mg $kg^{-1}$ soil in control ($P<0.05$). The concentration of $NO_3$-N was higher in planted area (5.36 mg $kg^{-1}$ under *C. mopane,* 5.16 mg $kg^{-1}$ under *H. binata* and 4.47 mg $kg^{-1}$ under *E. officinalis*) than control (4.02 mg $kg^{-1}$). The concentration of nitrate increased in planted area during January and was believed to be due to decrease in the rate of mobilization and uptake by the plant during winter. Some variations in concentration of $NO_3$-N during December, 1996 and May 1997 was believed to be due to growth of plant in these periods indicating an efficient utilization of $NO_3$-N by the plant. Browaldh (1997) observed higher concentration of $NH_4$-N and lower concentration of $NO_3$-N at closer distance of trees indicating an efficient uptake of nitrate and enhanced N-mineralization closer to trees. Comparing the plots, $NO_3$-N was higher under *H. binata* and *C. mopane* than under *E. officinalis* which in turn may be due to input of microbial fertilizer in the soil through N-fixing capability of *H. binata* and *C. mopane*. The input of microbial fertilizer in the soil through nodulation has already been reported (Basak & Goyal 1975).

### *Ammonical-nitrogen*

Extractable $NH_4$-N in soil varied from 0.86 to 8.02 mg $kg^{-1}$ (5.57 mg $kg^{-1}$) under *E. officinalis*, 0.98 to 8.37 mg $kg^{-1}$ under *H. binata* and from 1.03 to 8.15 under *C. mopane* compared to 2.47 to 13.02 mg $kg^{-1}$ in control. There were significant ($P<0.01$) seasonal variations in concentration of $NH_4$-N with the maximum being in June-September, 1997 and again in February-March. The dry season increase of $NH_4$-N pool was reported by Garcia-Mendez *et al.* (1991) in a highly seasonal dry tropical forest of Mexico. The higher concentration observed during the monsoon period from July to September was probably due to the low rate of nitrification which is inversely related to the soil moisture (Neill *et al.* 1995). Biological nitrogen fixation by the agricultural crop *Vigna radiata*, could also be the reason for increased $NH_4$-N concentration in this cropping period. The concentration of $NH_4$-N was higher (5.27 mg $kg^{-1}$) in unplanted soil compared to the soil under *E. officinalis* (5.57 mg $kg^{-1}$), *H. binata* (5.56 mg $kg^{-1}$) and *C. mopane* (5.57 mg $kg^{-1}$) soil. Neill *et al.* (1995) reported higher $NH_4$-N pool in pasture than in the forest soil. The incubation result of Ross *et al.* (1995) also confirm the predominance of $NH_4$-N in net immobilization of mineral nitrogen. The lower concentration of $NH_4$-N in autumn and summer was believed to be due to its

**Table 1.** Seasonal variation in soil organic carbon and extractable P under agroforestry; ***, significant at P<0.001.

| Months/Plots | Year 1996-97 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | D | J | F | M | A | M | J | J | A | S | O | N |
| Soil organic carbon (%) | | | | | | | | | | | | |
| *E. officinalis* | 0.184 | 0.174 | 0.176 | 0.153 | 0.163 | 0.176 | 0.185 | 0.187 | 0.181 | 0.155 | 0.202 | 0.215 |
| *H. binata* | 0.223 | 0.220 | 0.213 | 0.199 | 0.169 | 0.182 | 0.163 | 0.189 | 0.210 | 0.204 | 0.224 | 0.253 |
| *C. mopane* | 0.235 | 0.225 | 0.224 | 0.236 | 0.169 | 0.188 | 0.170 | 0.196 | 0.231 | 0.207 | 0.210 | 0.244 |
| Control | 0.166 | 0.164 | 0.156 | 0.112 | 0.131 | 0.167 | 0.203 | 0.158 | 0.169 | 0.137 | 0.156 | 0.149 |
| F value: Month, 45.4; Plot, 366.9; Month x Plot, 19.0, Significance: Month, ***; Plot, ***; Month x Plot, *** | | | | | | | | | | | | |
| Extractable phosphorus (mg $kg^{-1}$) | | | | | | | | | | | | |
| *E. officinalis* | 18.79 | 16.44 | 13.95 | 8.95 | 6.12 | 19.51 | 16.69 | 5.56 | 16.77 | 15.30 | 6.51 | 16.18 |
| *H. binata* | 19.49 | 14.92 | 14.14 | 6.26 | 5.11 | 21.82 | 20.57 | 9.50 | 15.62 | 18.43 | 4.56 | 15.71 |
| *C. mopane* | 17.48 | 16.10 | 14.01 | 5.89 | 4.41 | 21.72 | 15.39 | 9.36 | 19.59 | 12.22 | 8.37 | 16.32 |
| Control | 6.81 | 10.04 | 10.51 | 4.87 | 3.21 | 15.63 | 28.75 | 11.58 | 7.23 | 4.47 | 3.97 | 14.96 |
| F value: Month, 1430.9; Plot, 462.9; Month x Plot, 164.9, Significance: Month, ***; Plot, ***; Month x Plot, *** | | | | | | | | | | | | |

**Table 2.** Seasonal variations in soil $NO_3$-N and $NH_4$-N under different agroforestry systems. ***: significant at P<0.001, NS: non-significant.

| Months/Plots | Year 1996-97 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | D | J | F | M | A | M | J | J | A | S | O | N |
| $NO_3$-N (mg $kg^{-1}$) | | | | | | | | | | | | |
| *E. officinalis* | 3.30 | 8.02 | 4.87 | 4.17 | 3.70 | 2.61 | 8.04 | 3.04 | 3.33 | 2.49 | 8.22 | 1.71 |
| *H. binata* | 3.34 | 18.76 | 5.05 | 4.21 | 4.17 | 3.53 | 7.25 | 3.00 | 2.98 | 2.83 | 4.37 | 2.40 |
| *C. mopane* | 2.96 | 16.33 | 6.77 | 5.70 | 5.19 | 3.69 | 8.00 | 3.80 | 2.83 | 2.18 | 5.04 | 1.83 |
| Control | 2.90 | 3.39 | 1.88 | 5.32 | 2.87 | 5.19 | 6.55 | 1.43 | 2.92 | 3.54 | 6.46 | 5.72 |
| F value – Month: 994.3; Plot: 170.9; Month x Plot: 206.3, Significance – Month: ***; Plot: ***; Month x Plot: *** | | | | | | | | | | | | |
| $NH_4$-N (mg $kg^{-1}$) | | | | | | | | | | | | |
| *E. officinalis* | 6.93 | 3.48 | 5.81 | 7.31 | 5.22 | 2.71 | 8.00 | 7.60 | 8.02 | 6.74 | 4.15 | 0.86 |
| *H. binata* | 5.26 | 8.37 | 6.47 | 6.07 | 4.97 | 3.56 | 7.80 | 7.42 | 6.72 | 6.40 | 2.80 | 0.98 |
| *C. mopane* | 5.72 | 6.72 | 7.06 | 6.78 | 4.56 | 3.55 | 5.04 | 5.49 | 6.17 | 8.15 | 2.91 | 1.03 |
| Control | 2.47 | 8.78 | 6.50 | 6.73 | 4.58 | 13.02 | 3.12 | 6.96 | 6.08 | 6.68 | 3.69 | 2.47 |
| F value – Month: 588.5; Plot: 43.4; Month x Plot: 189.6, Significance – Month: ***; Plot: ***; Month x Plot: *** | | | | | | | | | | | | |
| $NO_3$-N/$NH_4$-N ratio | | | | | | | | | | | | |
| *E. officinalis* | 0.48 | 2.33 | 0.84 | 0.57 | 0.71 | 0.96 | 1.01 | 0.40 | 0.42 | 0.37 | 1.98 | 1.98 |
| *H. binata* | 0.64 | 2.24 | 0.78 | 0.69 | 0.841 | 0.99 | 0.93 | 0.42 | 0.44 | 0.45 | 1.57 | 2.47 |
| *C. mopane* | 0.52 | 2.44 | 0.96 | 0.84 | 1.14 | 1.05 | 1.59 | 0.69 | 0.46 | 0.27 | 1.74 | 1.79 |
| Control | 1.17 | 0.38 | 0.29 | 0.79 | 0.63 | 0.40 | 2.11 | 0.21 | 0.48 | 0.53 | 1.75 | 2.32 |
| F value – Month: 1.07; Plot: 0.98; Month x Plot: 0.99, Significance – Month: ***; Plot: ***; Month x Plot: *** | | | | | | | | | | | | |

temperature controlled conversion into nitrates.

The ratio of the available $NO_3$-N to $NH_4$-N was observed to be highest under *C. mopane* during January followed by October. However, the ratio was lowest in the cropping period from July to October 1997 and was highest in the early autumn to late winter. The ratio of $NO_3$-N and $NH_4$-N in most of the sampling occasions indicated an efficient utilization of $NO_3$-N by tree roots in combination with enhanced N-mineralization. The low ratio during cropping period was probably due to decrease in the rate of nitrification of $NH_4$-N which was positively correlated with soil moisture (Neill *et al.* 1995). The concentration of $NO_3$-N in January was two fold higher compared to $NH_4$-N though it remained low in control. This may probably be due to low utilization of nitrate during that period. The higher ratio of $NO_3$-N to $NH_4$-N in October-November (autumn) was due to moisture and temperature controlled N-mineralization/nitrification which resulted in decreased concentration of $NH_4$-N. When the plots were compared, the ratio in the control was low thus showing higher concentration of $NH_4$-N in the planted area. The ratio, however, was higher under *C. mopane* followed by *H. binata* and *E. officinalis. Emblica officinalis* as compared to the other two species utilising more $NO_3$-N which is reflected in the better growth rate and biomass produced by this species.

## Conclusion

The study demonstrated significant temporal variations in soil organic carbon, extractable P, $NO_3$-N and $NH_4$-N in an aridisol. The pool of available nutrients was generally higher during summer and low during spring season. Winter season increase in the concentration of these nutrients is attributed to the low absorption owing to plants senesce, strongly suggesting that labile carbon and N fraction accumulated during winter. Further studies are suggested to understand the mechanism controlling nutrient availability in different seasons. The concentration of P and $NO_3$-N were higher under the tree in cropped area than the control which owes to higher status of soil organic carbon and increase in microbial activities. However, concentration of $NH_4$-N was higher in the control compared to the planted area. Significantly low ratio of $NO_3$-N to $NH_4$-N during cropping period could be attributed to the resultant effect of uptake of $NO_3$-N, atmospheric nitrogen fixation by *V. radiata* and moisture controlled nitrification process. In depth studies on the subject are suggested so as to devise package of practices for making fertilizer prescription in agroforestry systems.

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