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# Availability and Management of Nitrogen in Soils of Arid Ecosystem

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**Abstract** In this paper, the work on the availability of nitrogen and its management for sustainable production has been reviewed with particular reference to soils in arid ecosystem. The available literature on status of soil nitrogen, its succession and transformation under natural ecosystems suggest the variability in arid regions which are dependent on the soil climatic conditions. In Indian arid zone particularly western Rajasthan, the organic carbon and nitrogen are reported as low as 0.05% and 0.007% respectively in sand dunes, however, the stabilization of dunes with vegetation increases these contents albeit slowly. Amongst tree species, *Prosopis cineraria* has been found to be a soil fertility restorer. Compared to the figure of 4 kg N ha$^{-1}$ annum$^{-1}$ for Indian subcontinent, the precipitation in arid region of western Rajasthan brings about 6-10 kg N ha$^{-1}$ annum$^{-1}$, however in Negev desert of Israel, this value goes upto 20 kg N ha$^{-1}$ annum$^{-1}$. Amongst different pathways of N loss, $NH_3$ volatilization is a major process operating in arid region. The ways to reduce such losses have been discussed. Use of on-farm organic residues and inclusion of legumes in crop rotation, are some of the management practices suggested which ensure importance for sustainable production, fertility maintenance and enhancing fertilizer N use efficiency in arid region

**Key words** Availability, Transformation, Management, Nitrogen, Arid Zone

In arid and semi arid regions, limited water resources and low crop productivity has discouraged the widespread use of N and consequently limited research interest in this element. However, with ever increasing demand of food, it is now realized that arid and semi arid region, will need to be exploited to the fullest extent. Further with the introduction of improved crop varieties which are responsive to fertilizer, N has become an important input in this ecosystem.

### *Content and form of N in arid soil*

Jenny and Ray Chaudhuri (1960) showed that the content of total N and organic matter in soil depend on the temperature, rainfall and altitude. In arid soils because of their low clay content and occurrence in hot climate with low rainfall, the N content is generallly low (Dhir 1977). The mean organic carbon content in the arid soil (below 300 mm rainfall zone) ranged between 0.05 to 0.2% in coarse, 0.2-0.3% in medium and 0.3-0.4% in fine textured soil. The soils in 300 mm to 400 mm rainfall zone had a relatively higher N content. Joshi *et al* (1989) reported low N contents in the arid soil of Haryana. In the soils of *Gujarat* also the content of organic carbon and total N was reported to be low ranging from 0.16-0.34% and 0.021-0.056% respectively (Joshi *et al.* 1989). Aggarwal *et al.* (1977, 1990) reported that the major part of N in the Aridisols of Rajasthan was in organic form of which the acid hydrolysable N constituted about 62-87% of the total N. Amongst the different fractions the order of distribution was amino acid > unidentified N > amonical N > hexoseamine N. The level and distribution of $NO_3$ –N in the soil profile is subjected to seasonal fluctuations. In general there is a slow build up of $NO_3$–N in the soil profile during the dry period, which disappears at the onset of rains (E1-Swaify *et al.* 1984). This phenomenon was first described by Hardy (1946) and Birch (1960) and is often called Birch effect. In the arid soils of Jodhpur the concentrtion of $NO_3$ in the upper layer of soil increased from nearly 3 ppm in winter to more than 5 ppm in summer (CAZRI 1989-90). The fluctuations in the concentration in the lower depths were not marked until rainy season (Fig. 1).

The vegetation contains only 5-10% of the total N found in the arid ecosystem (Table 1) as against nearly 100% in some tropical forests, 15% in deciduos forest and 2% in grasslands (Wallace *et al.* 1978). But biotic N even in such small quantity

**Table 1** *Nitrogen compartment size in Bajada areas of northern Mohave desert*

| Compartments | Range (kg N ha$^{-1}$) |
|---|---|
| Soil organic matter | 75 – 225 |
| Undecomposed litter and dead plant parts | 3 – 12 |
| Nonexchangeable fixed ammonium nitrogen | 60 – 120 |
| Biotic nitrogen components | |
| Perennial plant roots | 3 – 6 |
| Perennial plant branches and stems | 0.6 – 3 |
| Leaves, flowers and other new growth | 0.6 – 3 |
| Annual plants | 0.15 – 1.5 |
| Animals | 0.03 – 0.045 |
| Total biotic nitrgoen | 5.85 – 13.5 |
| Soluble mineral nitrogen in soil | 3 – 12 |

Source : Wallace *et al.* (1978)

remarkably influence the distribution of N in arid soils, both vertically and horizontally. A typical vertical distribution pattern of N is shown in the (Fig. 2), where N is shown to be concentrated in the upper part of the profile. This pattern is expected to be most pronounced where vegetation has a high shoot : root ratio. Horizontal pattern (Fig. 3) of distribution are striking under the desert situations where scattered occurrence of vegetation results in "island of fertility" (Garcia-Moya & Mckell 1970) or mosaic of N accumulation (Nishita & Haug 1973, Charly & West 1975) and N availability coin-

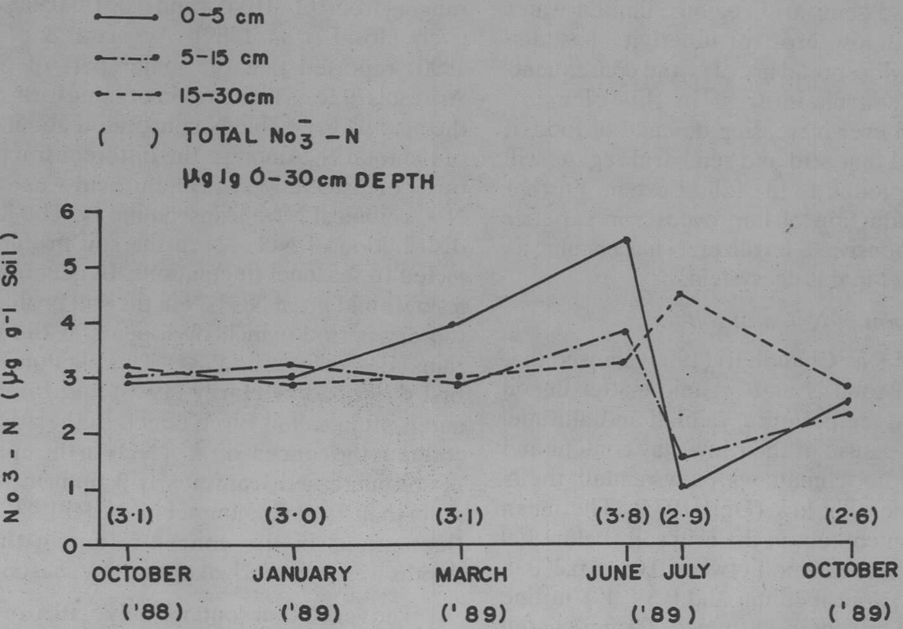

**Fig 1** Seasonal fluctuations in the concentration of $NO_3$ – N in the soil profile. (CAZRI 1989-90)

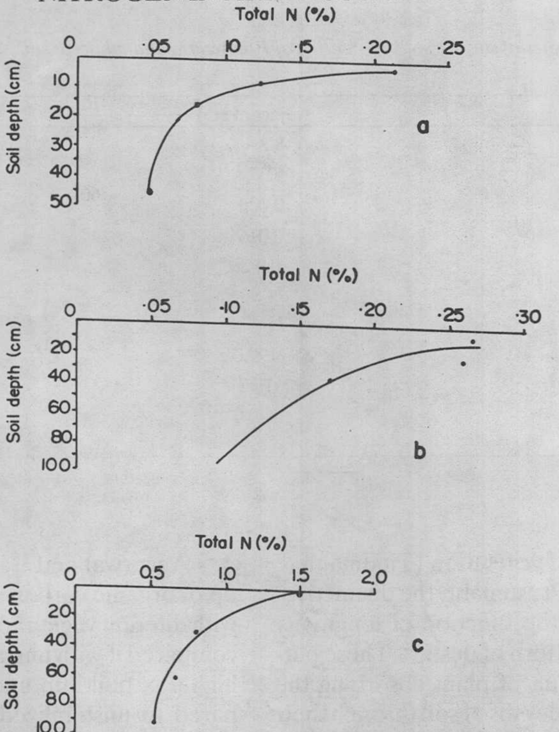

**Fig 2** Vertical distribution of N in some generalised soil profiles at three north American desert sites. a = big sagebrush (*Artemisia tridenta*), b = mixed desert shrub, and c = succulent shade scale (*Atriplex confertifolia*). (West & Klemmedson 1978)

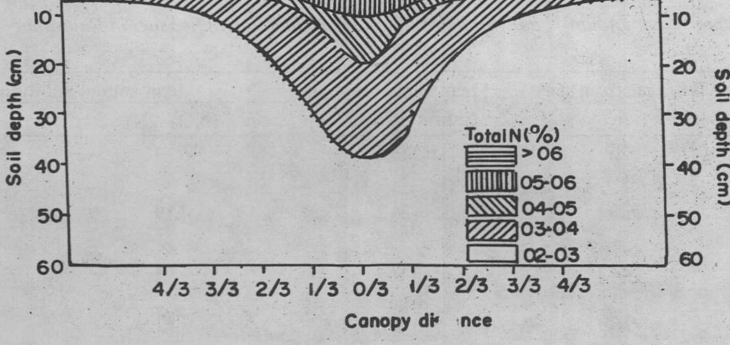

**Fig 3** Per cent total nitrogen concentration beneath an average size mesquite (*Prosopis juliflora*). (Klemmedson & Barth 1975).

**Table 2** *Chemical characteristics of surface soils (0–15 cm) of P. cineraria and adjacent soil*

| Characteristics | Adjacent soil | P. cineraria soil |
|---|---|---|
| pH | 8.2 | 8.0 |
| O.M.% | 0.37 | 0.57 |
| N % | 0.020 | 0.038 |
| S % | 0.016 | 0.028 |
| P % | 0.0.28 | 0.038 |
| Available nutrients (kg ha$^{-1}$) | | |
| N | 190.0 | 250.0 |
| P | 17.7 | 22.4 |
| K | 370.0 | 633.0 |

Source : Aggarwal *et al.* (1993)

ciding with the pattern of vegetation (Tiedmann & Klemmedson 1973 a,b). Presumably the distinctiveness of these mosaic is the function of longitivity and scattered vegetal pattern of destert. These patterns are largely the result of plant absorbing the nuttrient from the lower depths of soil through their root system and redisposing them as mulch on the floor of soil. Decomposer activity is enhanced by the moderate temperature and enhanced retention of moisture under the shade of trees and shrubs. Animals are also attracted to the island for the shade and food, and in turn affect N distribution. Aggarwal and Praveen-Kumar (1990) and Aggarwal *et al.* (1993) have reported higher fertility of soils underneath *Prosopis cineraria* as compared to the adjoining open site (Table 2).

Aggarwal and Lahiri (1981) studied the build up of organic carbon and N in the dunes stabilized with diferent vegetations for more than 14 years and compared it with unstabilized dune. They reported higher N build up under stabilized dunes as compared to unstabilized dunes. They also observed increasing trend in organic carbon and total N and stabilization of C/N ratio towards 10:1 in surface soils of stabilized dune. Mineralised N constituted the major part of total N and its content was relatively higher in unstabilized dunes. In the pastures, Dhir and Gajbhiye (1973) observed higher humus content in the soil near the grass clump which decreased with increase in the distance.

### *Nitrogen input in arid ecosystem*

Ecosystem of arid regions depends to a great extent on the N inputs from the atmosphere to

**Table 3** *Mean anuual amounts of ammonium-N and nitrate-N added by precipitation at five sites in Rajasthan*

| Station | Distance from sea (km) | Mean annual rainfall (mm) (1976-1978) | Mean annual addition (kg ha$^{-1}$) | |
|---|---|---|---|---|
| | | | ($NO_3-N$) | ($NH_4-N$) |
| Jaisalmer (185 mm) | 520 | 246.4 | 6.33 | 3.10 |
| Bikaner (291 mm) | 700 | 436.2 | 4.19 | 5.89 |
| Jodhpur (360 mm) | 580 | 437.4 | 1.84 | 3.63 |
| Pali (412 mm) | 500 | 450.0 | 4.01 | 2.97 |
| Palsana (567 mm) | 830 | 790.1 | 7.11 | 6.95 |

compensate for the losses of N from soil:plant system. The most important mechanism of atmospheric N input are, (1) N deposition through precipitation, and fallout and (2) biological N fixation.

*Precipition and resorption :* Global terrestrial inputs from resorption, precipitation and fallout are presently estimated at 66-200 million tons $yr^{-1}$ (National Research Council 1978) and thus of the same magnitude as biological N fixation. But West (1975) estimated that the N deposition for the arid regions on a world wide basis to be 12.5 kg $ha^{-1}$ $yr^{-1}$; 3.5 times more than the input through biological N fixation. Nitrogen deposition in the arid areas of USA have been reported to be generally less than 5 kg $ha^{-1}$ $yr^{-1}$ (Vlek 1981). Aggarwal *et al.* (1982) reported the N deposition as precipitation varying from 5.47 to 10.06 kg $ha^{-1}$ in the arid regions of India (Table 3). The concentration of $NO_3$-N in the rain water varied from 1.5 to 1.8 $\mu$g N $mL^{-1}$. In Israel the average deposition of N by washout alone was reported to be 40 g $ha^{-1}$ for each millimeter of rain for seven stations amounting to the contribution from 4 to 20 kg N $ha^{-1}$ (Yaalon 1964). A review of data in the literature by Harpaz (1975) suggested that the annual input through the rain in semi arid climate averaged about 5 kg $ha^{-1}$ and was of the same order of magitude as the values reported for annual N fixation by non symbiotic micro organisms.

*Biological N fixation :* Although a vast supply of N occurs in the atmosphere of earth, but it is present as inert mass and cannot be used by the higher forms of plant and animal life. The covalent triple bond of $N_2$ molecule ($N\equiv N$) is higly stable and can be broken only at elevated temperature and pressure. Nitrogen fixing micro organism like *Azotobactor* (0.3 kg N $ha^{-1}$ $yr^{-1}$) and *Clostridium* (0.1-0.5 kg N $ha^{-1}yr^{-1}$), plant alegal associations like *Azolla*, *Gunnera* and *Lichens* etc. on the other hand perform this seemingly difficult task at ordinary temperature and pressure. But in arid region leguminous plants are the most important N fixers. Out of the total of $135x10^9$ kg N returned to earth each year through biological $N_2$ fixation about 65% ($89x10^9$ kg) is contributed by nodulated legumes (Stevenson 1986). West (1975) estimated the contribution of biological N fixers in arid zone to be nearely 3.6 kg N $ha^{-1}$ $yr^{-1}$.

*Mineralization of nitrogen from organic matter :* The timing and extent of the net release of inorganic N from organic matter, determine the availability of mineral N for uptake by the crop or for utilization by competing micro organisms. The dynamics of N supply are particularly important in the rainfed agricultural systems of arid region, where N fertilization to overcome soil N deficits is still uncommon and is not without economic risk.

Soil organic matter has no well defined composition and attempts to characterize it on the basis of some of its identifiable components have met with varied successes (Bremner 1965). As a result, most studies concerned with net mineralization of soil N, have made no attempt to distinguish between the various organic compounds in soils, and have expressed the change in total soil N as a simple first order rate equation.

$$\frac{dN}{dt} = kN + A \ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

where, k is a decomposition constant, N is the nitrogen content of a given mass of soil at time t, and A is an accretion constant giving the amount of nitrogen added to the given mass of soil per unit time (Greenland 1971).

A more refined equation developed by Russell (1975) allows for year to year variation of the rate constant and includes a factor to account for additions of manure. The equation can be written:

$$\frac{dN}{dt} = k_1(t)\,N + k_2 + k_3\,(t)\,Y\,(t) \ldots 2$$

where, N is soil organic N, $k_1$ (t) is a time dependent decomposition coefficient, $k_2$ represents a constant addition of N not associated with cropping, Y(t) is plant biomass at time t and $k_3$(t) is the addition of N from plant residues which depends on the nature of the sequential crop. Russell used this equation and three more restricted variants to analyze the relationship between yield and equilibrilum soil N content for a series of long term cropping system experiments with and without additions of manure.

Although useful as a tool to analyze the effect of cropping patterns and cultural practices on the long term behaviour of organic N in the soil, these rate equations lack the necessary sensitivity to predict seasonal fluctuations in the availablity of inorganic N.

Attempts have been made to follow the short term nitrogen dynamics in soil by simulation of the various transformations in mechanistic models (Tanji & Gupta 1978). These models are based on the assumption that microbially mediated processes are kinetically first order in nature (Tanji & Gupta 1978)

$$\frac{d\,[\,\mathrm{org\,N}\,]}{dt}\,i = k_1\,[\,\mathrm{org\,N}\,]\,i + k_2\,[\,NH_4^+\,] + k_3\,[\,NO_2^-\,] + k_4\,[\,NO_3^-\,] \ldots\ldots 3$$

Various models incorporate environmental factos to allow for seaonal variations in the rate constants ($k_1$, $k_2$, $k_3$, $k_4$) of the transformations (Beek & Frissel 1973, Hagin & Amberger, 1974; Donegian & Crawford, 1976, Stanford & Smith 1972, Watts 1975). Incorporation of seasonality is particularly important for arid climates.

Molina *et al.* (1980) proposed a two pool model to predict the N mineralization in soil.

$$N_m = N_1\,(\,1 - e^{-k_1 t}\,) + N\,(\,1 - e^{k_2}\,) \ldots 4$$

where, Nm is the nitrogen mineralised in time 't' $N_1$ and $N_2$ are the pools of mineralizahle N. $k_1$, and $k_2$ are the rate constant of N mineralization. $k_1$ was adjusted for soil temperature using average $Q_{10}$ of two between 15 and 35°C (Stanford *et al.* 1973). The predicted amount of N mineralized was corrected for soil water content with a factor of the from ;

W = soil water content/optimum soil water content.

Cabrera & Kissel (1988) found that the method accurately predicted the amount of N mineralized in coarse textured soil, but in fine textured soil it significantly over predicted the amount of N mineralized. The over prediction of mineralized N was attributated largely to the improper soil water content factor and drying and sieving of soil samples before incubation.

Seasonal fluctuations of the soil conditions in arid climates are generally extreme. Temperatures may range from below 0°C to as high as 60°C while moisture content may range from field capacity to below the conventional wilting point. Such variations in the environment have a great impact on the dynamics of N transformations in soil. For instance, during dry periods carbon decomposition exceeds nitrogen mineralization (Birch 1960), resulting in a decreased C : N ratio which will favour net mineralization during the subsequent wet season. If temperatures are favorable, the onset of the rainy season will be accompanied by a flush of mineral N in the soil (Hardy 1946, Birch 1960). If in a winter rainfall climate, the early rains coincide with low soil temperatures, the mineral nitrogen flush may be delayed until early spring. A better understanding of the kintetics of mineralization in dryland agriculture would help to predict the availability of mineral N and allow for timely correction of N deficiencies through applications of fertilizers.

*Transformations of N in soil*

*Ammonification* : Ammonification of organic N in soil is affected by a number of factors, many of which are related to biological activity. Myers (1975) studying the temperature effect on ammonification in a tropical soil, found it to fit in an Arrhenius-type equation with maximum rate at about 50°C. The lower temperature limit for ammonification is gernerally around freezing (Sabey *et al.* 1956, Stanford *et al.* 1973). The effect of temperature on ammonification is generally uniform among soils (Stanford & Epstein 1974).

The optimum water potential for ammonification ranges from 10 to 50 KPa (Miller & Johnson, 1964, Stanford & Epstein 1974). The rate of ammonification declines linearly with decreasing water content (Miller & Johnson 1964, Reichman *et al.* 1966, Stanford & Epstein 1974). Robinson (1957) found little evidence of ammonification below the permanent wilting point (1.5 MPa) while Miller and Johnson (1964) and Reichman *et al.* (1966) found ammonification to proceed at matric suctions exceeding 1.5 MPa. Kowalenko and Cameron (1976) demonstrated the importance of temperature : water content interaction term in quantifying microbialy mediated ammonification. The effect of soil factors such as pH, salinity, and texture on ammonification has been studied, but good fundamental relationships have not yet been established (Nyborg & Hoyt 1978, Laura 1973 1974).

O'Brien (1978) mentioned that the proteolysis and deamination contribute substantially to ammonification of organic N in desert soil. Ordinarily the ammonium ion formed is converted to nitrate. However, in relatively alkaline soils of arid region a substantial part of $NH_4$–N is converted to ammonia and escapes to atmosphere because nitrification starts after a long delay period.

*Nitrification :* Ammonium N mineralized from organic matter can be either assimilated by microorganisms and plants or oxidized to $NO_3$–N by the process termed nitrification. It appears that the traditional view that *Nitrosomonas* alone being responsible for $NH_4$ oxidation is no longer tenable. *Nitrosolobus* and *Nitrasopira* were the dominant $NH_4$ oxidizers in a range of soils examined by Soriano and Walker (1973). It has been suggested by Verstraete (1979) that nitrification under low $CH_4$ conditions and where the competition from chemolithrophs (nitrifiers) is nonexistent due to poor environmental conditions, could well be due to methylotrophs.

The population of nitrifiers is generally low in arid soils. Sims and collins (1960) found maximum number of nitrifiers to be 800 $g^{-1}$ in an arid Australian soils. By contrast the number in cultivated soils may reach millions per gram (Alexander 1961). Skujins and Trufillo Y Fulgham (1978) reported that nitrification potential of arid soil decreased with depth and became zero in the layers not reached by precipitation. Alexander (1961) found seasonal variation in the population of nitrifiers in soil, the larger number being in warm rainy season. The *Nitrosomonas* population generally remained more stable than of *Nitrobactor.*

As a rule, the optimum temperature for nitrification in soil falls between 25 and 35°C. The rate of nitrification drops rapidly below 15°C to alomst zero at 0°C (Alexander 1965). There have been occasional reports of appreciable $NO_3$ accumulation in soils at temperatures above 40°C (Focht & Verstraete 1977). But it is not clearly understood whether the production of $NO_3$ at high temperature follows heterotrophic nitrification which involves soil organic N or $NH_4$ oxidation by thermophilic chemolithotrohps (Mahendrappa *et al.* 1966).

The optimum soil water potentials for nitrification are very close to those for ammonification. The limitation of high water potentials reflects the obligate requrement for $O_2$ and the need for adequate gaseous exchange between the soil and the surrounding atmosphere (Alexander 1965, Focht & Verstraete 1977). Nitrates are not formed in air dried soil nor are produced at high soil moisutre levels. But the moisture level at which nitrification ceases has not been well established. Justine and Smith (1962) have found low rates of nitrification at 1.5 MPa but no activity at $-11.5$ MPa. Little is known about the intermediate range of potential.

Nitrifiers also exhibit a remarkable ability to survive desiccation, at least at laboratory temperatures (Alexander 1965), but whether this capability extends to the field where high temperatures often accompany desiccation is yet unknown. Kowalenko and Cameron (1976) demonstrated the existence of a temperature: water content interaction on nitrification in soils subjected to a range of mesophilic temperatures and water potentials above -1.5 Mpa. Research to characterize the nitrification response to range of theremophilic temperatures and low water potentials, for a range of soils representative of the arid zone has been very limited.

The rates of $NH_4$ and $NO_2$ oxidation often follow first order kinetics. Substrate inhibition of nitrification is known to occur but it is pH dependent. The use of ammonium or ammonium forming fertilizer such as urea in arid zone soils may lead to high concentrations of mineral N and in the case of urea, to a temporary increase in soil pH (Hauck & Stephenson 1964, Pang *et al.* 1975a,b, Christianson *et al.* 1979). Thus, $NO_2$ might accumulate where high $NH_4$ and associated pH inhibit *Nitrobacter* activity (Alexander 1965). There is much less likelihood that ammonium oxidizers will be subjected to end-product inhibition, although high concentrations of $NO_2$ (500-2000 mg $L^{-1}$) have been found to inhibit *Nitrosomonas* at low pH (Focht & Verstraete 1977).

Various bushes in the arid areas have been reported to have a pronounced effect on nitrification Rixon (1969, 1971), Tiedmann and Klemmedson (1973a), Charley and West (1977). Munro (1966) and Neal (1969) showed presence of substances in the excudates of the grass roots which inhibit nitrification.

*Denitrification :* Very few denitrification studies have been made on arid lands, possibly because of the general notion that anaerobiosis is rare in the soils from this region. However, it was recognized two decades ago that under field conditions, poor $O_2$ supply to soil aggregates could result in localized anaerobiosis and denitrification (Allison *et al.* 1960, Burford & Millington 1968, Dowdell & Smith 1974). Soil moisture plays such an important role in governing soil aeration that production of gaseous $N_2O$ often responds repidly to incidental heavy rainfall (Burford & Millington 1968). Cawse and Sheldon (1972) reported a rapid reduction of nitrate following rewetting of soils to a wide range of moisture contents well below saturation, while nitrifiers continued to be active simultaneously. Some aspects of the variability patterns of aeration parameters of a soil were discussed by Fluhler *et al.* (1975, 1976) in relation to simultaneous nitrification and denitrification.

The effect of temperature on the rate of denitrification is well characterized. Some workers have observed optimum rates at 35°C (Bremener & Shaw, 1958, Stanford *et al.* 1975) but Nommik (1956) and Keeney *et al. (*1979) reported an optimum of about 65°C. An exponential increase of rate is typically observed between 15°C and 30°C, but below 12°C, the exponential increase does not generally hold. Denitrification can occur at temperatures close to freezing (Stanford *et al.* 1975). The reports of rapid denitrification at thermophilic temperatures are significant in studies of dentrification in hot arid soils. Keeney *et al.* (1979) reported complete reduction of $NO_3$ (100 $\mu$g N $g^{-L}$) to gaseous $N_2$ within 12 h, when a silt loam soil was incubated under helium at 60°C. The soil in question was not amended with carbon nor air dried before incubation. Lower rates of loss were found at 40°C, yet 60 % of the $NO_3$ was reduced within a 48 h period. Keeney *et al.* (1979) reported optimum temperature for denitrification to be very high (65°C) and proposed it to be due to a combination of biological denitrification and chemodenitrification.

Soil pH is an additional factor that may affect cycling of N via denitrification in the arid zone. It is generally accepted that denitrification is reduced at low pH, but the pH range for denitrification is normally much wider than that noted earlier for nitrification (Focht & Verstraete 1977). Temperature and pH also affect the composition of the gaseous products of denitrification. A higher $N_2O$ : $N_2$ ratio is observed at lower temperatures (Bailey 1976, Nommik 1956, Keeney *et al.* 1979) and in acid soils (Nommik 1956, Blackmer & Bremner 1978), while $N_2$ dominates at the higher temperatures and at close to neutrality. The inhibitory effect of $NO_3$ on $N_2O$ reduction is more pronounced at lower soil pH, but acid soils can reduce $N_2O$ to $N_2$ in the absence of $NO_3$ (Blackmer & Bremner 1978).

*Ammonia volatilization :* The volatilzation of $NH_3$ can be regarded as a chain of events, the overall rate of which can be controlled by any one link in the chain represented by

$$NH_4\,(aq) \rightarrow NH_3\,(aq) \rightarrow NH_3\,(g) \rightarrow NH_3\,(atm \quad \ldots 1$$

where, NH4 (aq) depends on soil cation-exchange reactions (Fenn & Kissel 1976, Gasser 1964) soil moisture content (Ernst & Massey 1960, Fenn & Escarzaga 1976), and net mineralization. Conversion from $NH_4$ in solution to aqueous $NH_3$ is an extremely rapid (first order) process with a rate constant of 24.6 $sec^{-1}$ (Emerson *et al.* 1960) and is thus rarely limiting. The concentration of $NH_4$(aq) changes proportionally with ammonical N, approximately linearly with temperature (Craswell & Vlek, 1980) and increases about 10 fold per unit increase in pH up to pH 9 (Vlek & Stumpe 1978).

Equilibrium between aqueous $NH_3$ and gaseous $NH_3$ is governed by Henry's Law with $K_H$ ($K_H = 0.0164$) a function of temperature (Beutier & Renon 1978). Whether equilibrium between $NH_3$ (aq) and $NH_3$ (g) is maintained, depends on the rate of $NH_3$ (g) evasion from solution and the rate of $NH_3$ (g) transfer away from the source sink interface. In still air, the partial pressure gradient of $NH_3$ determines the rate of gas dispersion, whereas in natural environments, temperature gradients and wind accelerate the transfer resulting in dispersion coefficients 10 to 600 times higher than the diffusion coefficient in still air (Inoue *et al* 1975).

Ammonia volatilization on global scale is estimated to be $170 \times 10^6$ tonnes annually or a yearly average of 10 kg N $ha^{-1}$ ( Burns & Hardy 1975). Measurements of $NH_3$ volatilization from natural arid ecosystem are lacking possibly reflecting inadequacy of suitable techniques and general notion that $NH_3$ volatilization under these conditions is not an important loss mechanism (Husz 1977, Noy-Meir & Harpaz 1977). But, heavy losses of N as $NH_3$ have been observed by Aggarwal *et al.* (1987) after the application of various $NH_4$ and $NH_4$ forming fertilizers in the arid sandy soils, particularly urea.

Terman and Hunt (1964) first suggested the chemical reactions involved in $NH_3$ loss from inorganic N materials. These reactions were presented in a generalized form by Fenn and Kissel (1973) as follows :

$$X(NH_4)_2Y + DC_aCO_3 \rightarrow D(NH_4)_2CO_3 + Ca_nY_x \quad \ldots 2$$

$$(NH_4)_2CO_3 + H_2O \rightarrow 2NH_3 + 2H_2O + CO_2$$

$$NH_4OH \quad \ldots 3$$

where, Y represents the anion of the $NH_4$ salt, and D, X and n are dependent on the valences of the anions and cations. The final reaction product, $(NH_4)_2CO_3$, is unstable and decomposes producing $NH_3$ and $CO_2$ gases. The amount of $NH_4OH$ formed during a given time will depend on the solubility of $Ca_nY_X$ and its rate of formation. If $Ca_n Y_x$ is insoluble, the reaction will proceed to the right producing additional OH ions and an increase in pH.

If $Ca_n Y_x$ is soluble then reaction [2] does not proceed strongly to the right and $NH_3$ loss will depend primarliy on the native pH of the soil. The $NH_3$-$NH_4$ equilibrium is pH dependent with lower pH values favoring the $NH_4$ form.

Ammonium sulfate reacts with $CaCO_3$ to form relatively insoluble $CaSO_4$ (Fenn & Miyamoto 1981).

$$(NH_4)_2Y + DCaCO_3 \rightarrow (NH_4)_2CO_3 + CaSO_4 \quad \ldots 4$$

The continuing precipitation of $CaSO_4$ in soil will depend on loss of $H_2O$ from the soil system. The rate of $NH_3$ loss increases up to 8 hrs at 22°C and then decreases. The soil pH reaches 8.5 at 8 hr and then decreases due to greater initial losses of $CO_2$ than $NH_3$ (Feagley & Hossner 1976, Fenn & Kissel 1973, 1975). Subequent $NH_3$ losses are greater than those of $CO_2$ and a drop in soil pH occurs.

Feagley and Hossner (1977) postulated a reaction where-by the intermediates go through $NH_4HCO_3$. The final reaction results in the same end products. In a soil of pH 8.5 and below, $CO_3$ will predominate even though the original reacant was $CaCO_3$.

When reaction [2] involves a N compound such as $NH_4F$, a compound which forms a very insoluble Ca reaction product, conditions conducive to large losses of volatile $NH_3$ are produced.

$$NH_4F + Ca\,CO_3 \rightarrow (NH_4)\,2CO_3 + Ca\,F_2 \quad \ldots 5$$

The pH of this soil system can rise to greater than 9 and result in 30 to 40% $NH_3$–N loss within one hour. The soil pH in this case very rapidly decreases to value even lower than that of the native soil.

Ammonium nitrate or $NH_4Cl$ do not produce insoluble salts of calcium in a calcareous soil. Represented in chemical form the process is essentially as follows :

$$2NH_4NO_3 + CaCO_3 \rightarrow (NH_4)_2CO_3 + Ca\,(NO_3)_2 \quad \ldots 6$$

Ammonia losses are consequently controlled by the native soil pH and are normally low in rate and quantity.

Urea which is the dominant source of nitrogen is first converted to the $(NH_4)_2CO_3$ by urease in soil which may decompose to form $CO_2$ and $NH_3$. The hydrolysis of fertilizer urea generally does not result in appreciable $NH_3$ losses in first two days (Fenn & Hosser 1985). Maximum $NH_3$ losses generally occur during third to fifth day under laboratory conditions. Aggarwal *et al.* (1987) have also recorded maximum losses (upto 20%) within first week of application of urea in arid soils. The amount of $NH_3$ loss depended on the quantity of urea applied in soil.

### *Management of nitrogen*

The N requirement of crops vary with their type and the yield level. The long term estimations of N requirement of crops under arid conditions may be very difficult as the yield levels vary considerably due to variations in rainfall. Stewart (1992) observed that under such conditions the crop yields may vary from zero to three times of average yield. Tucker (1988) concluded that using average yields in semi arid regions is too conservative and actually results in lowering average yields with time because of insufficient nitrogen availability for the very favorable years. However, the use of relatively high yield goals results in excess N applications in most years and can greatly reduce profit. The current concern over the potential for excess N to degrade the environment also makes this alternative unacceptable. Tucker (1988) presented several ground rules to arrive at logical yield goals. These include choosing yield goals based upon ; (1) highest yield within the past 5 years, provided crop management was good, (2) yield goal set a 1.5 times of long term average, and (3) yield goal based on soil capabilities as defined in standard soil surveys, using yields of top growers in the vicinity on the same kind of soil.

**Table 4** *Coefficient of variability (CV) in productivity and sustainability yield index (SYI) in crop production in the soils of arid and semi arid region*

| Location | Soil type | Rainfall (mm) | Cropping system | Year | Mean yield (t $ha^{-1}$) | CV (%) | SYI |
|---|---|---|---|---|---|---|---|
| Jodhpur | Aridisol | 310 | Pearl millet : | | | | |
| | | | i) Control | 1975 – 79 | 0.90 | 84.4 | 0.10 |
| | | | ii) 20 kg N $ha^{-1}$ | 1975 – 79 | 1.36 | 66.8 | 0.14 |
| | | | iii) 10 t FYM $ha^{-1}$ | 1975 – 79 | 1.64 | 45.6 | 0.30 |
| Bangalore | Alfisols | 890 | Finger millet : | | | | |
| | | | i) Control | 1979 – 90 | 1.25 | 24.1 | 0.47 |
| | | | ii) 10 t FYM $ha^{-1}$ | 1979 – 90 | 2.42 | 23.2 | 0.59 |
| | | | iii) 10 t FYM $ha^{-1}$ 25 – 11 – 10.5 $ha^{-1}$ | 1979 – 90 | 2.88 | 16.4 | 0.63 |
| | | | iv) 10 t FYM $ha^{-1}$ 50 – 22 – 21 $ha^{-1}$ | 1979 – 90 | 3.48 | 16.8 | 0.64 |
| | | | v) 50 – 22 – 21 $ha^{-1}$ | 1979 – 90 | 2.79 | 16.2 | 0.67 |

Source : Vekateswarlu and Hegde (1992)

The crops under arid conditions respond favourably to the N addition (Aggarwal & Vekateswarlu 1989). They observed that over long term the response of pearl millet to N ranged from 7.5 to 18 kg grain $kg^{-1}$N and of sesame from 4 to 14.5 kg $kg^{-1}$N. The response to N was more in the years of good rainfall. Venkateswarlu and Hegde (1992) mentioned that in long term the application of N either in from of organic or inorganic fertilizer reduces the year to year variation in the yield (Table 4).

**Table 5** *Cumulative ammonia volatilization losses and nitrogen use efficiency by pearl millet from different nitrogen fertilizers*

| Fertilizer | Ammonia volatilized % | Efficiency of nitrogen use % |
|---|---|---|
| urea | 16 | 25 |
| Ammonium sulfate | 12 | 32 |
| Urea coated with sulfur | 8 | 48 |
| Diammonium phosphate | 3 | 18 |
| Calcium ammonium nitrate | 0.1 | 24 |
| CD (P = 0.01) | 0.7 | |

Source : Aggarwal *et al.* (1987)

### *Addition of nitrogen in Soil*

*Fertilizers and manure :* Singh *et al*. (1979, 1981) have reported that the yield of pearl millet doubled with the application of 40 kg N $ha^{-1}$. Similar trend was also observed by Singh *et al.* (1981). But the efficiency of inorganic N fertilizers in general and that of urea in particular, in Aridisols, is often very low (Aggarwal *et al.* 1987) and result in undesirable economic burden to the user. Various studies in Jodhpur have revealed that the mixing of elemental S with urea (Table 5) (Aggarwal *et al.* 1987) or application of small quantity of ammonium sulphate before the application of urea (Praveen-Kumar & Aggarwal 1988) increases its efficiency. But in view of high cost of chemical fertilizers and the characteristic uncertain yield levels in this climate, Aggarwal and Venkateswarlu (1989) suggested the supplimentation of chemical fertilizers, with bulky organic manures. Singh *et al.* (1981) observed that under arid conditions of Jodhpur continuous application of sheep manure in general gave substantially higher yields than the application of urea alone.

Rao and Singh (1973) showed that substitution of 50% of fertilizer requirement by FYM resulted in yield levels nearly similar to those obtained with complete fertilization. Aggarwal and Praveen-Kumar (1994) on the basis of a six years long study on arid soils showed not only a beneficial effect of FYM application alone but also a synergistic effect of simultanous application of FYM and inorganic fertilizers on crop yield (Table 6). They have also shown that application of FYM not only increases the N-use efficiency of urea but also improves the fertility status of soil (Table 7).

*Crop residues :* Crop residues are an important source of nutrients. In our country the estimated yield of crop residues is 185.3 Mt annum$^{-1}$ for important arable crops (Bharadwaj 1981). It is estimated that 1/3 of the total quantity of residues can be left in field contributing about 1.24 Mt of N, 0.16 Mt of P and 2.0 Mt of K. These residues can be left on soil as mulch cum manure or can be incorporated in soil, or can even be burnt in field and the ashes may then be incorporaed. But the research on this aspect had been rather limited in our country as such and in arid regions in particular.

Leaving the crop residues in soil generally have a positive effect on grain yield (Table 8) (Hadmani *et al.* 1982, Aggarwal *et al.* 1992, Hegde *et al.* 1982). Rao and Singh (1993) have reported crop residues to be as efficient source of nutrient as other organics like cattle manure and compost.

Incorporation of crop residues into soil has been reported to increase the organic matter content of soil (Shipley & Regier 1977, Rasmussen *et al.* 1980, Hooker *et al.* 1982). Hegde *et al.* (1982) reported higher organic carbon and available P and K content in soil after 5 years of continuous incorporation of maize residues in soil. An increase in the organic carbon and available N, P and K after application of residues have also been reported by Dhillon and Dhillon (1991).

**Table 6** *The effect of nitrogen levels and farm yard manure (FYM) on grain yield of pearl millet (t ha$^{-1}$). Average of six years.*

| Treatment | Yield<br>t ha$^{-1}$ | N Use effeciency<br>% |
|---|---|---|
| Control | 0.53 | – |
| FYM | 0.77 | – |
| $N_{40}$ | 0.70 | 28.9 |
| FYM + $N_{40}$ | 1.01 | 42.50 |
| $N_{80}$ | 0.86 | 19.83 |
| FYM + $N_{80}$ | 1.11 | 27.10 |

Source : Aggarwal and Praveen-Kumar (1994)

Crop residues placed on soil surface (like in mulching) reflect light and insulate the soil and thus reducing soil temperature and evaporative losses of water (Bond & Willis 1969). Cannell *et al.* 1980, Tanaka 1985, Gupta & Gupta 1986, reported that under arid condition the mulching with local weeds increased, the moisture content from 3.7% to 4.9% but it was more effective under no tillage system. Gupta (1984) reported that mulching reduced the mean maximum temperature at 10 cm depth by 1 to 6°C in the fields of cowpea and pearl millet. Addition of crop residue also improves soil aggregation (Venkateswarlu 1987). This is mainly attributed to increased microbial activity during decomposition (Elliot & Lynch 1984, Elliot & Papendick 1986) adhesive action of decomposition products (Elliot & Lynch 1984) or increased activity of earth worms. Venkateswarlu (1984) and Gupta (1986) have

**Table 7** *Effect of continuous cropping of pearl millet and addition of farm yard manure on fertility status of soil*

| Properties | Initial values 1983 | Level of FYM addition (ha$^{-1}$ yr$^{-1}$)<br>1989 | |
|---|---|---|---|
| | | 0 | 10 |
| Organic carbon (%) | 0.27 | 0.25 | 0.33 |
| Available phosphorus (ppm) | 6.31 | 5.68 | 8.00 |
| Available manganese (ppm) | 5.54 | 5.60 | 5.86 |
| Available iron (ppm) | 2.00 | 2.09 | 2.18 |
| Available copper (ppm) | 0.16 | 0.16 | 0.19 |
| Available zinc (ppm) | 0.13 | 0.37 | 0.45 |
| Available nitrogen N (kg ha$^{-1}$) | 140.0 | 138.6 | 144.3 |

Source : Aggarwal and Praveen-Kumar (1994)

**Table 8** *Effect of crop residues on the straw yield (t ha$^{-1}$) of pearl millet.*

| Treatment | Residue | | | | | |
|---|---|---|---|---|---|---|
| N kg/ha | CB | | PM | | MB | |
| | NR | R | NR | R | NR | R |
| 0 | 0.75 | 1.12 | 0.81 | 0.96 | 0.83 | 0.98 |
| 20 | 1.19 | 1.50 | 1.10 | 1.14 | 1.02 | 1.41 |
| 40 | 1.21 | 1.44 | 1.20 | 1.28 | 1.22 | 1.32 |
| CD (P = 0.05) | | | | | | |
| Residue | 0.16 | | 0.16 | | 0.18 | |
| N levels | 0.16 | | 0.12 | | 0.08 | |
| Residues x N | NS | | 0.20 | | 0.19 | |

CB Cluster bean PM pearl millet MB Mung bean

Source : Aggarwal *et al.* (1993)

reported a decrease in bulk density and hydraulic conductivity of soil with the practices of residue management. They also reported an increase in hydraulic cunductivity of soil. Prasad and Power (1991) after reviewing a variety of results concluded that leaving organic residues in soil surface is likely to increase the hydraulic conuctivity and infiltration rate in soil.

*Legume based crop rotation :* Growing one crop on same piece of land may have adverse effect even under good fertility management conditions. Mann and Singh (1977) observed 62% reduction in pearl millet yield in pearl millet-fallow rotation in contrast to green gram-pearl millet. Singh (1980) reported that among single crop systems pearl millet-fallow rotation proved to be most remunerative from both yield and monetary return point of view. Among double cropping system pearl millet-cluster bean gave highest returns, per unit area (Mishra 1971). On the basis of the results of a long term study Singh *et al.* (1985) also reported that in arid soils of Jodhpur the yield of pearl millet in pearl millet-cluster bean rotation was 11% higher in comparison to continuous growing of pearl millet. Similar results were also obtained by Oswal *et al.* (1989) in rainfed soils of Haryana. The beneficial effects of legume cultivation may be attributed to the improved soil fertility (Table 9) (Das & Rao 1986, Oswal *et al.* 1989, Aggarwal & Praveen-Kumar 1993). Singh *et al.* (1985) in a long term study found an increase in soil organic carbon by 12% and available soil P by 25%.

The perceptible increase in the yield of sorghum with pea nut, mung bean and cowpea as preceeding crop was obtained by Singh and Das (1984). Singh and Singh (1977) on the basis of a long term study reported that cultivation of green gram in rotation with pearl millet supplied with 20 kg N ha$^{-1}$ gave similar yield as with direct application of 40 kg N ha$^{-1}$. In other words, growing of legume had an effect equivalent to 20 kg N ha$^{-1}$. However, there are differences on such legume effect with different grain legumes. For instance Singh *et al.* (1985) observed that rotation of peral millet with green gram or clusterbean was better than its rotation with moth bean. Reddy *et al.* (1993) reported that the yield and total N uptake of sorghum was maximum after green gram cultivation.

The intercropping of pearl millet and legumes in arid soils have also shown promising results (Mishra 1971, Punjab Singh & Joshi 1980, Sing *et al.* 1978).

## Conclusion

The foregoing discussion reveals that the soils of arid region suffer in general from two stresses that of nutrients and moisture. Due to these constraints, the yield levels of crops and efficiency of applied nutrients is generally low. Amongst the plant nutrients, soils are quite low in N and organic carbon and the crops do respond to nitrogen in all climatic situations. Because of variable yield levels in this arid region and weak socio-economic status of farmers, there is need to build-up and maintain soil nitrogen through integrated nutrients management by mobilizing the on-farm organic sources.

**Table 9** *Organic carbon and N-forms in soil as affected by cultivation of legumes for three years.*

| Treatments | Organic carbon % | Total – N ppm | Mineralized – N ($NH_4+NO_3$) ppm | Total hydrolysable N ppm |
|---|---|---|---|---|
| Fallow | 0.160 | 230.0 | 15.7 | 112.0 |
| Mung bean | 0.180 | 252.0 | 33.6 | 175.0 |
| Moth bean | 0.184 | 240.8 | 35.8 | 168.0 |
| Cluster bean | 0.184 | 249.2 | 47.0 | 175.1 |

Source : Aggrawal & Parveen Kumar 1993

Researches on rainfed agriculture, have shown the beneficial effect of integrating organic sources with inorganic sources of N for sustainability of yields. Better management of fertilizer N by regulating the ammoian volatilization processes also helps in enhancing its efficiency. Further research is needed on (a) establishing fertilizer N rates on the basis of total nutrient requirements for the cropping system under variable moisture conditions and availability of N through soil, organic and biological resource while taking into account fretilizer efficiency, (b) utilization of on-farm organic sources (plant and animal) and their management for higher N availability and fertility maintenance.

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