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On-Farm Measurements of pH, Electrical Conductivity and Nitrate in Soil Extracts for Monitoring Coupling and Decoupling of Nutrient Cycles

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ABSTRACT

Concepts of interacting nutrient and proton cycles, "decoupling" of mineralization and uptake, and the steady state soil solution, developed mainly to assess impacts of acid rain on forests and their catchment waters, are very pertinent to biological agriculture. In particular, they illustrate how decoupling of soil-plant nitrogen cycling also decouples cycling of protons and basic cations (chiefly Ca, Mg, K), and can result in acidification of soil and in loss of cations as well as of nitrate. In biological agriculture, loss of cations may be more important than loss of N because there is no equivalent to biological nitrogen fixation to replace them. It is proposed that on-site measurements of pH, EC (electrical conductivity) and nitrate (using semiquantitative nitrate strips) in 1:1 water extracts of soil are convenient tools for on-site monitoring of coupling/decoupling phenomena. Values of pH, nitrate and EC of soil samples taken from a variety of soil types, crops and farming systems are reported and relationships between the variables are examined. Several practical questions examined in the course of the studies provide examples of how the measurements can be of value in biological husbandry.

As predicted, there were strong linear relationships between nitrate concentrations and EC for samples from a given system or region. For many purposes, EC values give the same type of information as nitrate values, and are simpler and cheaper to obtain. Values of EC and nitrate were lowest under sod, intermediate in cultivated ground, and highest in cultivated ground to which manures or compost were added. In a laboratory experiment, growth of plants was found to reduce soil extract nitrate and EC to a greater extent than did incorporation of immobilizing residues. In eight comparisons of soils from potato or grain crops grown organically with those from crops grown with synthetic fertilizer on the same or nearby farms in eastern Canada and Maine (USA), EC values were consistently lower, and nitrate values the same or lower under organic management; there was a trend for pH to be higher under organic management. The techniques were used to monitor seasonal changes in the soil soluble nutrient pool and in lettuce tissue nitrate in an intensive organic vegetable production system on Vancouver Island, and to examine an intensive organic crop/livestock system in Colombia for possible sites of leakage of nutrients.

INTRODUCTION

Management of nutrient supply in ecological farming requires attention to the long term input/output balances of the major nutrients (Kaffka & Koepf, 1989; Patriquin *et al.*, 1986) and to seasonal patterns in the mineralization of organic N by soil organisms and uptake of the mineral N by crops (Howard, 1940; Doran *et al.*, 1987). When mineralization and uptake are "decoupled" (Ulrich, 1987), or when an excess of N is applied as fertilizer, nitrate accumulates; nitrate is poorly absorbed if at all in most soils and is lost readily by leaching and denitrification. Nitrate leached from agricultural systems contributes to eutrophication of surface waters and to non-potability of surface and ground waters (Croll & Hayes, 1988; Hill, 1982; Schroder, 1985; Strebel *et al.*, 1989).

In fertilized, annual cropping systems, loss of N typically amounts to 25 to 50% of that applied (see for example, Keeney, 1982; Cooke, 1977; Rosswall & Paustian, 1984). Some of the loss occurs directly from applied fertilizer, but in modestly fertilized annual cropping systems, some or most of the loss occurs after harvest when mineralization of organic N continues but uptake of nitrate ceases or is greatly reduced (Adams &Pattinson, 1985; Croll & Hayes, 1988; Strebel *et al.*, 1989). The total and relative amounts of N left in the soil as nitrate and contained in residues at harvest varies greatly between crop species (Wehrman & Scharpf, 1989). Very high losses can occur when N rich legume residues are ploughed into the soil (Adams & Pattinson, 1985). Losses from sod are generally low except under very intensive fertilization; however, large losses can occur when sod is broken (Croll & Hayes, 1988; Strebel *et al.*, 1989).

Loss of nitrate via leaching is accompanied by acidification of soil and loss of nutritive cations (Helyar, 1976; Ulrich, 1987), which may be as significant as the loss of N. In Atlantic Canada it is estimated that 74% of the lime requirement in agricultural soils is attributable to acidifying effects of N fertilizer and 26% to acid rain (Bird & Rapport, 1986); the energy involved in extracting, grinding and applying lime to soil accounts for 27.8% of the total annual energy expenditure in growing grain, and use of N fertilizer, for 18.1% (Lovering & McIssac, 1976), i.e. the energy requirements generated by the indirect effects of N fertilization are approximately equivalent to those generated directly by use of N. In biological farming systems, especially in developing countries, the loss of cations associated with leaching of N may be more serious than the loss of N because there is no equivalent to biological N_2 fixation to replace them.

Farmers can reduce losses of N by practices such as ploughing in straw to immobilize N, planting catch crops and reducing the need for fertilizer supplements; the latter is achieved, for example, by taking into account residual and easily mineralizable N in the soil profile (Addiscott *et al.*, 1991;

Dynisveld *et al.*, 1988), giving N "credits" for legumes in the rotation (El-Hout & Blackmer, 1990), and by synchronizing release of nutrients through decomposition and plant uptake as closely as possible (Doran *et al.*, 1987; Papendick *et al.*, 1987). To the extent that farmers can make better use of on-farm supplies of N, expenditures for fertilizer supplements can be reduced. In the case of organic farms relying mostly on on-farm resources for N, the benefit is often increased yield (Brinton, 1985; Doran *et al.*, 1987).

The efficacy of various techniques for conserving and supplying N depends to a large extent on site-specific environmental and management factors (Dynisveld *et al.*, 1988). Simple on-farm techniques for monitoring decoupling and coupling of the soil-plant system at the soil solution level could help farmers and researchers to develop systems that ensure adequate supplies of nutrients for crops when they need them, while minimizing losses of nutrients, acidification of the soil and expenditures for fertilizers. It is proposed that measurements of pH, EC (electrical conductivity) and nitrate in 1:1 water extracts of soil can fill this role, at least partially. The measurements can be made on-site using relatively inexpensive battery-powered instruments with electrodes for pH and EC, and semiquantitative colour comparison strips for nitrate (e.g. Hunt *et al.*, 1979; Anonymous, 1990).

Measurements of pH and, to a lesser extent, of nitrate in water extracts of soils are already conducted fairly routinely. pH measurements are most commonly conducted to determine lime requirements. Howard (1940) used data on nitrate, temperature and rainfall to characterize the seasonal cycle of turnover of nutrients in a sugarcane system in Northern India and to indicate when a green manure crop might best be introduced and turned under. Because of concerns over nitrate pollution and costs of fertilizer-N, there is a trend, when making recommendations for fertilizer-N, to reduce rates in proportion to amounts of nitrate in the soil profile before fertilizer application (e.g. Magdoff *et al.*, 1984; Blackmer *et al.*, 1991), and a variety of commercial kits and procedures have been introduced for determining soil nitrate in the field (Seim & Davis, 1990).

Measurements of EC are commonly used to monitor nutrient solutions in hydroponics systems (N. Kungl, Glasshouse hydroponics operator at Falmouth, N.S., personal communication; FA0, 1990), and sometimes to monitor nutrients in solid media (e.g. Adams & Winsor, 1973). Measurements of EC of water extracts of field soils are generally made routinely only when there is concern about excess salt build-up (Rhoades, 1982). It was considered that EC values might be useful as relative measures of the total quantity of ions in the soil solution, and therefore of the relative potential for losses of soil nutrients by leaching. Because the total quantity of ions in solution and the proportions of different ions can change as the dilution is increased, particularly in calcareous soils (Black, 1968; Rhoades, 1982), EC and ionic composition of 1:1 soil extracts are not reliable as absolute measures of the composition of the soil solution *in situ.* However EC should be valid as a relative measure of the concentration of ions in the soil solution within a particular soil type.

It was expected to find positive correlations between EC and nitrate, at least for organic farms in which large quantities of fertilizer salts such as potash were not being used. In cultivated soils, nitrification tends to be the most important biological process acidifying soil and bringing cations into solution (Black, 1968). Although positive relationships between nitrate and cations have been reported (e.g. Desai & Subbiah, 1951, cited in Black, 1968), and electrical conductivity is related closely to the total concentraton of cations (Rhoades, 1982), there appear to be no reports on the relationships between nitrate and EC.

In this paper, values of pH, nitrate and EC in 1:1 water extracts of soil samples taken from a variety of soil types, crops and farming systems are reported and relationships between these variables are examined. A laboratory experiment was conducted to compare the effects of adding an organic fertilizer (crab meal), of plant growth, and of adding straw (which we would expect to immobilize nutrients) to soil on the same variables and on ionic composition of soil extracts.

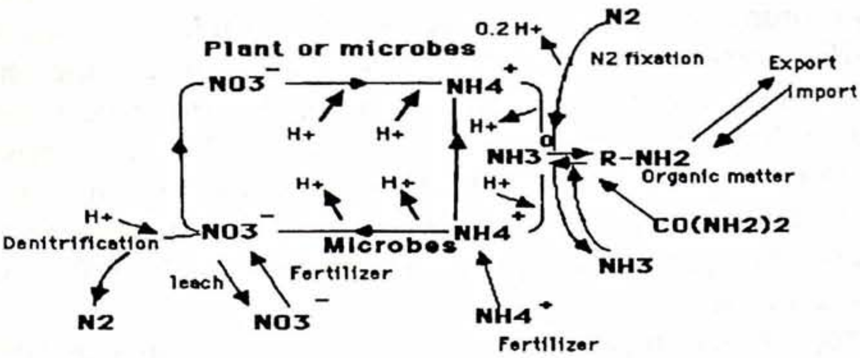
Several practical questions examined in the course of the studies provide some examples of how these types of measurements can be of value in biological husbandry: (i) Could pH, nitrate and EC data be used to distinguish between organically fertilized and conventionally fertilized soils in eastern Canada? (ii) How much N in crab meal, a material being used by organic farmers in eastern Canada, is likely to be made available in one season? (iii) Are there excessive levels of nitrates in soils and lettuce in an organic vegetable operation on Vancouver Island utilizing large inputs of composted sewage sludge and bloodmeal? (iv) What are some possible sites of leakage of nutrients in an intensive, organic crop/livestock system in Colombia?

BACKGROUND: INTERACTION OF NUTRIENT AND PROTON CYCLES AND THE CONCEPT OF COUPLING AND DECOUPLING OF NUTRIENT CYCLES

Besides affecting the availability of N to plants and the movement of N into aquatic systems, the manner in which N cycles in an ecosystem has important effects on the flows of protons (Fig. 1a) and hence on soil acidity. Through ion exchange, proton flows have a direct effect on the movement of cations into and out of the soil solution (Fig. 1c); in the soil solution, cations are subject to loss by leaching and runoff together with nitrate (Black, 1968). Soil acidity affects availability or mobility of nutritive (P, minor nutrients) and potentially toxic elements (chiefly Al, Mn,) (Black, 1968; Brady, 1974).

Most of the individual processes that affect soil acidity and leaching of nitrate and cations have been known for some time, e.g. the influence of nitrification and use of N fertilizers on soil acidity (Waksman, 1927), effects of acidification on leaching of cations (Black, 1968), the influence of the form of N and the cation/anion balance during nutrient uptake on rhizosphere acidity (Pierre *et al.*, 1970; Kirkby, 1969; Raven & Smith, 1976), and the acidifying effects of legumes (Nyatsanga & Pierre, 1973).

a. Cycling of nitrogen and protons:



b. Plant uptake of nutrients in ionic form/mineralization:

$$a\ CO_2 + b\ NO_3^- + c\ HPO_4^{2-} + d\ SO_4^{2-} + \ldots + g\ Ca^{2+} + h\ Mg^{2+} + i\ K^+ + k\ NH_4^+ + y\ N_2 + H_2O + (b+2c+2d-2g-2h-i-k)H^+ \rightleftharpoons \{C_a N_{b+k+2y} P_c S_d \ldots Ca_g Mg_h K_i H_{2x} O_x\}_{biomass} + (a+\ldots)O_2$$

c. Proton/cation exchange:

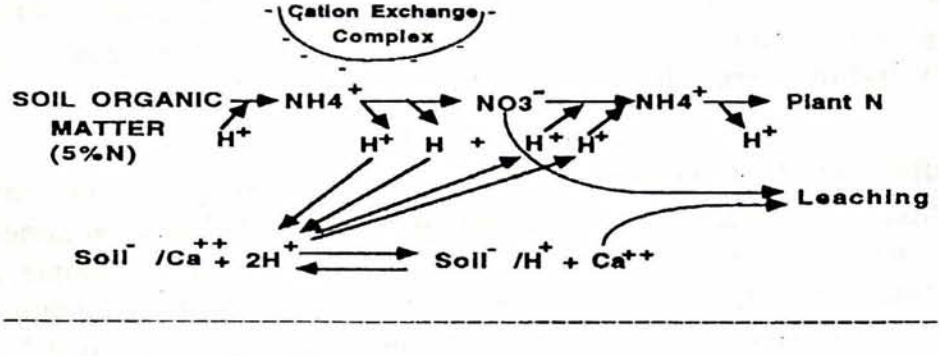


FIGURE 1. Biological processes producing and consuming protons and chemical equilibria affecting soil solution cation concentration and EC. (a): Consumption and production of protons during cycling of nitrogen (after Helyar, 1976; Raven & Smith, 1976). (b): Uptake of nutrients in ionic form/mineralization (after Ulrich, 1987). (c): Proton/cation exchange.

Helyar (1976) appears to have been the first to describe how the *cycling of nitrogen* at the agroecosystem level interacts with the *cycling of protons* (Fig. 1a) and of other nutrient ions (Fig. 1b), and to discuss its implications for management. He emphasized that "the cycling of nitrogen in an ecosystem is neutral, whether or not the acidifying nitrifying reaction occurs in soil . . . because the reverse (alkaline) process of nitrogen reduction occurs within the plant or microorganisms." Acidification is generated when nitrogen is lost from the system, or accumulates in it in a different form from which it was added. Helyar (1976) discusses ways in which inputs can be manipulated to minimize acidification.

Reuss (1977) considered the question of how cycling of protons associated with sulphur and nitrogen cycles compares to inputs of acidic compounds, or compounds that can generate acidity, in rainfall. Subsequently, the concepts of interacting proton and nutrient cycles were developed and tested mainly in connection with efforts to assess the impact of acid rain on forests and whole watersheds, i.e. for systems that are much less amenable than agroecosystems to liming and fertilization to mitigate effects of acid rain. In order to predict the longer term impact of acid rain, it is necessary to determine how much acidity is generated internally by natural phenomena and by practices such as clear cutting and the export of forest products (Rosenqvist *et al.*, 1980; Ulrich, 1987; Binkley & Richter, 1987).

Following approaches similar to those used in forestry, Coote *et al.* (1989) constructed a model to compare effects of the acidifying components of acid rain and of fertilizers on soil lime requirement. The model provided a considerably better prediction of lime requirements than traditional methods.

The concepts of nutrient/proton cycling, decoupling of nutrient cycles, and the steady state soil solution as elaborated by Helyar (1976), Reuss (1977), Ulrich (1983, 1987) and others are emerging as important ecosystem level concepts (Schulze & Zwolfer, 1987). They have as yet received little recognition in literature and texts dealing with agroecology or systems level aspects of agroecosystems (e.g. Eijasacker & Quispel, 1988; Lampkin, 1990). Following is a summary of points particularly pertinent to biological husbandry and to interpreting observations reported in this paper.

1. The effect of N transformations alone on proton generation and consumption can be determined by adding up the number of protons gained or lost at each step along the pathway of interest (Fig. 1a). For example, a nitrogen atom entering a system as ammonium and leaving it via leaching, denitrification or export of organic N, would result in net production of 2, 1 and 1 protons respectively. Seasonal patterns of proton consumption and production can be inferred by relating proton movement for individual steps to the time of year that those steps predominate. For example, a sequence in

which ammonium first accumulates (e.g. before soil warms up, or drains sufficiently to support nitrification) then nitrate (early in the season before there is much plant growth), followed by plant uptake of nitrate, would be accompanied by consumption, production and consumption of protons, respectively.

2. Other biological processes affect the production of protons. The net production of protons during plant uptake is stoichometrically equal to the equivalents of cations minus anions taken up; the net production during decomposition, to the equivalents of anions minus cations released or (in the case of nitrate and sulphate) produced (Fig. 1b; Reuss, 1977; Ulrich 1987; Haynes, 1990).

Similarly, the net annual production of protons in an ecosystem or a compartment of the ecosystem is a function of the cation and anion content in material flows into and out of the system (e.g. in rainwater, groundwater, harvested materials, eroded soil), and of the cation and anion flow associated with net changes in storage pools within the system (e.g. due to net increases or decreases in biomass or soil organic matter) (Ulrich, 1987; Verstraten *et al.*, 1990).

3. Transformations of N tend to have a dominant influence on the flows of protons in soil systems because: (i) oxidations and reductions of inorganic N release and consume protons respectively (Fig. 1a), (ii) N can be taken up as a cation or an anion and (iii) because of the large amounts of N circulating compared to S (which also undergoes oxidations and reductions) and to other nutrients taken up as charged species (Fig. 1b; Reuss, 1977; Ulrich, 1987).

4. Differences in seasonal patterns of proton movement and in net annual changes in acidity between different ecosystems are determined largely by the extent to which ammonium is nitrified and taken up as nitrate rather than as ammonium, and by the quantity of nitrate lost via leaching. In agroecosystems, nitrate is commonly the major form in which N is taken up, and commonly the uptake process is alkalinizing (Pierre *et al.*, 1970; Pierre & Banwart, 1973) and therefore decomposition of plant residues is acidifying (Fig. 1b). (These are net or mean effects; there will be spatial and temporal deviations from the mean effects). A quantitative model that incorporates most of the processes in Figure 1 and that provided a good prediction of observed changes in soil acidity, suggests that leaching of nitrate is the most important factor contributing to net acidification of soil in typical agroecosystems (Coote *et al.*, 1989).

5. There are important species—specific exceptions to the generalization that plants taking up nitrate alkalinize the rhizosphere. An example is buckwheat, which has an exceptional ability to take up Ca and Mg, thereby acidifying the rhizosphere even when growing on nitrate; this may be a factor in the ability of

buckwheat to take up P from low P soils (Bekele *et al.*, 1983). Also, there may be microscale variations along the root in response to nutritional limitations (Haynes, 1990).

6. The protons produced during nitrification exchange with basic cations (Ca, Mg, K, Na) on the cation exchange complex, bringing them into solution where they may be lost by leaching together with the nitrate (Fig. 1c). The processes are reversed when nitrate is taken up; however, if plant uptake lags behind mineralization and some nitrate is lost in the interim, basic cations are also lost, resulting in a net increase in acidity (Black, 1968; Ulrich, 1987). In the context of attempting to close nutrient cycles in biological husbandry (Hodges, 1982), the loss of cations is more critical than loss of N because there is no equivalent to biological N_2 fixation to replace them.

Besides nitrate, the principal anions that function as counterions for cations in the soil solution are bicarbonate, organic anions, sulphate and chloride. In alkaline soils, there is significant leaching of cations in association with bicarbonate (produced by respiratory activity), which contributes alkalinity to receiving waters. As pH drops below 7, this process becomes much less significant because of protonation of bicarbonate and because of degassing when soil solutions with elevated CO_2 become exposed to lower PCO_2. Organic anions can be important in organic soils (Reuss & Johnson, 1986; Robarge & Johnson 1992; Ulrich, 1989).

7. A variety of buffer systems operating at different pH ranges, including calcium carbonate (pH >8 to 6.2), silicate buffers (pH 6.2–5), cation exchange buffer (pH 5.0–4.2), aluminum buffer (pH 4.2–2.8), and iron buffer (pH 3.8–2.4), modify effects of proton fluxes on soil solution pH (Ulrich, 1987; pH's cited are those in salt solution, pH values in water are higher). Generally only calcium carbonate in the fine soil fraction and cation exchange buffers are important in shorter term acid buffering of agricultural soils (Coote *et al.*, 1989; Levine & Ciolkosz, 1988).

8. The acid-buffering capacity due to ion exchange (Fig. 1c) is a function of the total cation exchange capacity of the unit under consideration, and percent BS (base saturation). For a kaolonitic clay, Coote *et al.* (1989) found that the removal rate of basic cations by leaching was close to 1.0 at BS values of 80% and above; below BS 80%, the removal rate decreased reaching a value of approximately 0.35 at 20% BS, i.e. for this clay, buffering is incomplete when the BS falls below 80%, and an increasing fraction of any nitrate leached is accompanied by protons (or acidic aluminum cations) rather than basic cations.

9. Below 15–20% BS, (corresponding roughly to pH 4.2 in salt or circa 4.5 to 5 in water), aluminium is mobilized through ion exchange and dissolution reactions (Ulrich, 1987; Reuss & Walthall, 1989), reaching concentrations in

the soil solution which are phytotoxic to many crop species (Black, 1968; Taylor, 1989).

10. Besides nitrification, an important source of acidification in some agroecosystems is legume N_2 fixation which is not considered in the model of Coote *et al.* (1989). The nitrogen-fixing process itself is only mildly acidifying (Raven & Smith, 1976; Fig 1a; many researchers consider N_2 fixation to be neutral in regard to proton movement). However, nitrogen-fixing legumes tend to take up a large excess of cations over anions during N_2 fixation, acidifying the rhizosphere (Fig. 1b; Liu *et al.*, 1989). This process is reversed when the legume biomass decomposes. Export of legume biomass removes the decomposition system that would otherwise reverse the acidification that occurs during growth of the legume, and thus export of legume biomass can be strongly acidifying (Nyatsanga & Pierre, 1973; Liu *et al.*, 1989). Retaining the biomass can also be strongly acidifying, if fixed N is subsequently lost by leaching, e.g. when legume residues are ploughed in (Adams & Pattinson, 1985).

11. Ulrich (1987) notes that the turnover of charged (ionic) substances occurs almost entirely through the soil solution, and therefore that the soil solution is very sensitive to deviations from steady state flows of materials through and within an ecosystem. Localized or transient deviations from the steady state create stress (e.g. due to solubilization of aluminium) and a risk for losses by leaching, which can lead to longer term changes. He maintains that "ecosystems are developed and structured by organisms in such a way that a steady state is approached as closely as possible under existing environmental conditions. The more closely the steady state is approached, the longer the systems can maintain their own chemical state, and the less they change their chemical environment. A close approach to the steady state is therefore the precondition of maintaining ecosystems for time periods which are necessary for the evolutionary adaptation of organisms to their environment."

12. To maintain a steady state, decomposition and uptake processes must occur in the same compartment, and at the same rates. Ulrich (1987) proposes three reasons why natural terrestrial ecosystems become decoupled, and therefore deviate from a steady state, creating risks of transient or longer term stresses:

(i) Spatial decoupling of ion uptake and ion release, for example when leaf litter is deposited on the surface of the soil and root uptake occurs some distance below. Soil fauna help to create a steady state by mixing leaf litter into the mineral soil and producing porous crumbs.

(ii) Temporal decoupling due to climatic variability: high climatic variability means that the system oscillates around a mean value, the oscillations being caused by differential effects of climatic change on primary and secondary producers, e.g. in cool, wet years, the activities of decomposers may be reduced more than those of plants while the reverse is true in a warm/dry year. In the latter case, formation of nitrate can exceed uptake by plants considerably, resulting in a "mineralization and acidification push", and in ample nitrate, but increasing the risk of acid stress and loss of nitrate. Cool wet years, on the other hand, represent periods of low N supply, ~~decreasing pH values and~~*lowering the risk of acid stress and nitrate loss. Typically, seasonal acidification pushes occur in spring and fall, especially after prolonged dry periods during the summer. (iii) Temporal decoupling due to the limited lifespan of organisms, e.g. during the regenerative phase following die back of old dominant trees.

Decouplings may be accentuated by forestry practices such as clear cutting (which interrupts plant uptake and dries and warms the soils).

Application of the decoupling concept to agriculture

In agriculture, decouplings operate at the natural scale, but more than in forestry, are accentuated and ameliorated by management.

Many agricultural activities decouple mineralization and uptake systems, while others act to recouple or accelerate coupling of the two processes. Cultivation of soil containing weeds or crops and harvesting of crops, cause temporal decoupling by physically disrupting plant uptake. Many crops are selected to mature in a limited time interval, and are commonly harvested *en masse* (rather than selectively), resulting in abrupt declines of plant uptake. Practices such as minimum till reduce the aerial extent of decoupling due to cultivation. Practices such as relay cropping, catch cropping and cover cropping function to re-establish or couple the decomposition and uptake systems quickly following harvest of a crop (Duynisveld *et al*., 1988), thereby increasing the "resilience" (Vitousek *et al*., 1981) of the nutrient cycling system.

Earthworms and other soil fauna may be important agents of spatial coupling, as suggested by Ulrich (1987). Patriquin *et al.* (1986) documented an increase in pH and Ca in surface horizons after a farm changed from conventional to organic management. They suggested that it resulted in part from an increased abundance of dandelions and associated activity of earthworms after the change, the earthworms transporting calcium, leached deep into the subsoil during chemical management, back to the surface.

The removal of organic materials from sites of production can be regarded as spatial decoupling; in that case, recoupling occurs by recycling, and importation of fertilizing materials (imported also to compensate for erosion, runoff and leaching losses). Then there is often some difficulty recoupling or synchronizing the nutrient-supplying and plant uptake systems. In organi-

*correction made in reprint

cally managed systems, lack of synchronization often results in nutrient limitation for crop growth even when the total quantities of nutrients applied are adequate; alternatively, it may result in transient excesses of nitrate and cations in the soil solution which can lead in turn to losses, to toxic levels of nitrates in crops (Lorenz, 1978) and may exacerbate weed (Patriquin, 1988) and pest (Mattson, 1980) problems.

MATERIALS AND METHODS

Sampling sites

(i) Samples were taken from 27 organic and transitional farms located in the province of New Brunswick (Canada) and the state of Maine (USA) in northeastern North America. Sampling was conducted over the period June 10 to June 29, 1989. The farms were visited in conjunction with third party certification inspections by the first author for the Organic Crop Improvement Association of New Brunswick and for the Maine Organic Farmers and Gardeners Association. The farms are located in southern and western New Brunswick and in northeastern Maine. One set of samples was taken from a transitional farm in Prince Edward Island, Canada. For most of this region in 1989, most of the summer crops were planted or transplanted between May 10 and June 10. All soils had sand or sandy loam textures.

(ii) In 1990, samples were taken over the course of two cycles of lettuce production at an organic vegetable operation located near Comox, Vancouver Island, British Columbia in western Canada. This system employs large quantities of compost prepared from septic tank sludge, cow manure, crop residues, and wood chips. Prior to planting each crop, compost is spread on the soil to a thickness of approximately 2 cm and bloodmeal is applied at a rate of approximately 7.5 kg/10 square metres; the amendments are rototilled into the soil to a depth of 15–30 cm prior to planting the crop. The soil is a gravelly loam; the mixed compost/soil has 16–22% organic matter. A sample of the compost had a bulk density of 0.24; N 1.125%, C 28% (dry basis).

(iii) In March 1991, samples were taken from fields, compost piles and ponds at IMCA (Instituto Mayor Campesino), located at Buga, near Cali, Colombia, where they are practicing "CIPAV technology" (Preston, 1990; Murgueito, 1990). The samples were taken during a one day workshop on soil processes in biological farming systems. The soil types are mollisols with some characteristics of ultisols; texturally, they are clays or clay loams.

Soil sampling and analyses

Soils at (i) and (ii) were sampled with a standard 1.8 cm internal diameter soil corer inserted to a depth of 15 cm (i) or 30 cm (ii). For comparisons of organic and conventional fields, 40 cores were taken throughout a field; all fields were larger than 1 acre (0.4 ha). For many of the other comparisons, the scale of the vegetation/soil type being sampled was much smaller, and fewer cores were taken, but not less than ten. Ten cores were taken for each sample to be analyzed at site (ii), and these were separated into top (0–15 cm) and bottom (15–30 m) horizons. At (iii), a spade full of soil was taken from three separate sites within each vegetation/soil type.

The individual samples were mixed thoroughly, and spoonfulls of soil transferred into a 200 ml wide mouth plastic bottle to give 100 g fresh soil in total, weighed with a 500 g spring balance, or on a top-loading electronic balance. 100 ml of distilled water were added, and the bottle closed and shaken vigorously by hand for 30 seconds three times over the ensuing five minutes. In the case of soil (iii), more vigorous and longer shaking was required to completely disrupt soil aggregates. The cap was removed and soil allowed to settle for about two minutes. Approximately 10 millilitres of the suspension were poured onto a 9 cm diameter Whatman # 1 filter held in a plastic funnel to obtain some clear liquid for the nitrate test. It usually took about five minutes for sufficient liquid for a test to run through the filters. "Merckoquant" nitrate test strips (E. Merck, Darmstadt, Germany) were wetted with the filtrate and the intensity of the pink colour that developed was compared after one minute with standard colours for 0, 10, 25, 50, 100, 250 and 500 mg/L nitrate per litre. Interpolations were made as appropriate, usually to within not more than two divisions between the given colours (e.g. 150, 200 mg/L nitrate). When the values were in the upper part of detection range, samples were diluted and read again.

At (i), an EC electrode was inserted into the suspension, holding it above the settled sediment and the EC read using a Horizon Ecology Co. (Chicago, Illinois) EC meter. Finally, a combination pH electrode was immersed into the supernatant to a depth of approximately three cm, and the pH read using a Corning Model 610A pH meter. The EC meter was calibrated using a 1990 μS/cm (at 25°C) standard. The pH meter was calibrated using ph 4, 6 and 7 buffers. Electrodes were washed with distilled water and wiped with tissue after each reading.

At (ii) and (iii) EC and pH measurements were made using a Cole Parmer (Chicago, U.S.A.) "Water Test" meter, # 05556–00. This meter measures temperature, EC, pH and oxidation/reduction potential. The EC calibration is not readily adjusted, so instead of adjusting the calibration with each set of measurements for which the extract temperature might vary, the temperature was recorded and the EC values adjusted to 25°C using a EC-temperature relationship for potassium chloride (Taras *et al.*, 1971).

Composts

Samples of compost were diluted one part fresh weight of compost to three parts of water by volume. Values for conductivity and nitrate were multiplied by three to give values that could be compared approximately with values for soils in 1:1 soil to water extracts.

Nitrate in plant tissues

At site (ii), 6 lettuce plants were collected, combined, and a 5 g fresh weight sample ground using a mortar and pestle. The ground sample was shaken with 50 ml of distilled water. The concentration in the extract was determined using Merckoquant nitrate strips, as for the soil nitrate. Subsequently it was found that the level of nitrate extracted increased by a factor of 2.07 if the pulp was allowed to sit for one hour with occasional mixing. (Anonymous (1990) recommends 15 minutes with frequent stirring). Accordingly, the original values were multiplied by 2.07.

Laboratory experiment

An experiment was conducted to test effects of adding organic materials to the soil and of plant growth on soil extract EC, pH and ionic composition. The soil was one that had been collected from under corn at Farm 3 in eastern Canada on June 29, and stored in a burlap sack at ambient temperature. On July 5 it was sieved through a 1 mm sieve, and 110 g portions mixed with 300 g portions of silica sand. Each mixture was placed in a 1 L Mason jar or in a 4 inch diameter plastic pot and 39 ml distilled water added. This soil-sand-water mixture provides optimal aeration and moisture for mineralization and nitrification of N (Bremner, 1965). The jars were closed with polyethylene and the pots were enclosed in polyethylene bags to stop water loss but allow gas exchange. On July 17, soil was dumped out of the containers and 0.8 g of straw from winter wheat (0.38% N) cut into small pieces (approximately 0.5 cm), or 0.8 g of crab meal (5.0% N) were mixed thoroughly with the soil; control soils were similarly mixed. The soils were put back in containers. Eight oat seeds (cv Rodney) were planted in each of the pots. Jars were incubated at room temperature in the dark at room temperature (approximately 22°C.), distributed in a Randomized Complete Block design. Pots were placed approximately 15 cm below a bank of fluorescent lights operated on a 16 h day, 8 h night cycle at room temperature; light intensity was approximately 65 Wm^{-2} PAR. Water was added to jars and pots to make up for losses which were determined by weighing; no overflow or leaching from pots was allowed to occur.

There were 10 jars or pots for each treatment (soil only, soil+ straw, soil+ crab meal, soil+ oats). On August 14 and September 8, five pots or jars were removed from each treatment. Soil and plants in pots were dumped out, plants removed and the soil placed in jars as for other treatments. 100 ml distilled water were added to the samples in jars, which were closed and shaken vigorously for 30 seconds. Some of the suspension was poured into 50 ml conical tubes which were centrifuged at 5000 r.p.m. for 10 minutes. pH, EC and nitrate were measured on the supernatant liquid for each sample as for field samples. Twenty millilitres were taken from each sample and combined with other samples from each treatment to make a 100 ml composite sample which was suction filtered through a 0.45 micron filter, frozen and later analyzed at the Nova Scotia Environmental Chemistry Laboratory (Halifax, N.S., Canada) for major anions and cations.

The amount of water added to the soil/sand mixture initially plus that used for extraction resulted in a ratio of water to dry soil approximately equal to that when the soil was sampled in the field: field soil had a moisture content 19.5%, the soil used in the experiment, 13.3%; the calculated ratios of water to dry soil at extraction are 1.5:1 and 1.6:1 for the field and experiment soils respectively.

Lysimeter experiment

Observations on soil pH, EC and nitrate were made on soils in two successive lysimeter experiments set up for other purposes. The lysimeters are 1.2 m diameter× 0.6 m depth concrete cylinders; they have drainage exits and are filled with a B horizon soil with sandy loam texture. One cylinder in each of six pairs of cylinders had been amended with 10 kg of farm compost in 1987 (these are designated High Fertility or HF cylinders; others are designated Low Fertility or LF cylinders). In each cylinder, six open ended plastic buckets, 31 cm diameter by 27 cm height, were inserted to a depth of 22 cm. On May 1, 1991, different fertilizer treatments were applied within the buckets and mixed into the top 15 cm; then fababeans (5/pot, later reduced to 3) were planted. The fertilizer treatments were: no addition, urea-N at 152 kg N/ha; superphosphate at 166 kg P_2O_5/ha; potassium sulphate at 100 kg K_2O/ha; and gypsum at 186 kg Ca/ha. Three soil cores (1.8 cm diameter× 15 cm depth) were taken from each pot on June 27, and analyzed for pH, EC and nitrate.

Composite soil samples were obtained from the plus and minus compost cylinders on May 1 before adding fertilizers.

The fababeans were harvested August 10. On August 27, buckets were removed, all plant material was removed, and the surface 30 cm of each cylinder thoroughly mixed. Buckets were reinserted, and on August 29, new fertilizer treatments were set up with 50 kg N/ha (intended) added in the form of urea, mixed synthetic N-P-K fertilizer (11–11–11 formulation), spent grain, and spent yeast from a brewery; actual rates for the spent grain and yeast based on subsequent analyses of these materials were 40 and 39 kg N/ha respectively. Annual ryegrass and oilseed radish were each planted in 3 LF and 3 HF cylinders. On September 18, when plants were just coming out of the seedling stage, three soil samples to 10 cm depth were taken from each pot with a spatula, and analyzed for pH, EC and nitrate.

Standard analyses of soils

Analyses of soil organic matter, pH, cation exchange, P, K, Ca, and Mg were performed by A & L Laboratories East, London, Ontario.

RESULTS

Survey of organic farms in eastern Canada

Soil samples were taken from several soil/vegetation types on each of seven farms in June, 1989 (Table 1). On Farm 3, which was studied in most detail, fertility for vegetable crops is maintained by rotating strips kept in hay for 2–4 years with ground that is cultivated for eight years. In the first year of cultivation, old hen manure is spread on sod in mid-June, the sod is broken by rotovating, and corn is planted. The approximate year to year sequence is then: year 2: peas and beans, 3: beets, lettuce and spinach, 4: carrots, onions or potatoes, 5: corn with old hen manure, 6: peas or beans, 7: beets, lettuce, spinach or coles, 8: carrots. A buckwheat ploughdown is often inserted after crop years 4, 5 or 6. Cattle strip-graze crop residues in the fall.

Soil extract EC for different crops and fields on Farm 3 sampled on June 12 varied by 6.6 fold (Table 1). The values were lowest and consistently low under sod: values for samples from four hay sod or just broken hay sod sites on June 12 were in the range 30–34 μS/cm. Measured again on June 29, two of the sites under hay had increased to 44 and 45 μS/cm, while the broken sod had increased to 125 μS/cm.

On cultivated ground, values were 90 to 200 μS/cm on June 12; sampled on

TABLE 1

pH, EC and nitrate of 1:1 water extracts of soil samples taken from different fields or crops within farms in New Brunswick and Maine in June, 1989

Farm	Date (1989)	Field/ Sample	Description (tillage, vegetation Fertilizer)	pH	EC (μS/cm)	Nitrate (mg/L)
3	June 12 & 29	A1	In hay 8 years, J. 12	6.6	34	10
		A1′	same site, J 29	6.3	45	0
		A2	In hay 3 years, J 12	6.6	30	10
		A3	In hay 2 years, J 12	6.5	30	0
	A3′	A3′	same site, J 29	6.4	44	5
		A4	First year after hay, old hen manure, corn, J 12	6.2	200	75
		A4′	same site, J 29	6.2	240	125
		A5	Second yr after hay, old corn (not tilled), J 12	6.5	130	65
		A5′	same site, J 29	6.4	65	10
		A6	Second yr after hay, beans, J 12	6.4	130	70
		A6′	same site, J 29	6.2	156	100
		A7	Third year after hay, manured prev. fall, potatoes, J. 12	6.3	170	175
		A8	8 years after hay, bare J 12	6.6	90	20
		A8′	same site, J 29	6.1	170	100
		B1	3 year hay sod, just broken, J 12	6.5	32	5
		B2	same site, manured, J 29	5.8	200	100
		B3	same site, not manured, J 29	6.3	125	35
4	June 14	A1	Vegetables, ca, 45 t/ha old hen manure	6.4	410	175
		B1	Wheat; hen manure applied prev. yr to potatoes	6.5	80	12
		C1	Hay, not manured in 1989	6.6	36	10
6	June 14	A1	Vegetables, ca. 22 t/ha old hen manure	6.0	200	100
		B1	Forest, just cleared	4.5	51	5
11	June 16	A1	Vegetables 9 t/ha cow & hen manure liquid mix in fall of 1988	5.8	200	180
		B1	Orchard, grassed lane	6.1	60	5
		B2	Orchard, cult. lane	6.0	130	75
		C1	Potting mix for greenhouse	5.8	440	30
13	June 19	A1	Beets, old cow man. 22 t/ha	5.9	165	100
		B1	Potatoes, 22 t/ha old cow man. + 280 kg/ha fish scale	5.8	400	100
		C1	Wheat	6.6	66	20
18	June 23	A1	Squash, Sweet clover incorporated	6.5	300	250
		A2	Squash, Sweet clover + old goat manure incorporated	6.2	650	450
24	June 27	A1	Worm compost	4.4	2300	450
		B1	Garden, 45 t/ha worm compost	6.1	1100	400
		C1	Garden, 11 t/ha worm compost	6.0	190	100
		D1	Oats	5.9	100	50
		E1	Sod, higher ground	5.8	26	10
		F1	Sod, lower ground	6.1	36	10

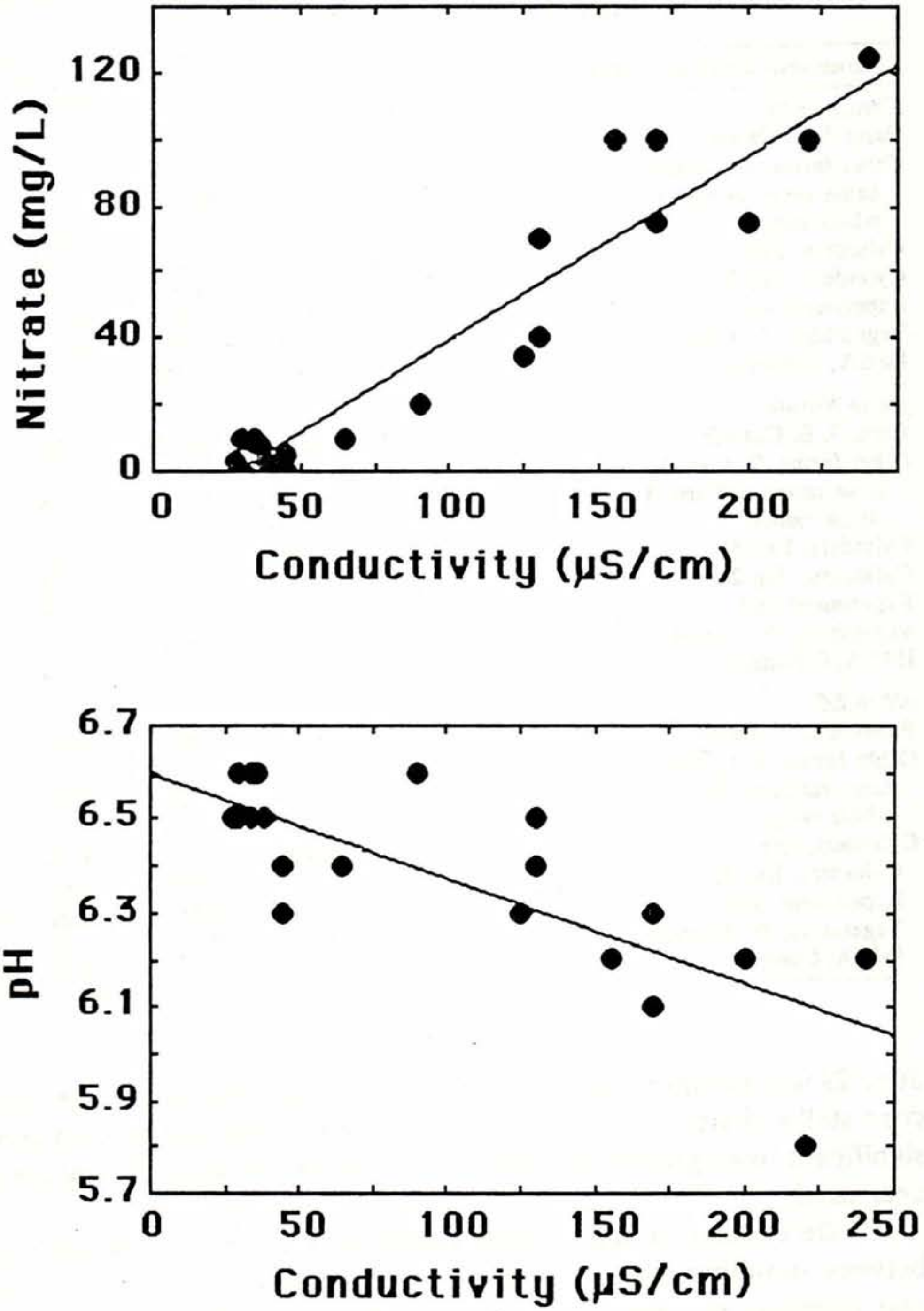


FIGURE 2. Relation of soil extract nitrate and pH to electrical conductivity for soil samples from Farm 3, eastern Canada.

TABLE 2

Parameters and statistics for regressions between nitrate and EC, pH and nitrate, pH and EC. Units are μS/cm for EC, mg/L for nitrate

Relationship tested and data set	n	r^2	P	Intercept	Slope
Nitrate to EC					
Farm 3, E. Canada	21	0.91	<0.001	-15.3	0.551
Other farms, E. Canada,					
same range as Farm 3	32	0.69	<0.001	-16.3	0.628
whole range	76	0.84	<0.0001	3.52	0.446
Cylinders, Exp 1	12	0.13	0.247	- 5.95	0.137
Cylinders, Exp 2	10	0.92	<0.001	-77.0	0.0991
Experiment soil	9	0.98	<0.001	-42.5	0.513
Vegetables, W. Canada	28	0.62	<0.001	-26.8	0.405
IMCA, Colombia	13	0.92	<0.001	-21.4	0.263
pH to Nitrate					(x 10^3)
Farm 3, E. Canada	21	0.60	<0.001	6.53	-3.75
Other farms, E. Canada,					
same range as Farm 3	32	0.003	0.76	6.05	-0.55
whole range	76	0.076	0.016	6.18	-1.09
Cylinders, Exp 1	12	0.307	0.062	6.22	-0.006
Cylinders, Exp 2	10	0.005	0.845	5.62	-0.0002
Experiment Soil	9	0.105	0.396	6.00	-0.28
Vegetables, W. Canada	28	0.027	0.404	6.29	-0.58
IMCA, Colombia	13	0.099	0.296	6.13	2.79
pH to EC					(x 10^3)
Farm 3, E. Canada	21	0.633	<0.001	6.60	-2.24
Other farms, E. Canada,					
same range as Farm 3	32	0.033	0.320	5.85	1.33
whole range	76	0.054	0.043	6.17	-0.45
Cylinders, Exp I	12	0.102	0.312	6.30	-0.001
Cylinders, Exp II	10	0.000	0.976	5.61	-0.0005
Experiment Soil	9	0.122	0.357	6.02	-0.16
Vegetables, W. Canada	28	0.035	0.340	6.36	-0.34
IMCA, Colombia	13	0.092	0.314	6.07	0.74

June 29 well before canopy closure, all values had increased except under old corn stalks (Farm 3, sample A5) where the soil was undisturbed and where significant weed growth occurred in the interim; in this case, soil extract EC decreased.

Nitrate content of soil extracts varied between vegetation/soil types and between sampling times in a manner similar to that for EC (Table 1), and the two variabies were highly correlated (Fig. 2; Table 2).

There is a negative Y intercept for the relationship between nitrate and EC. Rather than being linear over the entire range, the relationship appears to be zero order at low values of EC, and above a certain value, designated EC_{min} nitrate increases linearly with increasing EC, i.e. Nitrate (mg/L)= Slope× ($EC-EC_{min}$). To estimate these parameters, a regression was calculated

TABLE 3

Parameters and statistics for regressions between nitrate (values equal to or greater than 10 mg/l) and EC and calculated values for EC_{min} and F.

Data Set	n	r2	P	Int	Slope[a]	ECmin[b]	F[c]
E. Canada Farm 3	14	0.93	<0.001	−14.2	0.546	26.0	0.88
Other farms, same range	30	0.66	<0.001	−13.3	0.612	21.7	0.99
All farms, E. Canada	67	0.83	<0.001	7.98	0.437	−18.2	0.71
Lab Experiment	7	0.99	<0.001	−47.5	0.516	92.5	0.83
Cylinders, Exp. 2	10	0.92	<0.001	−76.92	0.992	77.5	1.60
Vegetables, W. Canada	28	0.62	<0.001	−26.8	0.405	66.1	0.65
IMCA, Colombia	5	0.91	0.003	−27.7	0.274	101	0.44

[a] Units are (mg nitrate/l)/(μS/cm)
[b] Units are μS/cm
[c] Units are nitrate milliequivalents/cation milliequivalents

excluding samples in which nitrate was less than 10 mg/L (Table 3), so that they are not biased by the zero order relationship at low EC/nitrate. Assuming that the cation content of the extracts in milliequivalents can be estimated by multiplying EC (μS/cm) by 0.01 (Rhoades, 1982), then dividing the slopes in units of mg/L nitrate per μS/cm EC by (0.01 × 62) gives the ratio of the equivalents of nitrate to equivalents of cations ("F"), which in this case is 0.88. The linear relationship and high F value suggests that nitrification is the dominant process bringing cations into solution in this system.

There was a significant negative correlation of pH with EC (Fig. 2) and nitrate (Table 2).

Anonymous (1990) cites a conversion factor of 1 to estimate kg N/ha in the top 30 cm from the concentration of nitrate (mg/L) in 1:1 extracts. The moisture content of sample A4 on June 29 was 19.5%. Assuming a bulk density of 1.1, then 100 mg nitrate/L in the 1:1 extract is calculated to correspond to 55.3 kg N/ha in the top 15 cm, which is close to what would be estimated applying the Anonymous (1990) figure to the top 15 cm only.

EC and nitrate values for soils sampled on the other farms varied in a similar way, with low values for sod, higher values for cultivated ground, and highest values for cultivated ground that received inputs of manure or compost in the current year (Tables 1 and 4, plus data for one site on each of 11 other farms, and for nine samples of a repetitive nature from farms in Tables 1 and 4, data not shown). For all organic fields considered together, other than those of Farm 3, the correlation between the two variables over the same range of EC values encountered at Farm 3 (0 to 250 μS/cm) is considerably lower than for Farm 3, although the slopes and intercepts of the regression are similar (Tables 2, 3). There is little correlation between pH and EC or between pH and nitrate for the different farms considered over an EC range of 0–250 μS/cm (Table 2).

Comparison of soils from organically and conventionally fertilized crops

Nitrification associated with use of urea and ammonium fertilizers is well known to cause acidification of soils (Black, 1968; Coote *et al.*, 1989). It was hypothesized that nitrate and EC of soil extracts from the conventionally managed fields would be higher than those from organic fields because of more rapid nitrification of N in synthetic fertilizers than of N in organic fertilizers, and because of the direct addition of fertilizer salts. It was hypothesized that pH would be the same or lower in soil extracts from conventionally managed fields compared to those from organic fields. pH might not be lowered even when acid production is occurring because of cation exchange; also farmers add lime to compensate for acidifying effects of fertilizers.

In eight paired comparisons, including five of potato crops and three of grains, EC values of soil extracts were consistently lower for crops grown with organic fertilizers or without fertilizer than for the same or similar crops grown nearby with synthetic fertilizers (Table 4). Soil nitrate values of the organically grown crops were equal to or lower than, but never higher than, those of the crops grown with synthetic fertilizers. In most cases there were not large differences in pH, and differences are not significant as assessed by paired t-tests. However there is a trend for lower values in the conventionally managed fields.

Four of the five comparisons with potatoes were conducted on farms on which most of the potatoes were grown conventionally, and farmers were experimenting with a small acreage of organic potatoes. These farmers attempted to apply approximately the same amount of N in organic fertilizers as they applied with synthetic fertilizers. Assuming 0.6% N in old manure (Lampkin, 1990), and 16% N for the fishscale meal (our analysis), rates of N application in the organic fertilizers for those farms for which good estimates of total amounts of manure or fish meal applied were available, were much greater than (Farm 15, field A-1 versus field C1) or were approximately equal (Farms 17, 22) to those for conventional production on the same farm. In the first case, (rate of N application greater in the organic field) the nitrate was approximately the same for organic and conventional fields, but EC was much lower in the organic than in the conventional field; in the other cases (rates approximately the same), both nitrate and EC were much lower in the organic fields.

EC values for soil from potatoes fertilized with synthetic fertilizers on five

TABLE 4

pH, EC and nitrate of 1:1 water extracts of soils taken from adjacent or nearby organically managed and conventionally managed fields of farms in eastern Canada and Maine, June 1989.

Farm	Date (1989)	Field/ Sample	Site Description	pH	EC (μS/cm)	Nitrate (mg/L)
			GRAINS			
1	June 10	A1	Wheat, strip with no fertilizer	6.0	138	50
		A2	strip with 100 kg 17-17-17	6.0	177	50
		A3	strip with 200 kg 17-17-17	5.9	205	55
12	June 19	A1	Wheat, ORGANIC, not fertilized	6.0	97	70
	B1[b]	B1[b]	Oats, CONVENTIONAL, N-P-K[a]	5.5	163	100
		C1[b]	Corn, CONVENTIONAL, N-P-K[a]	6.0	265	175
14	June 20	A1	Oats, ORGANIC, not fertilized	7.0	93	30
		B1	Oats, CONVENTIONAL, N-P-K[a]	5.5	125	40
			POTATOES			
10	June 16	A1	Potatoes, ORGANIC, manured previous fall	5.5	95	20
		B1	Potatoes, CONVENTIONAL, N-P-K[a]	5.7	550	180
15	June 21	A1	Potatoes, ORGANIC, 45 t/ha old man	5.3	250	240
		B1	Potatoes, ORGANIC, manure	5.4	90	40
		C1	Potatoes, CONVENTIONAL, N-P-K[a]	5.3	740	240
16	June 22	A1	Potatoes, ORGANIC, 11 t/ha old cow manure	5.7	250	150
		B1[b]	Potatoes, CONVENTIONAL, N-P-K[a]	5.6	840	400
17	June 22	A1	Potatoes, ORGANIC, 22 t/ha old cattle manure in fall	6.0	160	90
		B1	Potatoes, CONVENTIONAL, 900 kg/ha 15-15-15	5.8	720	420
22	June 25	A1	Potatoes, ORGANIC, 1100 kg/ha fish meal	6.0	520	200
		B1	Potatoes, CONVENTIONAL, 1000 kg/ha 15-15-15	6.0	1040	450

Crop & Variable	n	Mean Value Organic	Mean Value Conv.	Prob. 1-tail t-test
GRAIN				
pH	3	6.33	5.73	0.159
EC (μS/cm)	3	109	177	0.060
nitrate (mg/L)	3	50	77	0.162
POTATOES				
pH	5	5.71	5.68	0.337
EC (μS/cm)	5	239	778	0.000
Nitrate (mg/L)	5	120	338	0.003

[a] Precise values are not known. For the region, recommended rates for cereals are generally in range 200 to 400 kg/ha of 17-17-17 and for potatoes, 800 to 1000 kg of 15-15-15.

[b] The conventional crop was on a neighbouring farm; other conventionally raised crops were located on the same farm as the organically raised crops.

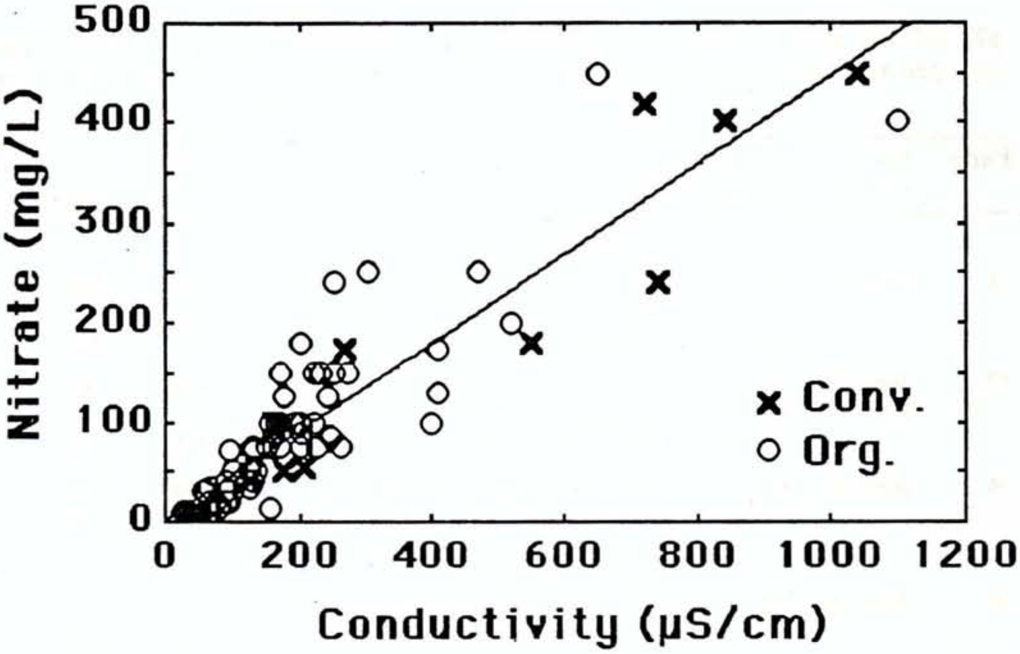


FIGURE 3. Relation of nitrate in soil extracts to electrical conductivity for all soil samples from eastern Canada and Maine. Data for samples from organically fertilized and conventionally fertilized fields are represented by different symbols.

farms were in the range 550 to 1040 versus 95 to 520 μS/cm for organically fertilized potatoes. For three grain fields fertilized with synthetic fertilizer, EC values were in the range 125 to 265 versus 93 to 138 for organically managed fields. The differences between potatoes and grains reflect the higher rates of fertilization of potatoes compared to grains. Although most of the EC and nitrate values for all organic fields (Tables 1, 4) were lower than those for conventionally managed potatoes (Table 4), there was some overlap; EC and nitrate values of similar magnitude to those for conventional potatoes were observed for soil with sweet clover ploughdown and goat manure (Farm 18, Table 1) and a garden receiving large inputs of worm composted manure (Farm 24, Table 1). The worm composted manure had an exceptionally high EC value. All EC-nitrate data are plotted in Figure 3; the data for conventional fields fall well within the range of points for organic fields. pH showed a weak but significant trend of decrease with increasing EC and nitrate (Table 2).

Effects of specific fertilizers on EC

The effects rock phosphate, and of some commonly used soluble fertilizers, including potassium sulphate and gypsum (permissible under Organic Crop

Improvement Association standards) on soil extract pH, EC and nitrate were examined in Cylinder Experiment 1 (Table 5). The fertilizers were added to LF (low fertility) and HF (high fertility) soil contained in large, drained cylinders maintained out of doors and subject to normal rainfall. Fababeans were planted after adding fertilizers on May 1, and the soil was sampled on June 27,

TABLE 5

pH, EC and nitrate in 1:1 water extracts of LF (low fertility) and HF (high fertility) soils to which various fertilizers were added; fababeans were planted after adding fertilizers. HF soils are ones to which compost was added in 1987; LF soils are the same soil without compost

Fertilizer treatment	Background fertility	pH		EC (μS/cm)		nitrate (mg/L)	
		Values on May 1, 1991, before experiments[a]					
No fertilizer	LF	6.5		44		2.5	
	HF	6.8		54		2.5	
		Exp. I: Values on June 27 (fertilized May 1)[b]					
No fertilizer	LF	6.1	P	58	P	2.5	P
	HF	6.3		70		2.5	
Rock P	LF	6.2	QR	56	P	2.5	P
	HF	6.4		70		2.5	
Super P	LF	6.1	P	124	Q	2.5	P
	HF	6.2		161		2.5	
K_2SO_4	LF	6.1	PR	91	P	2.5	P
	HF	6.3		97		2.5	
Urea	LF	5.8	S	142	Q	49	Q
	HF	6.2		150		38	
Gypsum	LF	6.0	PS	160	Q	2.5	P
	HF	6.3		164		2.5	
		Exp. II: Values on Sept 18 (fertilized Aug 27)					
No fertilizer	LF	5.5	X	81	W	10	W
	HF	5.6		109		13	
Urea	LF	5.4	X	207	X	166	X
	HF	5.7		242		196	
NPK	LF	5.4	XY	253	Y	148	X
	HF	5.8		283		184	
Spent Grain	LF	5.5	XY	133	Z	48	Y
	HF	5.7		161		75	
Spent Yeast	LF	5.6	Y	89	W	20	W
	HF	5.9		117		29	

[a]Soil Analysis Data (May 1)

Sample	O.M.	pH	CEC_{est}	CEC_{NH_4OAC}	Bray-1P	% Base Saturation			
						K	Mg	Ca	H
	%		(meq/100g)		(ppm-P)				
LF soil	1.8	6.3	4.8	2.3	15	2.1	13.1	59.6	25.1
HF soil	3.1	6.5	9.5	4.9	75	1.6	10.9	65.4	22.0

[b]The experiments were set up in a split plot design with background fertility as the main plot variable and fertilizers as the subplot variable. Within columns, fertilizer treatment values sharing a letter do not differ at the 0.05 level of significance; comparisons were made for the HF and LF values combined as there were not significant interactions between background fertility and pH, EC or nitrate ($P > 0.7$). Differences between background fertility levels were significant ($P < 0.05$) for all 3 variables in both experiments, except for nitrate in Experiment 2.

i.e. at approximately the same time of the season that field soils had been sampled (above).

Rock phosphate had no effect on EC, while all other fertilizer treatments increased EC. Urea caused a statistically significant decrease in pH, as expected. EC was highest in the gypsum treatment. Only in the urea treatment were there elevated levels of nitrate. There is a very poor relationship between nitrate and EC for these data ($r^2 = 0.131$; $p = 0.25$).

In a subsequent experiment, commercial N fertilizers (urea, synthetic N-P-K) and two types of brewery waste containing high concentrations of N were added at nitrogen rates of 50 kg (urea, N-P-K), 40 kg (spent grain) and 39 kg (spent yeast) per hectare; annual ryegrass or oilseed radish were planted and soil sampled after 21 days when the plants were just coming out of the seedling stage. Nitrate concentrations increased in the order: no addition, spent yeast, spent grain, NPK, urea; EC increased in the same order except that the value in the NPK treatment was higher than that for urea. Nitrate and EC were highly correlated (Tables 2, 3). The split plot analysis indicated no significant interaction of fertilizer treatment and background fertility (HF or LF), on any of the three variables. However a plot of pH versus nitrate illustrates a decline

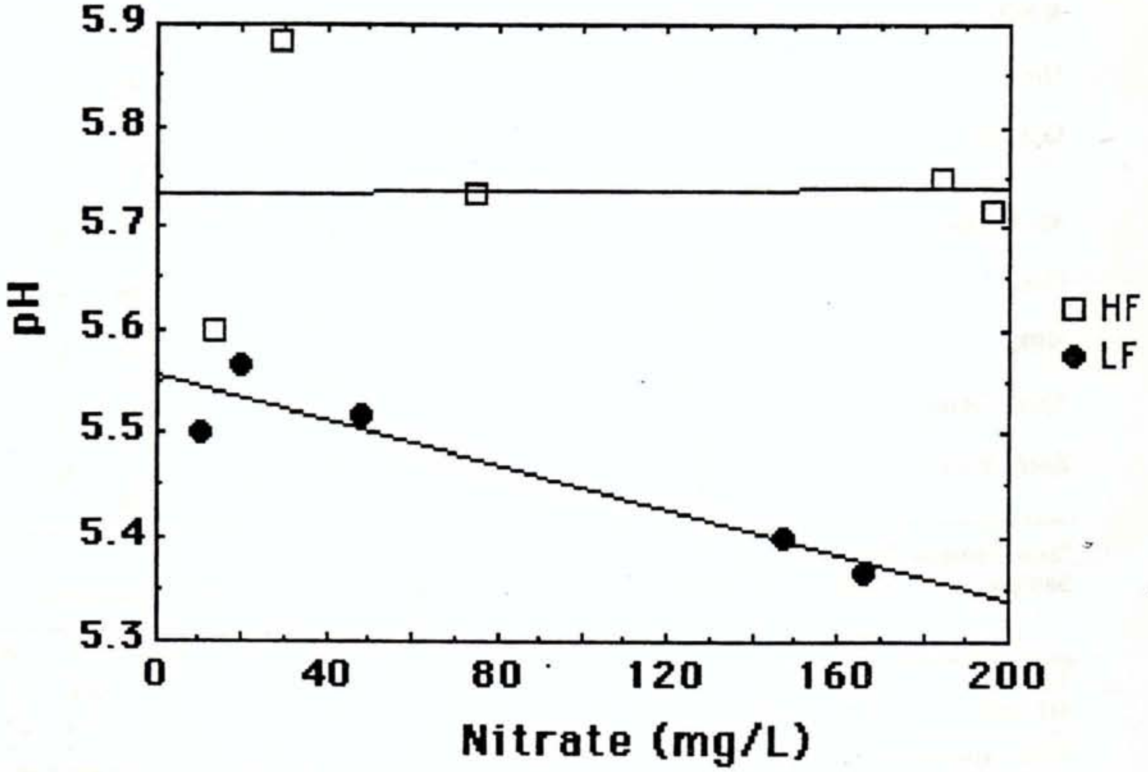


FIGURE 4. Relationship of pH to nitrate in HF (high fertility) and LF (low fertility) soils to which various N-containing fertilizers (none; spent yeast, spent grain, urea, N-P-K) had been added 20 days before sampling (data from Table 5). For the HF soils, $r^2 = 0.024$ ($P = 0.97$); for the LF soils $r^2 = 0.88$ ($P = 0.019$).

in pH with increasing nitrate in the LF systems but no such trend in the HF systems (Fig. 4). This can be attributed to the HF systems being better buffered due to higher CEC and content of basic cations (see soil analyses data in footnote to Table 5).

Experimental manipulation of soil solution variables

The main purpose of this study was to compare under experimental conditions the effects of key biological processes on soil extract properties. Soil from Farm 3 was amended with straw to immobilize nitrate, crab meal was added to increase the nitrate by mineralization and nitrification, and plants were grown to consume mineral N. After 28 and 53 days, soil extract pH, EC and nitrate were measured as in the field studies and concentrations of major ions were determined.

As expected, addition of straw reduced EC and concentrations of individual ions compared to soil with no additions; growing oats in the soil reduced all ions by larger factors, except for ammonium on day 53 (Table 6). Addition of crab meal increased EC and most constituent ions (exceptions being Na and CI on day 53). Chloride and sodium, which exist almost entirely in the soil solution (Russell, 1973), made up relatively large proportions of the total ionic constituents in the control and crab treatments.

Soil extract EC was highly correlated with nitrate measured by laboratory analysis (Table 2: $r^2 = 0.98$) and less well correlated with nitrate measured by test strips ($r^2 = 0.71$); the r^2 value for the correlation of nitrate values determined by formal analysis with those determined using strips was 0.80. There was little relationship between pH and EC or nitrate (Table 2).

An approximate conversion factor of 0.01 is cited for calculating total cation concentration in milliequivalents from EC values in μS/cm (Rhoades, 1982). For the experimental data, the observed factors are in the range 0.0078 to .0133 with a mean of 0.01 (Table 6). There was approximate anion/cation equivalence for the measured ions except for the samples from soil with growing plants, for which the sums of the measured anions amount to 46 and 17% of the cation sums at days 28 and 53 respectively.

As observed by others (reported in Black, 1968), there are very high correlations between nitrate and concentrations of Ca, Mg and K, and a somewhat lower correlation with Na (Table 7). The concentrations of nitrate were equivalent to 0.5 times or more of the total cation milliequivalents, except for the oat treatments in which nitrates were anomalously low (Table 6).

TABLE 6

pH, EC and ionic composition of extracts from soil incubated in the dark without amendments or with straw or crab meal or placed under lights, and oats grown in the soil.

Variable	0 days*	28 days				53 days			
		Cont	Straw	Oats	Crab	Cont	Straw	Oats	Crab
pH	5.8	5.8^{b**}	5.8^{b}	6.3^{a}	5.9^{b}	5.6^{a}	5.5^{a}	6.6^{c}	5.8^{b}
EC (μS/cm)	299	660^{a}	310^{b}	80^{c}	1800^{d}	835^{a}	520^{b}	70^{c}	2200^{d}
Ions (*meq/L*)									
Ca^{++}	1.70	3.20	1.63	0.56	14.0	5.60	2.81	0.70	14.5
Mg^{++}	0.40	0.88	0.38	0.12	2.84	1.36	0.63	0.12	2.85
K^{+}	0.28	0.46	0.40	0.04	0.72	0.48	0.45	0.02	0.80
Na^{+}	0.22	0.60	0.27	0.06	2.00	3.70	0.36	0.06	3.40
Total cat#	2.60	5.14	2.68	0.78	19.6	11.1	4.25	0.92	21.6
$NO3^{-}$ (strip)	1.86 (2.4)	4.72 (7.3)^{a}	1.69 (1.5)^{b}	0.06 (0.0)^{c}	15.7 (32.2)^{d}	5.72 (6.2)^{a}	3.57 (4.0)^{b}	0.02 (0)^{c}	16.5 (15.2)^{d}
$SO4^{=}$	0.46	0.88	0.53	0.30	1.50	0.92	0.04–	1.55	0.52
Cl^{-}	0.22	0.18	0.27	<0.03	2.08	4.28	0.34	0.10	4.25
$\frac{\textit{tot cations}}{(\text{EC} \times 0.01)}$	0.87	0.78	0.86	0.98	1.08	1.33	0.82	1.31	0.98
$\frac{\textit{tot anions}}{\text{tot cations}}$	0.98	1.12	0.93	0.46	0.99	0.98	1.04	0.17	1.03
$\frac{\textit{nitrate}}{\text{tot cations}}$	0.71	0.92	0.63	0.07	1.12	0.51	0.84	0.02	0.77

*0 days refers to the day that different treatments were set up which was after soil had been incubated moist for 2 weeks. Initial soil values were pH 6.2, conductivity 70 μS/cm and nitrate 0.16 meq/L. Soil Analysis Data: O.M.: 4.8%, pH: 6.2; $CEC_{est:}$ 13.0 meq/100 g; $CEC_{NH40Ac:}$ 11.1 meq/100 g; Bray-1P: 257 ppm; Base Saturation: 3.9% K, 7.0% Mg, 70.6% Ca, 18.5% H+.

**For each sampling time, values for pH, conductivity and nitrate (strip) are means of 5 separate samples; values within rows followed by different letters differ significantly ($\alpha = 0.05$) as assessed by 2-way ANOVA for control, straw and crab treatments, and unpaired t-tests corrected for family wise error for comparisons with oats.

#Traces of ammonium (ca. 0.02 meq/L) were detected in straw and oat treatments at 53 days, not in other samples.

pH, nitrate and EC monitored through two cycles of lettuce production

This system employs large quantities of compost prepared from septic tank sludge, cow manure, crop residues, and wood chips. The grower augments the compost with bloodmeal because he found that otherwise, lettuce appeared chlorotic, suggesting N deficiency. Still, he had concerns about excess N, given the heavy N loading on the system.

TABLE 7

Correlation matrix (r^2 values × 100) for variables measured in the lab experiment

Variable	Cond	Ca	Mg	K	Na	NO_3	SO_4	CI
Cond.	100							
Ca	98	100						
Mg	99	99	100					
K	83	76	80	100				
Na	60	58	62	51	100			
NO_3	99	99	99	81	54	100		
SO_4	93	90	94	90	60	93	100	
CI	58	56	59	47	99	52	55	100

Over both cycles of lettuce production, soil nitrate and EC increased initially, but fell before harvest (Fig. 5). The second cycle values were higher, probably corresponding to higher temperatures (daily maxima were in the range 14 to 25.5 first cycle, and 18 to 31 in the second cycle; minima were in the range 5.5 to 14.5 first cycle, and 11 to 18 second cycle; data from Environment Canada for Comox). Nitrate and EC tended to be higher in the 15–30 cm horizon than in the 0–15 cm horizon during the first cycle, while the reverse was the case in the second cycle. This pattern can be attributed to some high rainfall events during the first cycle and very little rain and greater evaporative loss during the second cycle (Environment Canada data for Comox). Soil was irrigated. Soil pH declined between the first and second crops. Leaf tissue nitrate followed patterns similar to those for the soil nitrate and EC (Fig. 5); values at harvest were in the range 200–500 μg/g tissue. There is a significant correlation between leaf tissue nitrate and soil nitrate in the top 30 cm ($r^2 = 0.35$; $P = 0.012$).

Survey of soils and ponds at farm practicing CIPAV technology

"CIPAV technology" involves integration of several livestock species, worm composting and biogas production with sugarcane, trees and *Azolla* (a nitrogen-fixing water fern) as major primary producers (Preston, 1990; Murgueito, 1990). There is little or no use of commercial fertilizer, and it is desired to close nutrient cycles as much as possible. A one-day survey of pH, nitrate and EC of soils and pond waters was conducted at a farm where CIPAV technology is practiced (Table 8). Oxidation-reduction potentials of pond water samples were also measured. There was a good correlation between nitrate and EC for the soil samples; the slope was the lowest for all systems examined (Tables 2, 3). There was no correlation between pH and EC or between EC and nitrate.

Values for nitrate were low and EC values were lowest under perennial vegetation including that which had been fertilized two months previously

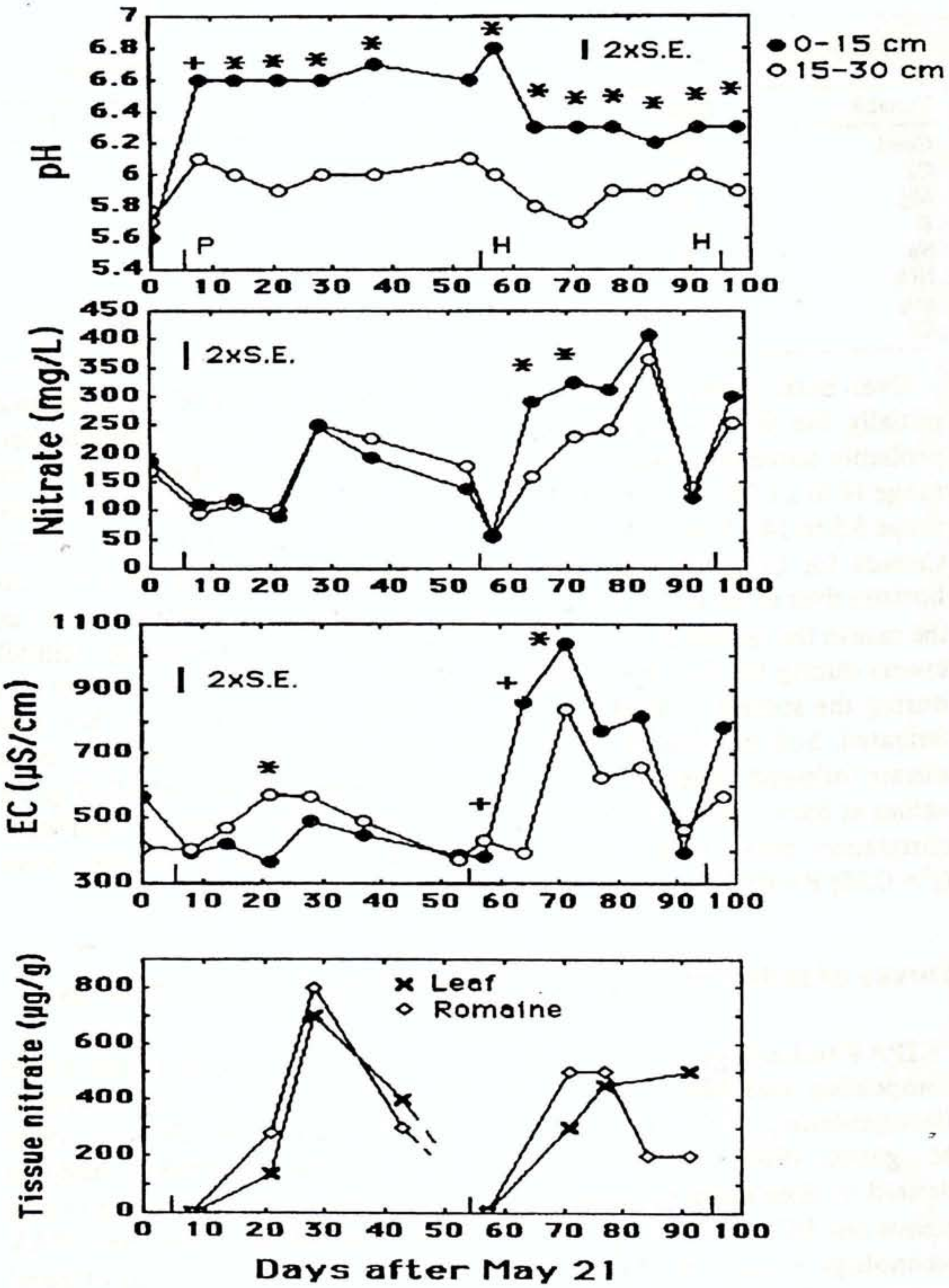


FIGURE 5. Soil extract pH, nitrate and electrical conductivity and lettuce tissue nitrates over two cycles of lettuce production. In the top three figures, data for the 0–15 and 15 cm horizons are plotted separately; +, * indicate that values for the two horizons differ at the 0.1 and 0.05 levels of significance respectively as assessed by paired t-tests. H = harvest of lettuce.

TABLE 8

pH, EC and nitrate of 1:1 extracts of soil (fresh weight of soil to volume of distilled water), or in pond water at IMCA Farm, Colombia.

Sample	pH/OR (mv)	EC (μS/cm)	Nitrate (mg/L)
1. Worm compost, (sheep manure + cane tops and residues)			
a. 15 days old	9.3	5332	0
b. 2 months	7.7	4136	0
c. 3–4 months (ready)	8.5	3779	0
2. Garden soil, compost applied 2 months before; young *Acacia* plants grown from cuttings	6.9	939	250
3. a. Garden, compost applied 6 months ago; crop of tomatoes grown, now lemongrass	6.0	243	50
b. As above, no compost	6.4	324	12
4. Cane field, cultivated, planting cane (no fertilizer)	6.3	462	80
5. Ratoon cane, 1.5m between rows; plants cut 2 months ago			
a. Close to plants where chicken manure was applied	6.7	80.9	0
b. Between rows, under trash	7.0	57.0	5
c. Between rows, no trash	6.4	72.6	10
6. Ratoon cane, as above but 0.75m between rows			
a. Close to plants, manured	5.5	110	3
b. Between rows, under trash	5.8	135	3
7. *Trichantera gigantea* (tree; leaves cut for forage)			
a. Close to tree	6.3	65.6	0
b. Between trees, under cane leaf mulch	5.0	51.8	0
8. *Gliricidia sepium* (tree, leaves cut for forage) 3 year old plants			
a. Cut 2 weeks ago; sample between plants, in row	5.6	70.9	10
b. Uncut plants ca. 2m height	7.0	53.3	0
9. Water from ponds			
a. Input water	8.1 (104)	111	0
b. No plants; + hen manure	8.1 (96)	176	0
c. Fish, very few plants	8.5 (61)	140	0
d. *Azolla* + Ducks	6.8 (219)	177	0
e. Covered with *Azolla*	7.2 (68)	108	0
f. Covered with *Azolla*	7.1 (39)	119	0
g. *Lemna*, heavily fertilized	6.8 (1)	142	0

with hen manure. Higher values were observed where compost had been applied to gardens, and in a recently tilled cane field (Table 8). Samples 5b and 5c were taken to determine if the trash (old leaves) immobilized nutrients; nitrate and EC were lower under trash. However nitrates were lowest next to the cane plants even though that was where the manure had been applied (compare 5a with 5b and 5c, and 6a with 6b).

There was no nitrate detected in ponds. The EC values were highest in ponds with few or no water plants, and were lowest where there was a cover of *Azolla*. A pond with a covering of *Lemna* that had been heavily fertilized with manure had an intermediate value, and the lowest oxidation reduced potential (Table 8). (*Lemna* is considered by CIPAV personnel to be particularly effective in purifying water receiving heavy loads of organic wastes).

Worm compost of different ages was sampled. The EC values (Table 8) are in the same range as those for worm compost sampled in eastern Canada (Table 1) but there was no nitrate present. Nitrate was detected after 6–9 months (CIPAV personnel, personal communication). The EC values declined with age, possibly due to leaching which was suggested by the presence of heavy weed growth around the perimeter of the compost piles.

DISCUSSION

The nitrate-EC relationship

Highly significant correlations between soil extract EC and nitrate were found for a diversity of systems. Although positive relationships between nitrate and cations in solution have been reported (Black, 1968) and electrical conductivity is related closely to the total concentration of cations (Rhoades, 1982), there appear to be no reports on the relationships between nitrate and EC.

Considering that the strip method for measuring nitrate is only semi-quantitative, the real relationships for the field samples are likely stronger than indicated by the r^2 values. In the laboratory experiment, the r^2 value for regression of nitrate on EC was 0.98 when a normal analytical technique was used for nitrate, and 0.71 when strips were used.

Seven out of eight of the regressions had negative Y intercepts, the exception being that for all farms in eastern Canada considered together. The relationships rather than being simply linear over the entire range, appear to be zero order at low values of EC, and first order above that: EC increases in the absence of nitrate to "EC_{min}" the lowest value of EC at which nitrate is observed, and above that, there is a positive linear relationship between EC and nitrate. This suggests that the ratio of nitrate to total cations brought into solution or to the total anions produced (above the EC_{min} values), designated "F" when the units of each are in milliequivalents, is more or less constant for a given system. A conversion factor of 0.01 was used to calculate milliequivalents of cations from EC expressed in μS/cm (Rhoades, 1982); the average factor calculated for the laboratory experiment was 0.01. Calculated F values for the systems from eastern Canada were all above 0.8, while the values for the vegetable system in western Canada and for the CIPAV system in Colombia were 0.65 and 0.44 respectively (Table 3). Evidently nitrification is the dominant process bringing cations into solution for the systems from eastern Canada; for the western Canada and Colombian systems, production of other anions (possibly bicarbonate) was also important but occurred in conjunction with nitrification.

Since nitrate extracted in water is not held electrically on soil colloids, and since there must be equivalent amounts of cations to maintain electrical neutrality in the soil solution, the linear relationships above EC_{min} (constant F values) suggest that EC measurements at least provide valid relative estimates of the total quantities in the soil solution and therefore of the relative potential for losses of nutrients by leaching. By using the conversion factor of 0.01, the absolute value for total amounts of cations in the soil solution can be estimated, although there is some uncertainty about how these might compare with real soil solution values *in situ* because of dilution/solubilization effects (Black, 1968), particularly in the soils with low F values. The ratio of extract to fresh soil was 1:1, thus values of nitrate or cations per kilogram of fresh soil are the same as the values expressed per litre of extractant. Whether the nutrients in the soil solution are actually lost will of course depend on factors such as rainfall, percolation/soil profile characteristics, and the types of crops grown.

For electrical neutrality, the ratio of milliequivalents of nitrate to milliequivalents of cations should not be greater than 1 (or nitrate in mg/l to EC in μS/cm >0.62, assuming a conversion factor of 0.01 as above), except in very acid solutions in which protons are the predominant counterion for nitrate. A few values greater than 1 (milliequivalents) or 0.62 (mixed units) were recorded in this study and are probably due to overestimation of nitrate by the strip method at high nitrate values. The F value for Cylinder Experiment 2 was 1.6 (Table 3); examination of the data in Table 5 shows that ratios of nitrate to EC for the samples with the three highest nitrate values exceeded 0.62. Five samples in Table 1 exceeded 0.62 (nitrate values 100–450 mg nitrate per litre). In the laboratory experiment, nitrate in the crab meal treatment at 28 days was greatly overestimated by the strip method (Table 6), giving a calculated milliequivalent ratio of 1.79; this sample had very high nitrate. The accuracy of the strip test for nitrate can be improved by reading the strips in a newly marketed, portable "Nitracheck Meter" (Hawk Creek

Laboratory Ltd., Glen Rock, Pennsylvania); the meter is reported to be suitable over the range 0 to 420 mg/litre nitrate and to read to units of 1 mg/litre nitrate.

Nitrate, EC and pH as indices of decoupling

Nitrogen is commonly a limiting nutrient for crop production, and uptake processes appear to be saturated at very low concentrations. Km values for uptake from solutions are typically less than 2 mg nitrate/litre and various crop species have been reported to reduce nitrate in solutions to less than 0.1 mg nitrate/litre (Barber, 1984). Hence when release of N through mineralization and uptake by plants are closely coupled or synchronized, levels of free nitrate remain very low, e.g. as under hay sod on farms 3,4, and 24 in eastern Canada (Table 1), and under cane and trees in the Colombian farm (Table 7), and in pots with oats (Table 5). In such circumstances, N is taken up as ammonium or perhaps simple organic N compounds (Barak *et al.*, 1990) and nitrate is not produced and/or nitrate is taken up very promptly after its production. In closely coupled systems, there will be little temporal variation in extract pH or EC, i.e. a steady state soil solution is maintained. EC values for samples from sod in different farms in eastern Canada varied over a narrow range, 26–60 μS/cm, and nitrate between 0 and 10 mg/l.

All of the samples from eastern Canada with higher values of nitrate and EC were from soil/plant systems that would be expected to be less tightly coupled than the sod systems. Within farms, differences between samples can be explained on the basis of the degree of spatial and temporal coupling or decoupling. For example, at farm 3 between June 10 and 29, EC and nitrate increased under sod from 30 to 44 μS/cm, under recently cultivated sod, from to 32 to 125 μS/cm, and when manure was added to recently cultivated sod, from 32 to 220 μS/cm. There were corresponding increases in nitrate and declines in pH. The increase under sod probably represents a mild "mineralization/acidification push" (Ulrich, 1987) in the early part of the growing season when the soil was still warming up. Where a lot of weed growth occurred in uncultivated corn soil during the same interval, EC and nitrate declined.

In the intensive vegetable operation on Vancouver Island, EC and nitrate increased initially, but declined subsequently due to plant growth. The intensity of the second cycle changes was greater than those of the first cycle, as would be predicted (Ulrich, 1987) given warmer, drier conditions in the second cycle. pH did not change much during the periods of plant growth, but fell between the first and second cycles, possibly due to loss of nitrate.

The alkalinizing property of plants growing on nitrate was well illustrated in the oat treatment of the laboratory experiment. By the end of the experiment, pH had increased to 6.6 from a value af 5.8 at zero days, and nitrate was reduced to near zero from 1.86 meq/L at day zero. The anion (not including bicarbonate or organic anions) to cation ratio was low under oats, which is characteristic of plants growing on nitrate (Kirkby, 1969). It remained low and decreased further between 28 and 53 days, suggesting that nitrate was simultaneously produced and consumed during that interval (i.e. that nitrate rather than ammonium was the main form of N taken up).

As well as by plants, nutrients can be taken up by microorganisms growing on low N, immobilizing residues. This phenomenon can be either beneficial or detrimental. For example, incorporating straw after harvest can help to tie up nutrients over the winter in humid temperate climates (Addiscott *et al.*, 1991), but if the incorporated residues do not begin mineralizing by spring, or if the highly leached residues are incorporated in spring, they can tie up nutrients for the next crop. In a crop rotation sequence of winter wheat to fababeans, the fababeans were deliberately planted after incorporating straw from winter wheat in order to stimulate N_2 fixation in fababeans (Patriquin *et al.*, 1986). One objective of the laboratory experiment was to compare effects of immobilization (achieved by incorporating wheat straw) with those of plant uptake on pH, EC and nitrate. Incorporation of straw resulted in a net lowering of nitrate and EC at day 28 compared to the control. Between 28 and 53 days, nitrate and EC in the straw treatment increased more than they did in the controls, indicating that net mineralization was then occurring. Nitrate and EC were not lowered as much during the immobilizing phase in the straw system as they were under the oats. Similarly, in the CIPAV system, nitrates and EC were lower close to cane plants than under trash between rows. According to McCartny and Bremner (1992) it is generally assumed that microbial assimilation of nitrate is a minor fate compared to plant uptake, leaching and denitrification, and is accounted for by inhibition of microbial nitrate reductase activity by ammonium or by the immediate products of ammonium assimilation. However, plant nitrate uptake and reduction are likewise inhibited by low concentrations of ammonium, although this effect is quite variable between species or cultivars (Fleming, 1983; Haynes & Goh, 1978; Taylor & Foy, 1985). A possible explanation for greater lowering of nitrate concentrations by plants other than by microbial immobilization, is increased movement of nitrate to plants driven by transpiration (Jackson *et al.*, 1989). Whatever the explanation, the differences suggest that catch or cover crops would be more effective than low N residues as agents for conserving nutrients.

In total, our observations confirm and illustrate the contention of Ulrich (1987) that the composition of the soil solution is highly sensitive to coupling/decoupling phenomena (Ulrich, 1987). pH, nitrate and EC each provide a different parameter of these phenomena.

Nitrate provides a direct measurement of the nutrient usually limiting plant growth and is therefore a sensitive indicator of coupling/decoupling. It may be possible to correlate the levels of nitrate at specific times of year with subsequent crop yield and hence indicate need for N supplements (e.g. Magdoff *et al.*, 1984).

In general, fluctuations in EC followed those of nitrate. There are exceptions however: high EC and low nitrate values may result when large amounts of soluble, non-nitrogenous fertilizers are applied, or in alkaline soils in which bicarbonate is a significant counter ion for basic cations. Conversely, high nitrate with low EC could occur under certain acidic conditions; this seems unlikely to occur, however, because of reduced or no nitrification at low pH (Black, 1968) and/or adsorption of nitrate due to increased anion exchange in low pH horizons (e.g. Lutz *et al.*, 1977). Thus the combination of EC and nitrate measurements can indicate the potential for loss of nitrate and/or other nutrients. For many purposes, the information provided by EC measurements is equivalent to that given by nitrate. and the technique is simpler and less expensive than measuring nitrate; in the absence of distilled water rainwater would probably have a suitably low EC for use as the extractant. If there is a strong relationship between nitrate and EC for a system, nitrate could be estimated from EC.

pH is less sensitive than either nitrate or EC alone as an indicator of transient decoupling because it is buffered by various processes including cation exchange. Exchangeable or titratable acidity (Binkley & Richter, 1987) would probably exhibit stronger correlations with nitrate and EC, but those are not practical measurements for routine on-farm use. pH in $CaCl_2$ solution, which Reuss and Walthall (1989) consider to be more a measure of base status of the exchanger than a direct measure of pH, would probably be better correlated with nitrate and EC and would be more sensitive than pH in water extracts to seasonal coupling/uncoupling processes. It may be appropriate to measure both values. In any case, pH values are of interest on their own (e.g. to look at differences between horizons in the soil profile, to assess the likelihood of aluminium toxicity, or to examine effects of different plants on rhizosphere soil pH, or of decomposing residues on pH). pH values do change in the longer term in response to loss of nitrate and cations, and thus can serve as a longer term monitor of decoupling. It is obviously important that measurements are made under similar conditions (time of year, soil type, crop), and to appreciate the limitations of pH measurements due to salt and dilution effects (Binkley & Richter, 1987; Reuss & Walthall, 1989).

When pH does exhibit a negative relationship with nitrate, as at Farm 3, low BS and/or low CEC can be suspected. Interestingly, such a relationship was not observed for the corn soil from this farm, which was used in the laboratory experiment. This soil was taken from ground that had just come out of the sod phase of the rotation and would be expected to have the highest CEC and BS. The benefits of building up soil organic matter were illustrated by data from the cylinder experiments: cylinder soil to which compost had been added five years previously, had higher CEC and BS than cylinder soil without the compost, and for this soil there was no relationship of pH with nitrate. In the soil without compost pH declined with increasing nitrate. Adding the compost thus significantly increased the "elasticity" of the soil system (Uirich, 1987).

There are many potential applications of these types of measurements to biological farming systems, some of which were illustrated in the course of these studies and are discussed below.

Differences between organic and conventional fertilization

The differences in soil extract pH, EC and nitrate between adjacent organically and conventionally fertilized crops were consistent with our initial hypotheses, i.e. that nitrate and EC would be higher and pH lower in the conventionally fertilized crops. The differences in nitrate and EC were large for the heavily fertilized potatoes. With sufficient baseline data, including information on the use of permissible soluble materials such as gypsum and potassium sulphate, it might be possible to develop standards for certain crops and regions for use in certification programs. For example, EC values exceeding certain levels might be considered presumptive evidence of use of synthetic fertilizers or of excessive amounts of organic fertilizers.

N release and tissue nitrate levels in an intensively fertilized organic vegetable operation

Large amounts of N are applied to this system as compost and bloodmeal. The farmer applied bloodmeal because it was observed that without it, lettuce appeared chlorotic. Peak levels of soil nitrate, which occurred in the second cycle, did not exceed 100 kg N/ha. Soil and tissue nitrates dropped to relatively low values at the end of the first cycle, while at the end of the second cycle there was a trend of decrease followed by an increase for tissue nitrate in one of the two lettuce varieties. Nitrate contents at harvest were in the range 200 to 500 $\mu g/g$ fresh lettuce. These values are on the low end of the ranges of values reported for organically or conventionally grown lettuce (Lairon *et al.*, 1984; Stopes *et al.*, 1988), and considerably lower than European maximum tolerated levels (3000–4000 $\mu g/g$ fresh weight, cited in Stopes *et al.*, 1988). There were significant correlations between leaf nitrate and soil nitrate, and between soil nitrate and soil extract EC.

These observations appear to confirm the farmer's contention that the lettuce was not accumulating excessive amounts of N, in spite of very high total N input. This may be attributable to the wood chips continuing to immobilize some of the N even after the composting process is completed . A sample of the compost had a C:N ratio of 33:1, versus a value of about 22:1 or less often cited for non-immobilizing materials (Black, 1968) , and of 17 to 10:1 for finished or fully mature composts (Anonymous, 1987; Dalzell *et al.*, 1987; Mathur *et al.*, 1986). Similarly, Sommerfeldt and MacKay (1987), reported that cattle manure containing wood shavings used in bedding required N supplements to avoid yield depressions. However with time it could be expected that immobilized N will be released, especially as the total inputs of N appear to greatly exceed the outputs. Yields for the two cycles were estimated as 12–14 kg fresh lettuce/m^2 (unpublished data). Assuming that the N content of fresh lettuce is approximately 0.2% (Anonymous, 1981), that represents an output of approximately 260 kg N/ha. Inputs are estimated as 540 kg N in compost applied to each lettuce crop (20 litres of compost/m^2 with B.D of 0.24 and N content of 1.125%) plus 105 kg N in bloodmeal (750 g bloodmeal/m^2 at 14% N). There was a trend of increasing soil and tissue nitrates at the end of the second production cycle, which if continued might have resulted in higher levels in the subsequent fall crop which was not monitored. (An average of 3.5 crops are produced over six months). Low light levels during the fall would be another factor conducive to high tissue nitrates (Lorenz, 1978).

The drop in pH between the first and second production cycles, which was especially pronounced in the surface horizon, may have been associated with leaching of nitrate. Leaching is suggested by the higher levels of nitrate in the deep than in the surface horizon towards the end of the first production cycle, which was also a period of high rainfall.

In conclusion, during the period of observation, the data confirmed the farmer's contention that he was not overfertilizing lettuce, but also suggest that further or routine monitoring would be appropriate. The techniques which were employed are relatively inexpensive, simple and could be conducted on site by farmers.

N release and pH effects of crab meal and other organic fertilizers

Urea and ammonium-N fertilizers acidify soil due to release of protons during nitrification of the added N (Coote *et al.*, 1989). When the nitrate is taken up by plants, the reverse process occurs, except to the extent that nitrate is lost in the interim. In organic farming it may be pertinent to determine whether a particular residue type gives alkaline or acidic reactions during decomposition. In principle, this will depend on the ratio of "excess base" (equivalents of $Ca+Mg+K+Na-Cl-S-P-NO_3$) to equivalents of organic N (EB/N) in the materials and on whether N released is nitrified or not (Fig. 1b; Pierre and Banwart, 1973). Assuming that most mineralized N is nitrified, organic residues are potentially acidifying during decomposition when $EB/N < 1$ and are alkalinizing when $EB/N > 1$; conversely, when the materials were formed during plant growth, the processes were respectively alkalinizing ($EB/N < 1$) and acidifying ($EB/N > 1$). Commonly, crop residues are potentially acidifying; some exceptions are buckwheat, tobacco and some legume residues (Pierre & Banwart, 1973). Data are not readily available for other types of farm residues such as manures and composts. In practice it would probably be more convenient to measure the pH than to attempt to predict it.

For two side by side field comparisons (Farm 3, samples B1, B2; Farm 18, A1, A2, Table 1), use of manures caused large increases in nitrate and measurable declines in pH. In the laboratory experiment on the other hand, use of crab meal caused a statistically significant increase in pH, an effect which can be attributed to its high content of calcium (about 15%; Anonymous, 1971).

Crab meal is a byproduct of the local crab and lobster industry and is used as a fertilizer by organic farmers. It was of interest to know how much of the contained N is likely to be available in the first year of use. The calculated addition of N to the experimental systems (0.8 g of 5.0% N crab meal per jar containing 155 ml water on extraction) is 18.4 meq. The increase in N in crab meal treatments compared to controls over 28 days was 10.9 meq, indicating 59% mineralization; there was no further increase (relative to controls) between 28 and 53 days. Similar but simpler sorts of experiments might be conducted on site to evaluate short term fertilizing value of different types of organic fertilizers or of green manures, or to compare the N-supplying potential of soils from different fields. For example, the fertilizers could be incorporated side by side in small field plots without crops, or with soil in plastic bags, and EC, pH and nitrate measured at 0, 10 and 20 days.

Use of the measurements to indicate possible sites of leakage

The observations on the system practicing CIPAV technology illustrated elevated levels of nitrate and EC and thus some potential for loss of nutrients by leaching in gardens receiving worm compost, and in recently cultivated cane fields. Worm compost piles had high EC values that decreased in older piles, but there was no free nitrate; lush growth of weeds around the piles indicated leakage of nutrients from the piles. The values were low under perennial vegetation even where it had been recently fertilized with hen manure, suggesting these sites are unlikely to be sites of high losses of N. No nitrate was observed in ponds.

The measurements were made during a one-day workshop on soil processes with personnel from CIPAV and from the Faculty of Agriculture of the National University of Colombia at Palmira, Colombia. In discussions, it was suggested that compost applications to the gardens are probably excessive, especially to the legume trees established from cuttings. In the case of cane it was suggested that an annual crop could be planted as there is a period of several months before the new cane establishes a closed canopy. It was noted that worm compost piles are not covered and therefore are likely to be losing nutrients by leaching. However, some leaching of the compost was considered necessary to remove toxins. Participants suggested that a layer of old cane leaves might be placed on the ground before making the compost piles; these leaves would immobilize nutrients leaching from the compost.

Conclusion

pH, EC and nitrate are dynamic soil solution variables whose magnitudes are determined mostly by biological processes which are of considerable importance in biological husbandry, particularly the decoupling and coupling of mineralization and plant uptake. Measurement of these variables, in combination with a basic understanding of the processes in question, appears to provide a convenient means of monitoring those processes. The precise significance of the absolute values of each of the variables and the relationships between them will vary between different farming systems, between different soil types and crops within a farm, seasonally, and from year to year. Thus it is appropriate to treat them in large part as empirical variables or phenomenological tools (Macrae *et al.*, 1989). For many purposes, such as surveying a system for potential sites of leakage of nutrients, the information gained from EC measurements is equivalent to that obtained from nitrate measurements, and the EC measurements are simpler and less costly. pH of water extracts may also change in response to short and longer term decoupling, the magnitude of change depending on the buffering capacity of the system; pH in salt solution would probably be more sensitive to decoupling phenomena.

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