17 Synchrony of Nutrient Release and Plant Demand: Plant Litter Quality, Soil Environment and Farmer Management Options

R.J.K. Myers[1], M. van Noordwijk[2] and Patma Vityakon[3]
[1] *ICRISAT, Patancheru 502 324, Andhra Pradesh, India;* [2] *ICRAF, PC Box 161, Bogor 16001, Indonesia;* [3] *Department of Soil Science, Khon Kaen University, Khon Kaen, Thailand*

Introduction

Synchrony refers to the matching, through time, of nutrient availability and crop demand. When supply and demand do not match, there may be periods of plant nutrient deficiency as well as periods of temporary surplus, even if total supply equals total demand. Lack of synchrony is of concern in two situations: when the supply comes too late for the demand, and when the supply comes earlier than demand in a situation where available nutrients in excess of current plant demand are at risk of loss from the system or of being converted into unavailable forms.

In its broad sense, synchrony has been promoted by varying the formulation, placement and timing of fertilizer inputs, and by other management options such as tillage, time of sowing or type of crop. The Tropical Soil Biology and Fertility program (TSBF; Woomer and Swift, 1994) has focused on the synchrony theme to find options for improving nutrient use efficiency by better management of plant litter and other organic inputs.

Myers *et al.* (1994) reviewed the relevant literature and found evidence for absence of synchrony in many crop production systems, but failed to find many unequivocal examples of improved synchrony through better management of organic inputs. None the less, the synchrony principle has attracted widespread interest among scientists as evidenced by the increasing use of the term in publications. The reasons for such interest have included the idea of finding management practices that might be attractive to poor, smallholder farmers in developing countries, and of avoiding some of the undesirable environmental effects of existing practices in both developed and developing countries.

Buresh (1995) and Van Noordwijk and Garrity (1995) reviewed literature on nutrient use efficiency of tropical cropping systems, with an emphasis on agroforestry. Four main aspects are:

1. Uptake efficiency: Plant nutrient uptake from stored, as well as recently added, organic and/or inorganic resources. Non-available nutrient sources can stay in the soil by chemical occlusion and the equivalent soil biological and physical phenomena, or can be lost to other environmental compartments, by leaching to deeper layers, beyond the reach of crop roots, or as losses to the atmosphere as gas, dust, or particulate ash.
2. Physiological efficiency: Internal redistribution of nutrients during plant growth and yield formation,
3. Processes that lead to spatial heterogeneity of nutrient supply, thereby reduc-

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ing overall efficiency (Cassman and Plant, 1992; van Noordwijk and Wadman, 1992), for example, horizontal nutrient transfer by trees, crops or farmers' practices, creating depletion and enrichment zones, or soil loss and displacement by erosion/deposition cycles.
4. Economic efficiency: Removal of harvest products, their exchange for external inputs and the recycling of harvest residues in the system.

Litter, or other organic input, quality and the time pattern of mineralization are important especially for aspects 1 and 3, but contributions of the synchrony concept to the overall nutrient use efficiency at farm scale and to the farmers' objectives depend on the integration of all aspects under local conditions.

Despite widespread recognition of the synchrony concept, there are few published data based on rigorous experimental evaluation. At a TSBF meeting in Watamu, Kenya in 1992, a working group developed a series of testable synchrony hypotheses (TSBF unpublished meeting report, 1992). In this chapter we report and discuss some of these testable hypotheses that relate principally to litter quality and the environment in which decomposition takes place. We then try to discuss some areas of the synchrony principle that have not so far been adequately developed. We also discuss some ideas about whether farmers might share the scientists' enthusiasm for synchrony.

Twelve Synchrony Hypotheses

Here we examine a testable set of hypotheses based on the synchrony concept, and outline a research framework that can be used to test many of the hypotheses. A key feature of the framework is flexibility which permits either detailed process studies or applied research. The general objective of synchrony-related research is to test the potential for maximizing nutrient capture in the soil–plant system by optimizing the timing, quantity, quality and location of inorganic and organic nutrient inputs. The synchrony hypotheses include some relatively untested concepts, whereas others are well-known and are included for completeness. The relevance of the hypotheses will vary with soil, climate, plant and farm conditions.

S1. The maximum crop yield achievable by the use of inorganic (mineral fertilizer) inputs can be approached or exceeded by optimizing the time of application, placement and quality of organic nutrient sources.
S2. In environments where significant leaching or denitrification occurs, plant uptake of mineral N applied at planting can be increased by simultaneous application of a low N organic material which temporarily immobilizes N early in the crop growth cycle and remineralizes N later on.
S3. Stabilization of organic matter in the soil is enhanced by the addition of mineral nitrogen simultaneously with the addition of organic materials of high C-to-N ratio.
S4. Residues high in lignin will result in a low net mineralization and plant uptake in the first cropping season, but will produce a greater residual effect in subsequent seasons.
S5. Residues high in tannins exhibit delayed nutrient release, but will after a lag period release nutrients rapidly.
S6. Immobilization of P by microbes, or blocking of P sorption and fixation sites, following addition of organic material can prevent fixation of P, thereby improving medium-term availability of P. This phenomenon would be best exhibited in P-fixing soils that are poor in organic matter and high in Fe.
S7. Nutrient uptake efficiency increases with the longevity of the plant. Implicit here also is the notion that relays of short-lived plants may act in the same way as long-lived plants.
S8. The nutrient uptake efficiency of the system will be increased by plants that have more rapidly growing, deeper and more extensive root systems.
S9. Incorporation of organic inputs, as opposed to surface application, accelerates the release of nutrients, thereby providing another option for modifying nutrient use efficiency.

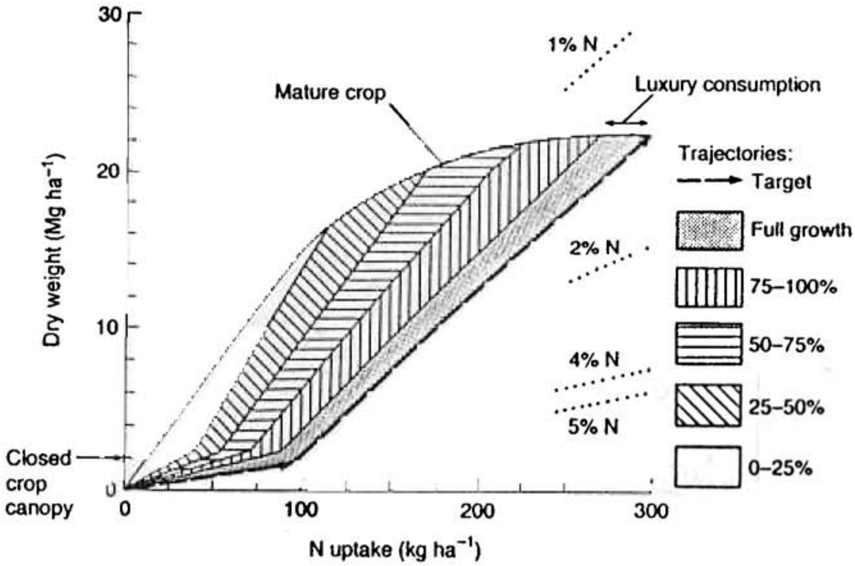

Fig. 17.1. Relationship between cumulative N uptake and cumulative dry matter production of annual crops; the different shadings indicate whether or not growth depressions will ocur if the trajectory of an actual crop development course enters a certain zone. The bold convex line shows the typical relationship at harvest time when crops are compared which grew at different N supply (based on De Willigen and Van Noordwijk, 1989).

S10. Improvement of nutrient uptake efficiency due to the use of organic inputs is more likely when crop growth and soil processes are less constrained by water deficits.

S11. Quality and quantity of organic inputs can influence faunal composition and activity, and thus affect the synchrony of nutrient supply and crop demand.

S12. The need for exact synchrony and crop demand can be reduced by storage of nutrients within the crop in excess of the crop's immediate requirement for growth.

With reference to the topic of this volume, note that hypotheses S1, S2, S4, S5 and S11 refer specifically to litter quality.

Plant Demand and the 'Internal Buffer'

Plant nutrient uptake can be viewed in two ways. Often it is considered to be directly determined by the nutrient concentrations in the root zone. Where such concentrations are just sufficient to maintain unrestricted plant growth, synchrony is ensured. Alternatively, plants are seen as regulators which control their uptake rates despite widely fluctuating external conditions. The truth is likely to be closer to the second than the first, but in practice, the regulation will be less than perfect. A lack of synchrony between N mineralization and N demand which leads to a build-up of mineral N in the rooting zone is not a problem so long as crop uptake occurs before the N is leached from the root zone.

In examining the role of the plant in synchrony, one needs to consider the exponential growth phase up to the closed crop canopy, during which high N concentrations in the leaves are maintained (if external conditions allow), and the linear crop growth phase, in which internal redistribution maintains high N concentrations in the photosynthetically active leaves, but the average N concentration in above-ground biomass can decrease. The relationship between crop dry weight and total N uptake at harvest time typically follows a convex (quadratic) approach to a plateau value (Fig. 17.1), but the trajec-

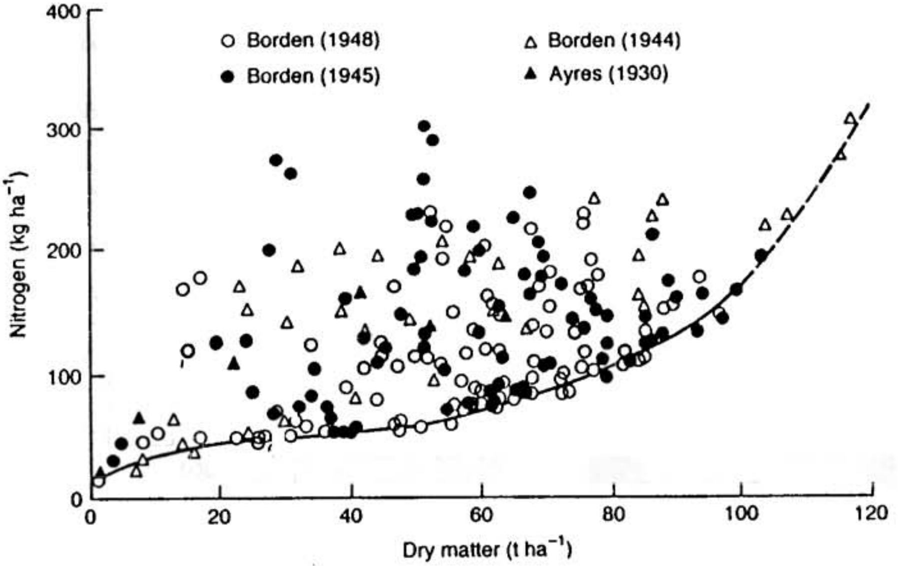

Fig. 17.2. Relationship between N uptake and dry matter yield of sugarcane showing the minimum required to achieve certain yields (R.J.K. Myers and D.R. Ridge, unpublished manuscript).

tories though time at different N supply are concave. Lines through the origin in Fig. 17.1 represent constant average N concentrations in the biomass: maximum yield is achieved by starting off at about 5% N in the tissue and switching over to about 1% N in all dry weight accumulated after the crop canopy has closed (at a biomass of about 2 Mg ha^{-1}); the 'target' uptake includes a certain degree of 'luxury consumption', which allows for temporary shortfalls in uptake without direct effects on dry matter accumulation. The figure is schematized for modelling purposes; versions with real data can be found in De Willigen and van Noordwijk (1987). According to their model, there is a target for the regulation of uptake, and growth is reduced if the target is not met. However, some reduction of uptake below the target can occur without reduction of growth, due to the internal buffer (otherwise referred to as luxury uptake). The existence of this internal buffer reduces the need for exact synchrony since it means that there can be some storage of nutrients within the plant and reduction of the risk of nutrient loss by leaching and gaseous loss. The potential of this internal buffer is substantial, with some plants able to contain double the nutrient concentration necessary for maximum growth (Fig. 17.2). In practice, the concentrations are usually only 10–20% higher than needed.

In semi-arid systems in particular, excessive early nutrient uptake may be a disadvantage if there is excessive use of water and there is insufficient water available to complete floral development and grain filling. When grain sorghum is grown where water stored in the profile before sowing is important, use of wide rows helps achieve balanced water use (Myers *et al.*, 1986) which implies also a synchrony for nutrients. However, when water is less limiting, or in semi-arid areas where rainfall distribution is favourable, a considerable proportion of the mobile nutrients can be translocated from vegetative parts into grain. As a result, a crop could perform quite well in completing its growth cycle from use of subsoil water low in nutrients, when dry topsoil conditions make most of the nutrients inaccessible. In these cases, the plant has a mechanism for ensuring its well-being when nutrients are highly available early in the growth cycle but in short supply as the crop matures. In the absence of this mechanism, available nutrients would remain in the soil for longer and there would be the risk of loss or reduced availability.

Plant species differ in the rate and degree to which later nutrient uptake can compensate for deficiencies early in growth. Such compensation is likely to be limited in crops where the vegetative parts are harvested.

Leaching Rates, Root Development and the External Buffer

Roots contribute to synchrony through variation between species and cultivars in their capacity to explore the soil volume. Root depth is most important for mobile nutrients, whereas intensity of exploration and mycorrhizae are particularly seen as important with the immobile nutrients. Active root exploration and mycorrhizal development are important to the rapid acquisition of nutrients during the period when the plant's needs are greatest. Root depth is important when mobile nutrients are at risk of loss by leaching (de Willigen and van Noordwijk, 1989), or when nutrients are naturally present in subsoils in significant concentrations, or in mixed systems where deep-rooted plants can assist the mixture to achieve synchrony. Wetselaar and Norman (1960) observed that a lack of synchrony resulted in leaching of nitrate which reduced N uptake and yield in a shallow-rooted crop (grain sorghum). However, in a deep-rooted crop (pearl millet) the root system recovered nitrate that had leached below one metre, and N uptake and dry matter production were higher than with the sorghum. A similar difference was observed between shallow-rooted maize and deep-rooted upland rice on an acid soil in Lampung, Indonesia (H. van Noordwijk, unpublished).

Leaching losses of mobile nutrients are not necessarily closely related to infiltration rates. Bypass flow of water through macropores or through old root channels (Van Noordwijk *et al.*, 1991) can leave behind mobile nutrients protected within the soil matrix, and thus reduce the need for synchrony. Surface heterogeneity by ridge tillage is also effective in increasing bypass flow and increasing N-use efficiency of organic N applied in the ridge.

Root system architecture is undoubtedly important. In acid soils that are high in soil solution aluminium, the shallowness of the root system of crops such as corn is a cause of lack of synchrony. With such crops, synchrony must be close to perfect to avoid losses of N below the root system. One of the claimed advantages of agroforestry systems is the supposed mix of deep and less-deep root systems providing a more efficient capture of mobile nutrients. In contrast, monocropping in a range of environments has been shown to be 'leaky' with respect to mobile nutrients as reported by Campbell *et al.* (1975) in a temperate environment, Catchpoole (1992) in the subtropics, and Wetselaar (1962) in the tropics.

Aspects of Synchrony Relevant to Nitrogen

In the review by Myers *et al.* (1994), much of the discussion of synchrony was about nitrogen. Here we will restrict ourselves to some areas that were not covered in detail in that chapter, and some areas where new ideas have developed.

Plants may have characteristics which avoid the need for synchrony, or provide buffering against asynchrony. Many plants have the capacity to accumulate more N than needed for growth as seen above for sugarcane. Perennial species are good examples, particularly those with seasonal leaf drop preceded by a substantial withdrawal of N from leaves (Table 17.1). In this example, the eucalypt tree achieves the maximum standing crop of N early in the life cycle, and thereafter conserves the N within the plant or recycles it through litter.