Chapter 4

Relationship of Agronomic Practices to Soil Nitrogen Dynamics

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Abstract

Soil nitrogen (N) dynamics are a major concern of soil nutrient status and its supply for crop uptake and growth. They are a central focus of agroecosystems. Agronomic practices play a central role in regulating soil N dynamics; the methodologies for investigating soil N mineralization are diverse, but debatable. This chapter discusses the pros and cons of different methods for measuring soil N mineralization, including laboratory, *in-situ*, and modeling procedures. This chapter illustrates the influence of agronomic practices on root architecture that potentially affects crop nutrient uptake. The relationship between agronomic practices and soil N dynamics were fully discussed, which can substantially inform soil fertility and crop nutrition management.

Keywords: agronomic management, nitrogen dynamics, methodology, N mineralization, crop N uptake

1. Agronomic practices reflect the history of managing soil N dynamics

Nitrogen (N) is the most important plant mineral nutrient [1]. It was first discovered in the late eighteenth century, and N's role in improving crop production was widely recognized by the mid-nineteenth century [2]. Long before these discoveries, ancient farmers often unknowingly employed agronomic practices that resulted in managing soil N availability, thereby helping to ensure the human food supply and nutrition. There were two major sources of N in agroecosystems before synthetic N fertilizers—soil N and legume-based biological N fixation. Ancient farmers constructively developed tillage schemes and rotated nonlegume and legume crops to manage both N sources for millennia. Because the appearance of commercial synthetic N fertilizers in the early twentieth century brought significant changes to traditional agronomic practices, the history of agronomic practices from the perspective of managing soil and biologically fixed N dynamics would seem to be a fruitful review.

Plow tillage is a form of soil N management. Much of the soil N is in complex organic forms, such as decomposing plant and animal residues [3]. Most plants can only take up inorganic N (NH_4^+ and NO_3^-) [4] although the basic amino acids are absorbed by some plant species (e.g., *Picea abies*) [5]. Inorganic N and basic amino acids in soil are mainly derived from N mineralization processes. Tillage practices can promote mineralization because disturbance exposes naturally protected (i.e., aggregate-protected) soil organic matter (SOM) to microbes, enhancing microbial activity and N mineralization (Tisdall and Oades [6]). Therefore, plow tillage was considered a great agricultural advance and, from the archeological evidence, has had a very long history. Foot plows [7] also called "digging sticks" are shown in Egyptian tomb paintings [8]. A wooden model of oxen and plow was found in an Egyptian tomb dating from 2000 BCE [8]. In Asia, one of the oldest existing Chinese books titled "Lü Shi Chun Qiu" (compiled in 239 BCE) or "The Annals of Lu Buwei" [9] demonstrated the details of when and how to till according to soil and weather conditions and served as an early example of a practical farming guide.

Rotation can also be a tool to manage soil N through legume bio-fixation of N, depending on the crop species. Monocropping, especially with nonlegumes and heavy-nutrient-using crops (e.g., tobacco and corn) can deplete soil N [10]. Rotation practices, even simple fallow, help to restore soil N [11]. This practice was evident in early Roman times. One of the Rome's greatest poets, Virgil (70–19 BCE), wrote in his poem Georgics (from the Greek, "On Working the Earth") "For the field is drained by flax-harvest and wheat-harvest, drained by the slumber-steeped poppy of Lethe, but yet rotation lightens the labour." This emphasizes that fallow was necessary to rotate with those crops requiring more nutrients. On the other hand, rotations that include a legume crop can bring biological N fixation into agricultural production systems. Although ancient farmers knew nothing of the biological N fixation process, and nothing about the importance of mineral N to plant growth, they intentionally included legume crops into crop sequences. This was evident in the Pliny the Elder's (23–79 CE) book on natural history that mentioned several legume successions as alternatives to conditions that forbade fallowing [12].

Synthetic fertilizer N application in agricultural production has a relatively short history compared to tillage and rotation practices because knowledge regarding N in plant nutrition and N synthesis techniques is recent. In 1836, Jean-Baptiste Boussingault (1801–1887) investigated manure, crop rotation, and N sources and for the first time concluded that N was a major component of plants and that the nutritional value of fertilizer was proportional to its N content [13]. However, ammonia could not be easily synthesized from constituent elements until 1908, when the Haber-Bosch process was developed. After that, synthetic fertilizer N started to play a greater role in agricultural production, helping to improve global food security [14].

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2. Influence of synthetic fertilizer N on traditional agronomic practices

The appearance of synthetic fertilizer N brought a huge increase in the global food supply. Erisman et al. [14] estimated that around 50% of the world population's food requirements are currently met by using synthetic fertilizer N. However, synthetic fertilizer N fundamentally disturbed the soil N cycling balance in agro-ecosystems and brought significant changes to traditional agronomic practices. Our unpublished data (Zou et al. [91]) show that synthetic fertilizer N can promote or prime soil N mineralization depending on the indigenous SOM level and the amount of synthetic N.

Synthetic fertilizer N played a role in developing modern no-tillage farming. Agriculture derives numerous benefits from no-tillage, including fuel and labor savings, increased soil C stocks and erosion resistance. But few people recognized the fertilizer N contribution to no-tillage until early Kentucky no-tillage × N fertility trials revealed its importance [15]. No-tillage without N fertilizer significantly lowered yield compared to conventional tillage without N fertilizer. However, no-tillage with N fertilizer produced yields comparable to those of conventional tillage with fertilizer N. From this perspective, one can speculate that added fertilizer N compensated for reduced soil N mineralization in no-tillage. Other factors, including herbicide and equipment development, also made no-tillage farming feasible in Kentucky and the rest of the Southeast and mid-Atlantic states in the USA, beginning in the 1960s [16]. At the time, the move away from tillage was viewed with much skepticism, but eventually no-tillage was accepted as a revolution in farming. By 2009, approximately 36% of U.S. cropland, planted to eight major crops, was in no-tillage soil management [17].

Although ancient farmers knew nothing of biological N fixation, legume crops had been an important cropping system component worldwide before synthetic N became available [12]. However, crop rotation was discouraged during the Green Revolution, partially because pest control benefits from crop rotation could be replaced by chemical crop protectants [18]. Also, the N credits from biological N fixation could be easily replaced by synthetic fertilizer N. However, soon after the height of the Green Revolution, many studies reported that no amount of chemical fertilizer or pesticide could fully compensate for crop rotation benefits [19]. Rotation systems then came back into fashion. Currently, 80% of all corn, soybean, and wheat planted acres in the United States are in rotation.

3. Systematic understanding of agronomic practices and soil N dynamics

This brief review of agricultural history shows that managing N dynamics is one of the central reasons farmers developed and implemented specific agronomic practices. Furthermore, in the last few decades, new knowledge indicates how transient N can have negative impacts on global environments and human health [20]. A systematic understanding of "How does soil and crop sequence management influence nitrogen dynamics?" will significantly influence agronomic practice development but also has global meaning for the quality of human life. The aim of optimal agricultural N management is to enhance net N mineralization at times when crops need N, to synchronize soil N mineralization with crop N uptake, and to minimize N loss. To systematically understand this topic, three sequential steps need clarification:

1. How do agronomic practices affect soil organic matter pools?

2. How do soil organic matter pools contribute to soil N availability?

3. How do agronomic practices influence crop N uptake capacity?

Soil organic and crop residue N pools provide the organic N for N mineralization. This microbial process, primarily heterotrophic, also requires soil organic C (SOC) as an energy source [21, 22]. Thus, to understand how soil and crop management affect mineralized soil N, it is critical to first evaluate whether and how tillage, rotation, and fertilizer N application affect SOC and N sequestration. Soil organic matter sequestration has been reported to be linked with soil aggregate formation. The dominant concept that explains SOC and N sequestration is based on the aggregation-SOM model [23]. Zou et al. [24] reported that using NT and/or rotation practices in burley tobacco production maintained desirable soil physical and chemical properties by macroaggregate stabilization, which led to conserving SOC and TSN stocks [24]. The basic idea is that soil organic matter functions as a nucleus/binding agent for aggregate formation. Aggregates are important reservoirs of SOC and N that are protected from microbial access and less subject to physical, chemical, microbial, and enzymatic degradation (Six et al. [25]).

Appropriate and precise estimation of soil N mineralization has been a challenge since the early 1900s [26]. Temporal and spatial variability are large because this process is determined by internal soil factors (e.g., SOM level, labile C and N pools, soil microbial community) and external environment factors (e.g., temperature, precipitation and aeration) [27–29]. Agronomic management, such as plant species and N fertilizer application, may also affect N mineralization [30, 31]. With current technologies, it is impossible to predict N mineralization by taking these factors into consideration simultaneously. Instead of being a measure of available N supply, N mineralization estimates by current methods should be considered an index of N availability [32].

Isotopic tracers and incubation methods are the two main approaches used to estimate N mineralization. The isotopic tracer method can measure gross N mineralization, but isotope methods are expensive and can also have methodological problems with mineralization rate estimates and other assumption violations [33]. Although incubation methods can only measure net soil N mineralization (net soil N mineralization = gross N mineralization–N immobilization), incubation can fairly estimate the available N pool, which has a practical value for efficient N management in agroecosystems. Therefore, long-term biological mineralization has been considered the most suitable soil N availability index and is often used to validate other indices derived from more rapid chemical or biological assays [4, 34]. There are, however, many variations to incubation methods, including environment, sample pretreatment, and incubation time, and each variation has advantages and disadvantages. To use incubation to meet research objectives, assumptions, benefits, and liabilities of each variation should be considered.

An experimentally derived N availability index might not necessarily reflect total crop N uptake. Besides the amount of available soil N, crop N accumulation also depends on N uptake capacity. Crop N uptake capacity might be determined by either/both genetic and environmental controls. Genetics can control crop growth rate and biomass accumulation, which would result in different N demands at different growth stages [35]. Crop species have different root architectures, mostly controlled by genetics [36]. However, roots, the dominant nutrient uptake organ directly exposed to the soil, interact with a wide array of soil physical, chemical, and biological factors that vary in time and space [37]. To understand the impact of agronomic management practices on crop N uptake or yield, both soil N availability and root architecture must be considered.

For this review, literature concerning the effect of agronomic practices on crop N uptake or yield is reviewed in three sequential steps. First, the mechanism and effect of agronomic practices on SOC and STN sequestration are described. Second, the pros and cons of long-term incubation methodologies for estimating N mineralization are described. Finally, the potential effects of soil and crop management on root architecture are discussed.

4. Mechanisms and effect of agronomic practices on soil C and N sequestration

The link between SOC and total soil N (STN) decomposition and stabilization and soil aggregate dynamics has been developed, recognized, and intensively studied since the 1900s [23]. Soil organic C and N dynamics are important to agricultural production because these affect soil nutrient cycling and plant productivity [38]. The C and N dynamics are also important to the environment because they can affect greenhouse gas emissions and water quality [39, 40]. These processes happen in a heterogeneous soil matrix and have multiple interactions with soil biota [23]. The task of elucidation is complex. Aggregate-SOM models can explain some of these complexities. Aggregates not only physically protect SOC and SON, but also influence soil microbe community structure [41], limit oxygen diffusion [42], regulate water flow [43], determine nutrient adsorption and desorption [44, 45], and reduce surface runoff and erosion [46]. All these processes have fundamental effects on soil C and N sequestration and stabilization.

More current studies to understand the impact of agronomic practices on soil C and N sequestration have been based on the aggregate hierarchy concept proposed and developed by Tisdall and Oades [47, 48]. To apply the theoretical aggregate-SOM models, the first consideration is the physical separation of soil into different aggregate size classes. Two main methods to separate soil aggregates are widely used by researchers: dry and wet sieving [49]. The disruption of aggregates is mainly due to slaking and microcracking when the soil is initially dry. Dry sieving of air-dried samples is used to characterize the aggregate size distribution with minimum destruction. Wet sieving is used to simulate microcracking and slaking [50]. Water-stable aggregate stability from wet sieving procedures was reported to be closely correlated with SOM stabilization because SOM can act as a transient binding agent (Tisdall and Oades [6]) and has served as an effective early indicator of soil C change in numerous studies (e.g., [51]). The wet sieving procedure has been frequently used to evaluate the agronomic practice effects on both SOM sequestration and soil structural stability [52, 53]. In the wet sieving procedure, sample pretreatment is important [46]. The rewetting pretreatments for soils can cause different results when comparing soils and management history treatments [46]. Cambardella and Elliott [54] showed that capillary-wetted soils retained more macroaggregates (>250 μm) than slaked soils. Bissonnais [46] demonstrated that the different aggregate breakdown methods and frequency of crusting soil samples can dramatically affect soil aggregate stability within the same soil management system. Adopting minimum breakdown aggregates in the sieving procedure keeps comparisons between treatments relative to the natural field conditions.

The effect of agronomic practices (including tillage, rotation, and fertilizer N application) on SOC and STN, according to aggregate-SOM models, has been studied intensively in grass and grain crop production systems [55–59], but not in leaf harvest crop production systems. In these studies, no-tillage increased or maintained SOC and STN compared to conventional tillage. With aggregate separation, conventional tillage can increase large aggregate turnover rate, diminishing the macroaggregate proportion and SOC and STN concentrations [54]. In contrast, no-tillage increases macroaggregates and SOC and STN accumulation.

Most studies show that rotation increases SOC and STN sequestration, compared to monocropping [57, 60]. Crops in rotation schemes have different impacts on SOM stabilization, depending on the quantity and quality of crop residues. Wright and Hons [61] found that crop residue production was similar among wheat, sorghum, and soybean fields, but the wheat field had significantly higher SOC and STN in surface soil than the other two fields, which indicates that the higher C:N ratio in wheat residue can play a role in SOM stabilization. Kong et al. [57] reported that the quantity of crop residue/carbon production had a linear relationship with SOC sequestration in sustainable cropping systems. Therefore, when evaluating crop rotation schemes on SOM sequestration, examining crop residue quantity and quality is important.

Studies on the effect of fertilizer N application on SOM sequestration have produced the most controversial results. Some studies report that fertilizer N application increases SOM because higher fertilizer N input causes more crop residue to be returned to soil [56]. Mulvaney et al. [62] reported that fertilizer N application decreased soil N in the long-term Morrow plot study and argued that synthetic N application enhanced soil microbial decomposition due to the decreasing C:N ratio. Others have found no effect of N fertilizer application on SOM sequestration [63, 64].

5. Methodologies of soil N mineralization measurement

There are many different methods available for long-term aerobic incubation, in laboratory and field, depending on soil sample pretreatment and other incubation conditions [65].

5.1. Laboratory incubation methods

Most aerobic laboratory incubation methods have common features, including maintenance of optimal soil water status (typically with 60% water-filled pore space), constant temperature (commonly 25, 30, or 35°C), and periodic sampling to estimate N mineralization rates [34]. Although there have been several standardized protocols (e.g., [26, 66]), there is significant variation in aerobic incubation details.

5.1.1. Leaching versus non-leaching processes

In early studies with long-term N mineralization incubation, samples were usually incubated continuously in a container without periodic leaching of the accumulated inorganic N. The merit of this method was convenience, but there could be cumulative inhibitory effects, such as pH decline, on mineralization during the incubation [67]. Thus, nonleaching approaches were not recommended for long incubation periods. Stanford and Hanway [68] proposed a periodic leaching approach during incubation. Briefly, 0.01 M $CaCl_2$ was used to leach mineralized N from the sample at the end of each incubation period [69]. The merit of leaching would be avoidance of accumulation of unspecified toxins. While being a time-consuming and apparatus-requiring process, there was also an additional technical concern with potential leaching of soluble organic N during the incubation [65, 70].

5.1.2. Excluded crop residue versus included crop residue

Crop residue can contribute to the soil inorganic N pool by N mineralization or immobilization, depending on the residue C:N ratio. Most laboratory incubation methods exclude such contributions by discarding visible pieces of residue in the pretreatment sieving process [33]. Some laboratory methods cut entrained residues into pieces that are mixed with soil for incubation [71]. Certainly, discarding large portions of residue might influence estimates of the N credit from the previous crop because soil fertility guidelines usually recommend a different fertilizer N rate for the current crop that depends on the previous crop.

5.1.3. Field-moist soil sample versus dried and/or ground soil sample

Using dried and/or ground soil is convenient for a large amount of soil samples that require time to process or for cooperative projects where soil samples come from multiple locations at different times. However, several days are needed to rewet soil for preincubation, which also causes an N mineralization flush during the first weeks of incubation. Numerous studies report that sample sieving and drying-rewetting causes rapid microbial death and enhances microbial respiration and activity, producing an N mineralization bloom [72–75]. Using field-moist samples might cause less physical damage during preincubation protocols and cause a better transition from field to lab conditions than dried and/or ground soil samples. However, field-moist soil samples intended for incubation need to be gently crushed through the sieve (usually 2–4 mm) immediately after sample collection.

5.1.4. Homogenized soil versus undisturbed soil cores

Most laboratory incubation methods utilize a homogenized sample created by sieving. However, there are reports that homogenized samples do not well represent the effects of field soil tillage. Laboratory soil should have a physical structure similar to that of the field environment the sample represents, but sieving artificially "tills" soil from undisturbed/no-tillage environments. This can expose aggregate-protected SOM and enhance the microbial activity, over-estimating the N mineralization. Undisturbed cores may be a better option for laboratory incubations intended to differentiate the impact of tillage on N mineralization [76].

5.1.5. Constant temperature versus variable temperature

Most laboratory incubation methods use a constant temperature, which does not reflect temperature fluctuation in field conditions. Carpenter-Boggs et al. [77] proposed a variable temperature method for laboratory incubation in which soil samples are incubated in a variable temperature incubator (VTI) that mimicked field soil temperatures under a growing corn canopy. They reported that the VTI technique provided a lower sample variance and a smaller initial flush of N mineralization than constant incubation temperature (35°C).

5.2. Field (*in-situ*) incubation methods

Due to the uncertainty about the extrapolation of laboratory N mineralization values in the field, estimating N mineralization from SOM and crop residues in field conditions would be a compelling research topic for investigators because more efficient N fertilization practices could be hastened if a reliable *in-situ* N mineralization method was developed. So far, there have been three dominant *in-situ* research techniques: buried polyethylene bags, covered cylinders, or resin-trap core methods.

5.2.1. Buried polyethylene bag method

The buried polyethylene bag method for *in-situ* N mineralization was proposed by Eno [78]. The main driving force behind this technical development was the realization that soil temperature variance results in considerable changes in the soil NO_3^- production rate. In that preliminary laboratory study, soil in sealed polyethylene bags had an equal nitrification rate compared to soil contained in ventilated bottles. Polyethylene is permeable to oxygen and carbon dioxide, but no NO_3^- diffused through the polyethylene bag during the 24-week incubation period. The preliminary results and polyethylene characteristics mean this technique has the potential to estimate aerobic *in-situ* soil N mineralization.

Although this technique mimics field temperature conditions at a low cost, the technique does not reflect transient field moisture conditions [79]. Elevated NO_3^- and carbon dioxide concentrations inside the bags may promote denitrification [80]. Physical damage to the bags by insects or plant roots may result in loss of mineralized N into the field soil via diffusion and mass flow [77, 78]. Another major limitation of this technique is the inevitable disturbance of soil, which does not allow a valid comparison of tillage effects on N mineralization in field conditions [76].

5.2.2. Covered cylinder method

The covered cylinder method was developed as a more durable alternative to the buried bag. This technique allows incubation of intact soil cores [81]. Covered cylinders are usually constructed from PVC or metal pipes that are capped to exclude rainfall, which is also assumed to stop inorganic N leaching [82]. Although the tubes are open at the bottom, aeration is less than that in field soil, which might result in higher denitrification potential. Modifications such as using gas permeable caps or perforations in the tube sidewall were often added to promote air exchange and reduce denitrification potential [83, 84]. However, sidewall aeration holes could potentially allow mineralized N loss. Water may enter the soil tubes through aeration holes, causing N leaching at the bottom of the soil column. Furthermore, plant roots may potentially grow into the soil column via aeration holes or the open bottom, absorbing mineralized soil from the tubes. Another major limitation of this technique is that the soil in the tube usually has a lower soil moisture content than the surrounding field [79].

The basic principle of the covered cylinder method was to limit N leaching by sheltering incubating soil from precipitation. Based on the same principle, there was another *in-situ* method called the “rain shelter” [76, 85], which simply used a shelter over the sampled area to prevent leaching. Except for considerations regarding the quality and durability of the rain shelter and surface water run-on during intense rainfall, the major drawback of this technique is a lack of ability to reflect field soil moisture fluctuations.

5.2.3. Resin-trap soil core method

Buried polyethylene bags and covered cylinder methods can capture variation in field temperature, while failing to reflect moisture and aeration conditions, which are reported to play a large role in soil N mineralization [28]. An alternative *in-situ* method was proposed that employs ion exchange resins to capture mineralized N leaching from undisturbed soil cylinders [86, 87]. The major modification of this technique is an open cylinder top, which allows precipitation and air to freely enter the intact soil column, and a resin trap at the bottom to capture inorganic N that might otherwise leach from the tube. There are some concerns about whether the soil tube causes abiotic differences between soil in the tube and the surrounding field soil. Wienhold et al. [88] reported that soil inside the cylinders was slightly wetter and warmer than adjacent soil, which likely increases soil N mineralization. They pointed out that the magnitude of change in soil N mineralization was likely much less than the normally observed field core-to-core variation. This method was found to better track true field conditions [79] and has the potential to become a standard procedure [89].

The drawback with intact cores and resin bags is a large resource demand. This technique requires preliminary studies to ensure leached ions are efficiently trapped under field conditions. Resin duality, adsorption capacity, and bypass flow are all factors that can potentially influence resin effectiveness in capturing leached N. The extraction of adsorbed N from the resin is also time-consuming. Kolberg et al. [87] reported that five extractions with KCl were required to completely release adsorbed N.

5.2.4. Other modifications to in-situ incubation methods

Except for the major design developments mentioned above, some minor modifications to *in-situ* incubation methods have been suggested. Hatch et al. [90] proposed a method to combine the soil core with acetylene inhibition, which would limit N loss by nitrification due to uncontrolled soil *in-situ* incubation conditions. The big concern with this modification is that the tube must be sealed at the top, causing a loss in practical application to the field environment if rainfall is a concern. Given consideration on different drainage characteristics in resin-trap soil cores relative to the surrounding soil, Hanselman et al. [79] developed a "new" type of resin-trap soil core method in which resin is mixed with soil to create an artificial uniform soil column. This method is impractical when undisturbed soil structure is a research concern, as in a comparison of conventional and conservation tillage [76].

5.3. Method selection

As discussed above, each method, including laboratory and *in-situ* methods, has unique assumptions, advantages, and disadvantages. There is no standard method that will work for every situation. The selection of method depends on the nature of the study, available resources, and site-specific factors. Although laboratory methods might not reflect natural field conditions, they can provide reasonable relative values to estimate differences due to soil type and certain management practices. Zou et al. [91] reported that discarding plant residue in the laboratory incubation method neglects the potential effect of plant residue on soil N mineralization. The primary merit to field incubation is a more practical estimation of N mineralization, which might be more useful in management decision making. However, the substantial time and apparatus requirement for the *in-situ* incubation methods must be considered. Zou et al. [92] reported that soil C and N fractions contribute variably to predict soil N mineralization in different rotation systems, but SOC (which can be calculated from soil organic matter, a common index in the routine test package of many soil testing laboratories) was the best overall NSNM predictor in their study. The principle is that both biotic and abiotic factors control the soil N mineralization process. Knowing the advantage and disadvantage of each method can help the investigator choose the best method while reducing misinterpretation.

6. The influence of agronomic practices on root architecture

Plant roots are a fundamental component of terrestrial ecosystems and function to maintain nutrient and water supply to the plant [92]. Although root system architecture is controlled mainly by genetic factors [93], plant root systems exhibit high developmental plasticity. This plasticity is possible because root development results from continuous propagation of new meristems. In a heterogeneous soil matrix, a wide array of physical, chemical, and biological factors can affect the initiation and activity of root meristems [37]. Previous studies have reported that certain crop root traits enhance productivity in resource-limited environments due to improved nutrient and water scavenging abilities [94–96]. Agronomic practices can influence crop nutrient uptake capacity by affecting the root growth environment.

Tillage affects root growth mainly by changing soil structure, strength, and penetration resistance. Any particular root increases its length through primary growth when cells of the meristem divide, elongate, and push the root tip forward through surrounding materials. Turgor pressure in the elongating cells is the driving force and must be sufficient to overcome cell wall constraints and other additional constraints imposed by the surrounding environment [97]. Compared to conventional plow tillage, numerous studies on grain crops report that no-tillage increases mechanical impedance, which can result in reduced root length density, root surface density, and lower biomass production [98–100]. Similar results were found in a no-tillage burley tobacco study [91, 101]. Furthermore, greater mechanical impedance with no-tillage not only restricts root growth but also changes root morphology, restricting main root axis elongation, stimulating lateral root branching and root thickening [102, 103].

Nutrient supply and distribution (or fertilizer application) can affect root system architecture mainly by signaling [104, 105]. Typically, roots proliferate in volumes where nutrients are most concentrated [106]. However, the mechanisms of plant root response to the different nutrient elements might be controlled by different pathways and signals [107–110].

There have been few studies on the effect of crop rotation on plant root architecture. Given the basic factors controlling root development, the hypothesis is crop rotation may differentially influence root architecture compared to monocropping systems, if rotated with residue-rich or deep-rooted crops that can increase SOM levels and soil structure. In this case, rotation affects root proliferation by changing soil structure in a manner similar to that observed with no-tillage. If rotation involves legumes, more N nutrition is provided than found with monocropping. In this case, rotation could affect root architecture by changing soil nutrient supply in a manner similar to that found with fertilizer application.

The effects of agronomic practices on crop N uptake not only affect SOM sequestration and soil N mineralization but also alter the soil environment for plant root proliferation. Similarly, in a paper titled “A New Worldview of Soils” [111], soil productivity is broadly defined as the soil’s unique ability to supply water, nutrients, air, and heat, among other life-sustaining resources, adjusting that supply to the demands of plants and microbes. Soil resources fall into two main components: (a) nutrients and moisture and (b) an environment suited for root growth and microbial activity.

7. Conclusion

Agronomic practices reflect agriculture’s N management history. Current agronomic practices have two major responsibilities: (1) promote global food production and (2) maintain the agroecosystem environment. This review shows that soil N dynamics have the potential to provide a framework to understand how agronomic practices connect these two responsibilities. Systematically understanding N cycling in the context of a suite of soil and crop management practices provides a foundation to understand, develop, evaluate, and reshape those agronomic practices.

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