SOIL NITROGEN DYNAMICS IN THE EARLY ESTABLISHMENT PHASE OF A FOREST PLANTATION IN PENINSULAR MALAYSIA

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WAN RASIDAH, K., VAN CLEEMPUT, O. & ZAHARAH, A. R. 1999. Soil nitrogen dynamics in the early establishment phase of a forest plantation in Peninsular Malaysia. A study was conducted on the dynamics of N in the soil as a consequence of clear-cutting and replanting of a forest area with *Acacia mangium* trees. Measurements were carried out within the first two years of tree growth. Soil N fluctuations at different soil depths under and between trees were monitored. Mineral N concentration fluctuated conspicuously within the measurement period. It varied between 1 and 7% of the total N. The nitrate-N (NO_3^--N) content for 0–45 cm depth soil continuously decreased with stand age. For example, for stand age of 3 to 6 months, the total decrease was 44 $\mu g\ g^{-1}$ (35% decrease) for the soil between the trees, and 74 $\mu g\ g^{-1}$ (51% decrease) for the soil under the trees. These values generally dropped with stand age. The concentration remained at the baseline from stand age of 18 months until the last measurement period. The ammonium-N (NH_4^+-N) behaved rather differently. From the stand age of 3 to 6 months, the soil NH_4^+-N concentration increased at both sampling locations, being most prominent between the trees. It then decreased and at 24 months, an increase was noted again in the 0–5 cm soil layer under the canopy. The amount of mineral-N decrease at the beginning of measurements was not in good synchrony with the amount of N increase in the *Acacia mangium* tree. The potential mineralisation measured showed a high rate during the first year, declined in the second year, and increased again after two years. This fluctuation coincided with the changes in mineral-N content. The increase of NH_4^+-N at the beginning could be due to the mineralisation of root residues from the previous vegetation, while the apparent increase at the last measurement stage in the first 5 cm soil layer under the trees came from the mineralisation of litter. Apart from soil transformation processes, uptake by the plants was one of the reasons leading to the lower concentration of mineral-N under the trees compared to those between the trees.

Keywords: Clear-cutting - highly weathered soil - mineralisation - reforestation - soil N

WAN RASIDAH, K., VAN CLEEMPUT, O. & ZAHARAH, A. R. 1999. Dinamik nitrogen tanah di peringkat awal penubuhan ladang hutan di Semenanjung Malaysia. Satu kajian telah dijalankan berhubung dinamik nitrogen tanah kesan daripada penebangan menyeluruh kawasan hutan dan penanaman semula dengan anak benih *Acacia mangium*. Data-data diambil untuk dua tahun pertama pertumbuhan pokok. Turun naik nilai N tanah dicatatkan bagi beberapa kedalaman tanah di bawah silara, di bawah pokok dan di kawasan terdedah (antara silara pokok). Kepekatan mineral N menunjukkan perbezaan yang jelas bagi setiap masa pengukuran. Ia berubah di antara 1 dan 7% daripada jumlah N. Kandungan N-nitrat (NO_3^--N) pada kedalaman tanah 0–45 cm menurun secara pantas dengan kemerosotan sebanyak 44 $\mu g\ g^{-1}$ (35%) untuk tanah di antara pokok dan 74 $\mu g\ g^{-1}$ (51%) untuk tanah di bawah pokok pada umur ladang di antara 3 hingga 6 bulan. Kepekatan nutrien ini berada pada tahap terendah pada usia ladang 18 bulan sehingga ke akhir pengukuran. Perubahan kepekatan N-amonium (NH_4^+-N) adalah berlainan. Pada umur ladang 3 hingga 6 bulan, kepekatan NH_4^+-N tanah meningkat pada kedua-dua lokasi persampelan, dengan nilai lebih ketara pada kedudukan di antara pokok. Kepekatan NH_4^+-N menurun selepas peringkat ini dan pada umur ladang 24 bulan, terdapat peningkatan pada kedalaman 0–5 cm tanah di bawah pokok. Jumlah pengurangan mineral N pada peringkat awal pengukuran tidak selaras dengan jumlah peningkatan N dalam pokok *A. mangium*. Pengukuran potensi mineralisasi menunjukkan kadar yang tinggi pada tahun pertama, pengurangan pada tahun kedua dan peningkatan kembali selepas tahun kedua. Keadaan turun naik ini selaras dengan perubahan kandungan mineral N. Peningkatan kandungan NH_4^+-N pada peringkat awal mungkin berpunca daripada mineralisasi residu akar pokok-pokok terdahulu, sementara peningkatan jelas pada pengukuran akhir pada lapisan 5 cm tanah atas dipercayai berpunca daripada mineralisasi luruhan. Selain proses transformasi tanah, pengambilan oleh tumbuh-tumbuhan merupakan satu daripada faktor yang menyebabkan kepekatan mineral N bagi tanah di bawah pokok lebih rendah berbanding dengan tanah di antara pokok.

Introduction

Large scale planting of timber trees in Malaysia has been increasing lately due to the timber shortage faced by the country. The involvement of the private sector in plantation forestry is due to the low labour requirement compared to other plantation sectors and the perceived economic viability of forest plantations (Malaysian Timber Bulletin 1995). In addition, the Government has approved several incentives such as a ten-year tax exemption on income for the private sector engaged in forest plantations.

A large part of the forest areas in Peninsular Malaysia is dominated by the highly weathered, acidic and low fertility Oxisol and Ultisol soils. Because of rapid and efficient nutrient cycling coupled with conducive climatic conditions, vegetative growth is usually vigorous. Nutrient supply comes mostly from atmospheric deposition, biological fixation and biomass decomposition (Hilton 1987). The contribution from the soil itself may not be significant as it has low weatherable minerals. Thus, tree plantations established on these areas show varied performances that are partly caused by site factors (Petch & Kong 1985, Racz & Zakaria 1987, Lim 1988). *Acacia mangium*, one of the species planted under the Compensatory Forest Plantation Programme in Malaysia, appears to have rather wide edaphic tolerances (Butt & Sia 1982). Nevertheless, good growth has only been reported on moderately- to well-drained, deep and fertile soils (Butt & Ting 1983, Zulkefli 1989).

A number of studies have examined soil properties under matured tree legume plantations (Virginia 1986, Haggar *et al.* 1993). Mature tree legumes usually have an intensive and deep rooting system, capable of influencing soil development by altering the physical and chemical properties of the soil they are occupying (Virginia 1986). But what happens in the soil under a young plantation has not received enough attention even though soil N transformations are known to be very rapid at this stage. Fisher (1995) observed a significant increase in total soil nitrogen beneath *A. mangium* three years after planting in Costa Rica. He also found that biological activities might have had more influence on the bulk density than organic material alone.

Clear-cutting, burning and replanting of a forest area are known to have an important influence on the properties of the soil. Removal of vegetation causes depletion in nutrient uptake and subsequently an increase in mineralisation and immobilisation. There is also increase in NO_3^--N mobility after vegetation removal (Vitousek 1981). Burning, depending on the intensity, can have variable effects on the subsequent tree growth. Panitz and Adzmi (1992) found twenty percent improvement in the height growth and fifty percent improvement in the diameter growth of *A. mangium* at one year after planting on a site which was burnt before planting. Biological processes could have taken place at different rates as the regulating factors such as moisture, temperature and substrate availability vary. In forest plantation establishment in Malaysia (first rotation), clear-cutting and burning prior to replanting are common as lower operational costs are incurred. In March 1992 we initiated a series of measurements to examine the soil N dynamics in a plantation ecosystem of *Acacia mangium* Willd. at different stand ages within the two years of initial growth. Measurements were partitioned into four different depths (0–5, 5–15, 15–30 and 30–45 cm) and at two locations, under the canopy and in the interspace between trees.

Materials and methods

Site description

The plantation area chosen for this study was located within the Kemasul Forest Reserve in Pahang, Malaysia (3° 28' N, 102° 23'E). Forest plantation was started in the Kemasul area in the early 1970s with softwood species. The area planted was increased in 1982 following the establishment of fast-growing hardwood species. To date, more than 20 000 ha have been planted with *A. mangium* as a major species.

Survey of the area showed that the soil belongs to the Batu Anam series, Aquoxic Tropudult according to Soil Taxonomy classification. It was developed from iron poor shales parent material. Internal drainage was poor and the slow infiltration coupled with strong structures limited free root development. These constitute major limitations for good tree growth. The fertility level is rather low (Table 1).

Annual precipitation was 1521 mm for 1992, 2257 mm for1993 and 2211 mm for 1994. The highest value was recorded around May and November each year. Average monthly temperatures also showed two peaks of hot weather, around April and September. It ranged from 25 to 28 °C.

Table 1. Properties of the soil at the experimental site

Soil depth (cm)	pH	Clay (%)	C (%)	N (%)	C/N	CEC ($cmol_c\ kg^{-1}$)
0–5	4.60	32	0.73	0.10	7.3	4.75
5–15	4.45	32	0.63	0.09	7.0	3.35
15–30	4.47	44	0.34	0.07	4.9	2.28
30–45	4.42	38	0.22	0.06	3.7	3.62

Plot establishment

Before planting, the previous vegetation was cut and except for the valuable logs that were transported out, other residues were left to dry on site and subsequently burnt. Burning was carried out to minimise or to control diseases as well as to ease planting activities. *Acacia mangium* seedlings were planted in December 1991 at a density of 900 trees ha^{-1}. However, where unburnt or partially burnt woody materials were present, the spacing became irregular. Seedlings were obtained from the nursery on site. No uprooting and manuring was carried out. The water supply relied solely on the rainfall received.

Our measurements were conducted at different ages of growth. Because we did not know the actual age of the planted seedlings, we expressed our findings based on the age of the stand, taking the replanting date as zero time.

Soil sampling and analysis

The first sampling was carried out at 3 months after transplanting and continued afterwards at the stand ages of 6, 12, 18 and 24 months. Soil was taken at 10 locations within the plantation area at 0–5, 5–15, 15–30 and 30–45 cm depths under the trees and at the centre among four trees (between the canopies). For each location, samples were composited for each depth and transported to the soil laboratory at the Forest Research Institute Malaysia in an ice-box. Immediately after arrival, samples were kept in a cold room and extracted the following day. Soil analysis was carried out using fresh samples and the data were converted to dry weight basis using the moisture data. Total nitrogen was extracted using the micro-Kjeldahl's digestion method and determined colorimetrically using Technicon autoanalyser II system. For the extraction of mineral nitrogen, samples were shaken with 1 N KCl for one hour, centrifuged and filtered. The filtrate was treated with chloroform to suppress microbial activity and then analysed for NH_4^+-N and NO_3^--N by the distillation procedure.

Five soil cores were taken randomly from each depth as above for the determination of bulk density. Samples were transported immediately to the laboratory after sampling. They were dried at 105 °C for 48 h or until constant weight. The fresh weight, the oven-dry weight and the volume were recorded for the calculation of bulk densities that were used to convert the data into kg ha^{-1} basis.

Nitrogen mineralisation

Potential soil N mineralisation at different growth stages was made through laboratory incubation at 30 °C. This temperature was used on the basis of our observation that the temperature of the study site was higher than the temperature of the other parts of Kemasul where the canopy had already closed. It was quite bare with the seedlings just been planted. The same sampling procedure as described was followed for this measurement except that samples were taken at stand ages of 8, 14, 20 and 26 months. These samples were air-dried, crushed and separated from gravel with a 2-mm mesh sieve. Soil with less than 2-mm size was used in this determination. Portions of the samples were used to determine soil field capacity. For the measurement of mineralisation capacity, the moisture level of the soil was adjusted to 2/3 field capacity to avoid anaerobic condition. The sample vials used were covered with parafilm. Incubated samples were withdrawn each week until four weeks for the analysis of NH_4^+-N and NO_3^--N using the same procedure as described for the soil analysis. The amount of KCl solution added was adjusted with the initial amount of water added to obtain the moisture level to 2/3 field capacity. No pre-incubation was used since the experiment lasted four weeks. It would have been necessary for short term incubations. Evaluation of the N mineralisation in the laboratory is carried out to get information, under controlled conditions, of the potential (maximum) values. This information shows what a soil can provide. These are of course not values found in the field, but they give an indication of what one eventually can expect. It provides a general idea of an important fertility parameter.

Results and discussion

Mineral nitrogen in the soil

Figures 1(a) and 1(b) describe the pattern for NH_4^+-N concentrations in the soil across the range of stand ages. There was an accumulation of NH_4^+-N in the first 15 cm at the first 6 months after planting in the soil between the trees (Figure 1a). After this period, the value decreased to the baseline and seemed to stabilise at the 18-month-old stage. Looking at the procedure for site preparation, there had been removal of logs and burning of the above-ground vegetation, but virtually no uprooting or removal of the below-ground biomass. This had left behind a considerable volume of roots, which in time had decomposed. This process could possibly have been one of the contributors to the observed NH_4^+-N increase. The decrease of NH_4^+-N after this period could have been largely due to uptake by vegetation, since, at one-year-old, there was quite substantial root growth in the *A. mangium* and surrounding weeds. Another possibility could have been the slower rate of nitrification in the soil exposed to full sunlight having a lower moisture level as compared to the soil under the canopy. This results in a higher NH_4^+-N decrease in the former soil.

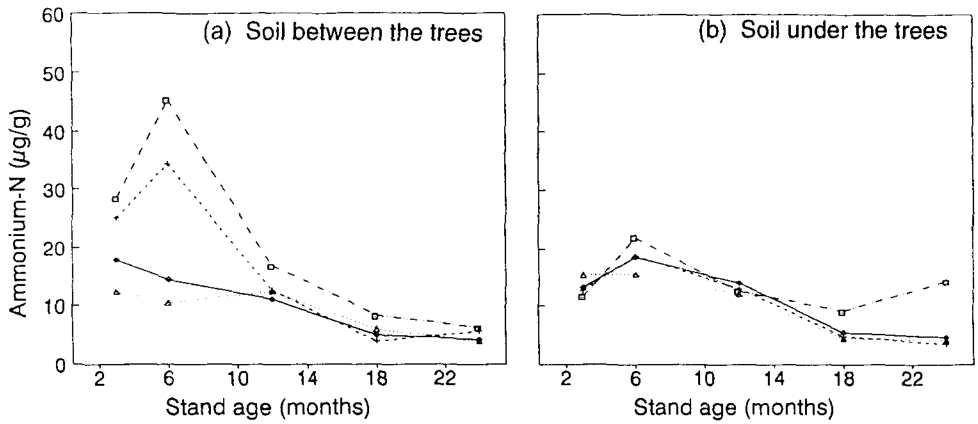

Figure 1. Ammonium-N (NH_4^+-N) concentration in the soil at various stand ages

An initial NH_4^+-N increase was also discovered in the soil under the canopy (Figure 1b), but the values were small compared to the soil between the trees. For stand age of 18 months and up, NH_4^+-N concentration increased in the top 5 cm soil layer (Figure 1b). This NH_4^+-N might have come from the mineralisation of litter that was abundantly present at this stand age and above.

Another important characteristic from these two figures is the distinct difference in NH_4^+-N concentration in the upper 15 cm soil during the initial phase of plantation establishment (at 3- and 6-month measurements). The reason for this phenomenon is not completely known, but it could be due to uptake by *A. mangium* roots. At 2 to 6 months, seedlings are likely to be establishing themselves and not taking up much NH_4^+-N, hence the increase in soil NH_4^+-N concentration.

Although there was an initial increase in NH_4^+-N concentration, no NO_3^--N increase was observed, which was eventually due to leaching or runoff. This was, however, difficult to assess with no soil solution measurements. A decrease in the concentration was noted at every measurement (Figure 2). The total NO_3^--N decreases in 0–45 cm soil between the trees were 44 µg g^{-1} (35% decrease), 50 µg g^{-1}, 17 µg g^{-1} and 6 µg g^{-1} for stand ages of 3 to 6 months, 6 to 12 months, 12 to 18 months and 18 to 24 months respectively. The corresponding values for the soil under the trees were 74 µg g^{-1} (51% decrease), 45 µg g^{-1}, 18 µg g^{-1} and 5µg g^{-1}. At the beginning of the measurements (3-month-old plantation),the NO_3^--N concentration was higher for the soil under the trees than that between the trees. Measurements at later growth stages showed a lower NO_3^--N concentration, which means that the rate of depletion particularly at the first 30 cm was higher in the soil under the trees. This could be due to uptake by the trees and also by a comparatively higher rate of nitrification as explained in the preceding paragraph. For both soils, the rate of depletion generally decreased with stand age. The high soil NO_3^--N concentration initially could be the result of burning as any ammonium produced via nitrification would immediately be nitrified in the absence of vegetation.

The N-demand by *A. mangium* roots could probably be one of the causes for a rapid disappearance of NO_3^--N in the top 15 cm layer of the soil under the trees (Figure 2b). This is also based on our observation on root activity. Six-month-old *A. mangium* roots were still concentrated under the trees. When soil pH is low, NO_3^- may be absorbed more rapidly than NH_4^+ (Petterson 1981). After two years of tree growth, the NO_3^--N level was less than 5 µg g^{-1} of soil.

Nitrate leaching could hardly be visualised in this soil since there was no increase in NO_3^--N concentration at lower depths throughout the study period. It could be that NO_3^--N moves through the soil profile fairly quickly and it may not be picked up in the lower profile soil sampling. Figures 1 and 2, however, do imply that the NO_3^--N decrease in the soil proceeded at a faster rate than the NH_4^+-N decrease. We speculate that surface runoff was another important path of nitrate loss. After a heavy downpour, most of the water might have moved laterally as could be clearly seen in the field from the soil movement path. This was due to the undulating topography and high clay content in the soil at lower depths.

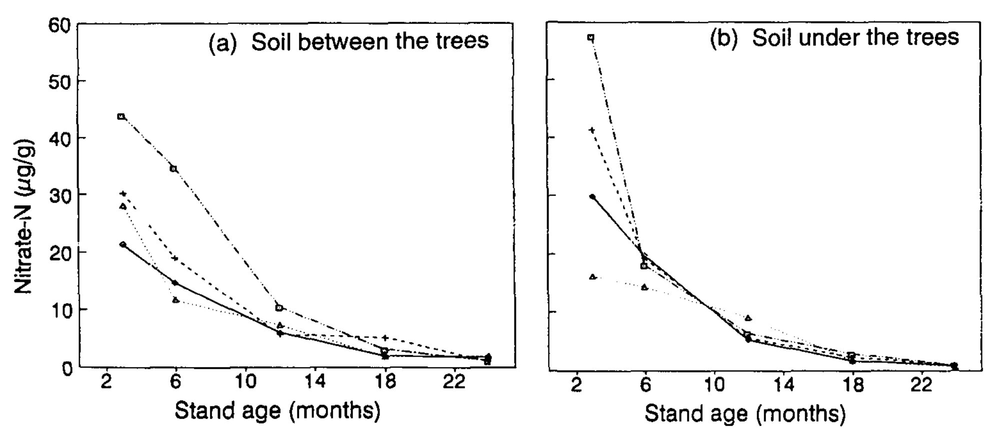

Figure 2. Nitrate-N (NO_3^--N) content in the soil at different stand ages

Total nitrogen in the soil

Table 2 presents the total inorganic N concentration (NH_4^+-N + NO_3^--N) and its relative composition compared to the total soil N, measured for the same soil. The amount of NO_2^--N was negligible, probably due to the acidic soil condition. A large part of the N present in this soil was in the organic form. This N becomes available upon mineralisation, the main soil-resident, biological way of converting the organic-N into inorganic-N (Tate 1987).

On a percentage basis, the proportion of mineral-N to total-N was reduced from 7.76% at stand age of 3 months to 0.85% at stand age of 24 months for the soil under the trees, and from 7.15 to 0.92% for the soil between the trees. Apart from immobilisation, this high rate of mineral-N decrease can be the result of the following circumstances: 1) uptake by vegetation, 2) loss through surface runoff, and 3) loss through gaseous emission. Nitrate leaching can also be another pathway for N loss in this ecosystem considering the high nitrate mobility. The loss through gaseous N emission (particularly N_2O and N_2) could be significant because, even though the soil is acidic, high moisture and temperature are most favourable for this process to take place.

The amount of total mineral-N was quite similar between the two sampling locations (Table 2). However, in the upper soil layer, mineral-N was higher in the soil taken between the trees at the early age. With canopy closure, the concentration in the soil increased, believed to be due to the mineralisation of litter.

Table 2. Mineral nitrogen (mg kg^{-1}) in the soil at various stand ages

Soil depth (cm)	Stand age (months) 3	6	12	18	24
Under the trees					
0–5	69.32	39.97	19.04	12.05	15.26
5–15	54.17	38.08	18.75	7.09	4.62
15–30	43.13	38.40	19.40	7.27	5.69
30–45	31.49	29.84	21.27	6.46	4.99
Total (kg ha^{-1})	254.7	207.6	115.8	42.66	34.54
	(7.76)	(3.89)	(1.94)	(1.31)	(0.85)
Between the trees					
0–5	72.32	79.92	27.39	11.60	7.56
5–15	55.23	53.39	18.43	9.34	6.92
15–30	39.29	29.03	17.17	7.20	6.16
30–45	40.39	22.15	19.81	8.10	6.07
Total (kg ha^{-1})	266.6	210.0	111.4	48.49	37.37
	(7.15)	(4.88)	(2.40)	(1.38)	(0.92)

Figures in parentheses are percentages of the total (Kjeldahl) nitrogen.

Nitrogen increase in the tree

Comparing total N increase in *A. mangium* and total mineral-N depleted from the soil (Table 3), the N uptake was much lower than what had been supplied. At six months after planting, only about 2 kg ha^{-1} increase was observed in the tree compared to 52 kg ha^{-1} mineral-N decreased from the soil. This represents about 50 kg ha^{-1} of unaccounted-for N which could be immobilised, utilised by the surrounding weeds, leached or washed away or have undergone other transformation processes. Between the stand ages of 7 and 12 months, the unaccounted-for N increased to 80 kg ha^{-1}. This period coincided with the monsoon season when the area received relatively higher rainfall. Thus, N loss through surface runoff and leaching could also have been higher. Even though uptake by the plants had increased, mineral-N release had also increased tremendously. From the stand age of 13 to 18 months, the unaccounted-for N had decreased, yet the amount was still high (more than 47 kg ha^{-1}). Only after 18 months, the N uptake exceeded mineral-N decrease from the soil. Mineralisation-immobilisation seem to be the key processes in this soil and the whole data indicate poor synchronisation between N release and N demand.

Table 3. Total N uptake by *Acacia mangium* and the amount of mineral N decrease from the soil at different growth stages (in kg ha^{-1})

Stand age (months)	N increase in *A. mangium*	Mineral-N decrease from the soil
4–6	1.94	51.85
7–12	14.67	95.20
13–18	20.60	68.02
19–24	58.66	9.62

Potential nitrogen mineralisation rate

It appears that net N mineralisation rates fluctuated in the same manner as the changes in NH_4^+-N concentration in the soil. Higher rates were observed at the 8-month stand age measurement, decreased at the 14- and 20-month and increased again at the 26-month stand age measurement (Table 4). Mineralisation of root residues seems to be the only possible explanation for the increased mineralisation at the beginning, while at the last measurement, the high availability of litter from *A. mangium* enhanced the nitrogen mineralisation. As a higher amount of litter was available under the canopy, an increased mineralisation rate was also more pronounced in this soil compared to the soil taken between the trees.

Table 4. Potential nitrogen mineralisation rates in the soil (mg kg^{-1} 26 $weeks^{-1}$) calculated for six months duration in each sampling period

Soil depth (cm)	Stand age (months)			
	7-12[a]	13-18[b]	19-24[c]	25-30[d]
Under the trees				
0–5	212.2	136.1	100.6	254.3
5–15	221.0	63.7	127.4	188.5
15–30	177.3	66.0	121.9	147.4
30–45	139.1	60.8	102.4	80.6
Between the trees				
0–5	201.8	112.3	72.8	211.9
5–15	274.8	126.9	80.1	98.8
15–30	232.2	106.9	100.9	64.2
30–45	202.5	110.0	120.1	52.3

a: soil sampled at stand age of 8 months; b: soil sampled at stand age of 14 months; c: soil sampled at stand age of 20 months; d: soil sampled at stand age of 26 months.

Conclusion

Our observations show that nitrogen fixing trees do not at all time improve the soil fertility. For almost two years after the establishment of *A. mangium*, mineral N level was rapidly depleted. Clear-cutting and burning led to a low sustainable ecosystem as far as soil nitrogen was concerned. Rapid loss of N from the soil mineral N pool occurred during a period when plant roots were not extensive to capture it. An improvement was noted only after two years, coming from the mineralisation of litter. Even then, this was only observed in the upper soil layer under the trees that was in close contact with the litter. Harvesting activities also played a role. When uprooting was not practised, a large volume of organic matter was made available for decomposition. This material contributed nutrients for the initial plant growth.

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