*Journal of Plant Biology*, March 2000, 43(1) : 41-47

# Plant Succession and Interaction between Soil and Plants after Land Reclamation on the West Coast of Korea

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**Plant succession and the interaction between soil and plants after reclamation were investigated on the west coast of Korea. Our study included one natural tidal flat site (Namdong, 3 km$^2$), and five sites that differed in the number of years since being reclaimed: Hyundai A, 6 km$^2$ (1 yr); Hyundai B, 5 km$^2$ (2 yr); Jangdeog, 5 km$^2$ (8 yr); Mado, 2.5 km$^2$ (12 yr); and Baegseog, 1 km$^2$ (30 yr). The number of plant species occurring at each site was 10, 9, 15, 30, 28, and 38, respectively. Based on distribution ranges of the plants along gradients of salt and moisture contents in the soil, and species associations and life forms, plant succession was divided into two sere groups, hydrarch and xerarch. The major species of the former were *Phragmites communis* and *Typha angustata*, but the sequence of the sere could not be identified. Species associated with the latter were [*Suaeda japonica*] → [*Salicornia herbacea, S. japonica, Atriplex subcordata, Suaeda asparagoides*] → [*Aster tripolium, Carex scabrifolia, Zoysia sinica, Limonium tetragonum*] → [*Artemisia scoparia, Calamagrostis epigeios,* and *Setaria viridis*] → [*Imperata cylindrica* var. *koenigii, Sonchus brachyotus, S. viridis*] → [*Aeschynomene indica, Lotus corniculatus* var. *japonicus, Trifolium repens*, and other non-halophytes]. In certain circumstances, the first and second stages replaced *S. japonica* with *C. scabrifolia* and *Z. sinica*. The progression of interactions between soil and plants through succession was salt leaching → increase in species richness and biomass → increase in soil organic matter → increase in total nitrogen and decrease in bulk density of soil, and/or salt leaching → increase in phytomass → decrease in soil-available phosphorus.**

*Keywords*: Glycophytes, Halophytes, Interaction, Reclaimed land, Soil, Soil salt, Succession, Tidal flat

Because plant species that grow on reclaimed lands differ in their degree of tolerance to salt, their habitats vary according to the soil salt content of the reclaimed lands (Waisel, 1972; Reimold and Queen, 1974; Min and Kim, 1999a). When tidal inundations are blocked after reclamation, soil salts are leached by fresh water or rainfall (Min and Kim, 1997a, 1997b). Over time, the reclaimed land soil is transformed until it possesses the salt content of common land soil. In areas that are periodically inundated by tides, the zonation of the plant community is not regarded as successional, because the tidal-flat vegetation in these areas is not formed by interactions among plants but, rather, by erosion and silt accumulation (Corre, 1985). On reclaimed lands, plant succession proceeds after reclamation.

The main factor that determines succession is the variety of soil environments on reclaimed lands. Because these soil properties change rapidly, the rate of vegetational succession is faster on reclaimed land than on common land (Beeftink, 1979; Joenje, 1979). In the early stages of succession, the plant species are mostly annuals. Species diversity reaches a maximum 9 ~ 10 years after reclamation (Noordwijk-Puijk et al., 1979). The variability in succession rates is related to the pattern of creek distribution along different topological altitudes. Rates of salt leaching also vary according to geographical properties.

On reclaimed lands, plant successional seres depend on the chances for immigration of propagules, as well as the microenvironment of the ecesis site. For example, seres can be described as comprising *Salicornia* → *Puccinellia* → *Juncus* (Gillham, 1957; Chapman, 1960); *Spartina* → *Salicornia* → *Suaeda* → *Limonium* → *Atriplex* (Purer, 1942); *Zostera* → *Salicornia* → *Glaux* → *Juncus* → *Phragmites* (Miyawaki and Ohba, 1965); or *Salicornia* → *Suaeda* → *Aster* → *Sonchus* → *Calamagrostis* → *Imperata, Setaria* → *Miscanthus* (Min et al., 1989). Although the areas of reclaimed land in Korea are large and increasing, few reports have been made on the succession of halophytic communities. The continuum structures of plant communities along the gradient of soil salts, from tidal flats inland, were studied by Kim et al. (1975) and Min et al. (1989). In addition, Kim (1971) and Min and Kim (1999a) studied plant distribution as it related to soil salt content on reclaimed lands. However, patterns of succession

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have not been followed during the time that elapses after reclamation.

This paper is a follow-up to one previously published (Min and Kim, 1999a, 1999b). The purpose of this study was to investigate vegetational succession, and the interaction between soil and plants after reclamation.

## STUDY AREAS AND METHODS

The six study sites on the west coast of Korea are the same as in our previous reports (Min and Kim, 1997a, 1997b, 1999a, 1999b). They include one intertidal flat: Namdong (control area, 3 $km^2$); and five sites that varied in the number of years since being reclaimed: Hyundai A (1 yr, 6 $km^2$); Hyundai B (2 yr, 5 $km^2$); Jangdeog (8 yr, 5 $km^2$); Mado (12 yr, 2.5 $km^2$); and Baegseog (30 yr, 1 $km^2$).

Field surveys were conducted from June to September of 1984. The survey for flora was carried out twice, with the identification and nomenclature of plant species based on Lee (1981). We limited the area to be studied at Namdong to that below mean high tides; total area was used at the other sites. Soil sampling and analysis methods followed those described by Min and Kim (1999a). We calculated correlation coefficients between soil properties, or between soil properties and biomass, using the formula of $y = ax + b$. The data on the relationships between plant distribution and soil salt content, and for delineating plant species association were those used by Min and Kim (1999a, 1999b).

## RESULTS AND DISCUSSION

### Leaching of Soil Salts after Reclamation

Changes in soil electrical conductivity (EC) and soil moisture content (MC) after reclamation are shown in Table 1. MC was relatively high in Namdong and relatively low in Jangdeog; moisture contents at the other sites were similar. The mean values of EC were 1.97 mmho in Namdong and 0.81 ~ 1.05 mmho in the other areas. The EC in the former was homogeneous, but heterogeneous in the latter. Low readings of EC at Hyundai A and B are explained by the short amount of time (1 or 2 years) that had elapsed since reclamation. The soil texture at both these sites was mostly sand, which caused rapid salt leaching. EC was still high at Baegseog 30 years after reclamation because this area was somewhat influenced by seawater (Min and Kim, 1997a, 1997b).

### Changes of Flora and Inference of Successional Sere

The flora found on the six sites is shown in Table 2. A total of 39 different species were surveyed. The number of species per site (with years since reclamation in parenthesis) was 10 at Namdong (control area); 9 at Hyundai A (1 yr) 15 at Hyundai B (2 yr); 30 at Jangdeog (8 yr); 28 at Mado (12 yr); and 38 at Baegseog (30 yr). These species were assigned to one of five Groups, according to growth habit and the time that elapsed before they appeared after reclamation. Group I: *Triglochin maritimum, Zoysia sinica, Phragmites communis, Carex scabrifolia, Salicornia herbacea, Suaeda japonica, Limonium tetragonum, Aster tripolium, Artemisia scoparia*, and *Suaeda asparagoides*. These species were common to all six areas. Group II: *Atriplex subcordata, Calamagrostis epigeios, Typha angustata, Setaria viridis, Sonchus brachyotus*. These species normally appeared two years after reclamation.

Group III: nine species, including *Rumex maritimus*. These plants grew sparsely, and did not form a patch. Group IV: six species, including *Zoysia japonica*. These plants formed large patches. Species in both these groups appeared eight years after reclamation. Group V: nine species, including *Lotus corniculatus*

**Table 1.** Moisture contents and electrical conductivities of soil at the six study sites. Numbers in parenthesis are years after reclamation.

| Area* | Moisture content (%) | | | Electrical conductivity (mmho) | | |
|---|---|---|---|---|---|---|
| | mean | SD | range | mean | SD | range |
| Namdong | 24.6 | 4.8 | 15.3-34.1 | 1.97 | 0.55 | 1.00-3.30 |
| Hyundai A (1) | 20.4 | 2.4 | 12.7-23.3 | 1.05 | 0.52 | 0.02-1.90 |
| Hyundai B (2) | 18.6 | 3.1 | 5.3-23.4 | 0.99 | 0.48 | 0.01-2.00 |
| Jangdeog (8) | 15.9 | 5.2 | 10.1-20.0 | 0.93 | 0.11 | 0.01-4.70 |
| Mado (12) | 17.3 | 3.6 | 13.2-25.5 | 0.92 | 0.62 | 0.04-3.00 |
| Baegseog (30) | 19.2 | 5.6 | 12.8-28.6 | 0.81 | 1.02 | 0.10-2.60 |

var. *japonicus, Puccinellia nipponica, Fimbrystilis longispica, Bromus japonicus, Pennisetum alopecuroides, Phacelurus latifolius*. These species appeared 12 years after reclamation.

Group I was composed of halophytes, which grow in saline areas, while Group II comprised salt-tolerant species that appear in the early stages after reclamation. Plants in these two groups can be displaced by glycophytes if soil salts have leached sufficiently so that levels are now similar to those found in common soil. The soil salt content varied along topographical altitudes so that halophytes were able to grow up to 30 years after reclamation. Soil in lower areas was partially influenced by seawater, especially at Baegseog, where soil salts had not leached (Min and Kim, 1999a, 1999b). Only halophytes could grow in those unleached areas. Four species in Group I - *T. maritimum, Z. sinica, C. scabrifolia,* and *S. japonica* were able to grow in areas that were fully inundated by seawater Their high salt tolerance enabled them to exist in various habitat types (Min and Kim, 1999a). These species associations were significant at

**Table 2.** Plants in the six study sites. Numbers in parenthesis are years after reclamation.

| Species | Namdong | Hyundai A (1 yr) | Hyundai B (2 yr) | Jangdeog (8 yr) | Mado (12 yr) | Baegseog (30 yr) | Group |
|---|---|---|---|---|---|---|---|
| *Triglochin maritimum* | ○ | ○ | ○ | ○ | ○ | ○ | I |
| *Zoysia sinica* | ○ | ○ | ○ | ○ | ○ | ○ | |
| *Carex scabrifolia* | ○ | ○ | ○ | ○ | ○ | ○ | |
| *Salicornia herbacea* | ○ | ○ | ○ | ○ | ○ | ○ | |
| *Suaeda japonica* | ○ | ○ | ○ | ○ | ○ | ○ | |
| *Limonium tetragonum* | ○ | ○ | ○ | ○ | ○ | ○ | |
| *Aster tripolium* | ○ | ○ | ○ | ○ | ○ | ○ | |
| *Artemisia scoparia* | ○ | ○ | ○ | ○ | ○ | ○ | |
| *Phragmites communis* | ○ | ○ | ○ | ○ | ○ | ○ | |
| *Suaeda asparagoides* | + | | ○ | ○ | ○ | + | |
| *Atriplex subcordata* | | | ○ | ○ | ○ | ○ | II |
| *Calamagrostis epigeios* | | | ○ | ○ | ○ | ○ | |
| *Setaria viridis* | | | ○ | ○ | ○ | ○ | |
| *Typha angustata* | | | ○ | ○ | ○ | ○ | |
| *Sonchus brachyotus* | | | + | ○ | ○ | ○ | |
| *Rumex maritimus* | | | | + | + | | III |
| *Poa acroleuca* | | | | + | + | + | |
| *Cyperus amuricus* | | | | + | + | + | |
| *Artemisia princeps* var. *orientalis* | | | | + | | + | |
| *Eriochloa villosa* | | | | + | | + | |
| *Paspalum thunbergii* | | | | + | | + | |
| *Polygonum aviculare* | | | | + | + | + | |
| *Erigeron annuus* | | | | + | + | + | |
| *Artemisia capillaris* | | | | + | + | + | |
| *Bulbostylis barbata* | | | | + | + | ○ | IV |
| *Trifolium repens* | | | | + | + | ○ | |
| *Plantago major* var. *japonica* | | | | + | + | ○ | |
| *Zoysia japonica* | | | | ○ | ○ | ○ | |
| *Imperata cylindrica* var. *koenigii* | | | | ○ | ○ | ○ | |
| *Aeschynomene indica* | | | | ○ | ○ | ○ | |
| *Lotus corniculatus* var. *japonicus* | | | | | + | ○ | V |
| *Puccinellia nipponica* | | | | | | + | |
| *Fimbristylis longispica* | | | | | | + | |
| *Persicaria hydropiper* | | | | | | + | |
| *Plantago camtchatica* | | | | | | + | |
| *Erigeron canadensis* | | | | | | + | |
| *Bromus japonicus* | | | | | | ○ | |
| *Pennisetum alopecuroides* | | | | | | ○ | |
| *Phacelurus latifolius* | | | | | | ○ | |
| Total | 10 | 9 | 15 | 30 | 28 | 38 | |

○, forming patch; +, rare.

the 1% or 5% level (Min and Kim, 1999b).

Except for the four salt-tolerant species just mentioned, the other plants found in Groups I and II were newly introduced after seawater was blocked during reclamation. These included annuals such as *S. asparagoides, S. herbacea, A. subcordata,* and *S. viridis* biennials *L. tetragonum, A. tripolium,* and *A. scoparia*; and perennials *C. epigeios* and *S. brachyotus*.

The plants of Groups III, IV, and V were non-halophytes (i.e., glycophytes) that grew in common land soil. They were able to grow on reclaimed land because, although the salt content was high soil depths greater than 50 cm, plant roots were mainly distributed at the surface, where soil content was low (Min and Kim, 1997a). *Aeschynomene indica, Z. japonica, Imperata cylindrica* var. *koenigii, Lotus corniculatus* var. *japonicus*, and *Phacelurus latifolius* formed large and pure stands, but the other species were distributed mostly in mixed communities, either sparsely or in a narrow range. Therefore, these species were not associated with others (Min and Kim, 1999b). That is, during the process in which halophyte communities were replaced by glycophyte communities, the non-halophytes temporarily formed mixed or unstable communities according to their various environments.

Although *S. herbacea, Suaeda maritima,* and *A. tripolium* grow in dry areas of natural or disturbed salt marshes (Ferrari et al., 1985), their broad range of salt tolerance enables them to also inhabit intertidal flats (Slim and Oosterveld 1985; Min and Kim, 1999a). As an illustration from research by Slim and Oosterveld (1985), *Salcornia europaea, A. tripolium,* and *S. maritima* were found on a sandy tidal flat. When that land was first reclaimed, *A. tripolium* appeared in two years and *Puccinellia maritima* after three years. *Trifolium repens* arrived four years after reclamation, and had formed large patches by seven years post-reclamation. Intrusions by non-halophytes may be delayed because of high clay-silt content in the sediments (Min and Kim, 1997a).

The schematic diagram found below and in Figure 1 describes the successional sere on reclaimed land, based on our previous work (Min and Kim, 1999a, 1999b) and on life forms of Lee (1981).

- First, the distribution range of each plant species along soil salt contents (Min and Kim, 1999a)
- Second, vegetation profiles and species associations in the six study sites (Min and Kim, 1999b)
- Third, life forms of each plant species, i.e., annuals, biennials, perennials (Lee, 1981)

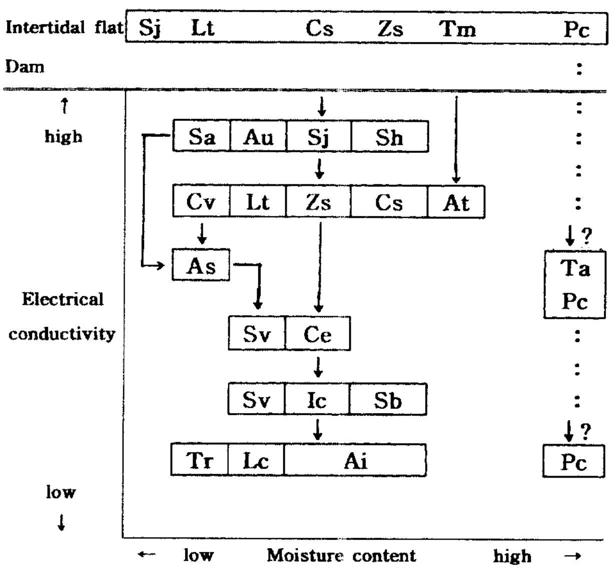

**Figure 1.** Inferential successional sere of plant species through desalination after reclamation. Ai, *A. indica*; As, *A. scoparia*; At, *A. tripolium*; Au, *A. subcordata*; Ce, *C. epigeios*; Cs, *C. scabrifolia*; Ic, *I. cylindrica* var. *koenigii*; Lc, *L. corniculatus* var. *japonicus*; Lt, *L. tetragonum*; Sa, *S. asparagoides*; Sb, *S. brachyotus*; Sh, *S. herbacea*; Sj, *S. japonica*; Sv, *S. viridis*; Ta, *T. angustata*; Tm, *T. maritimum*; Tr, *T. repens*; Zs, *Z. sinica*.

Because the root systems of *P. communis* and *T. angustata* develop 2 m below the sediment surface (Dykyjova and Kvet, 1978), and because no data are available on the water and salt contents at that level, these two species are ambiguous in successional sere. *P. communis, T. maritimum, S. japonica, C. scabrifolia,* and *Z. sinica* commonly grow on intertidal flats along the west coast of Korea. This plant community changes from halophytic to non-halophytic through the desalination of sediments after reclamation.

In this process, two successional seres were classified. One was a hydrosere, appearing on wetlands or tributaries. The successional community was composed of a few, very persistent species-*P. communis, T. maritimum, T. angustata,* and *Typha orientalis*. *P. communis* is especially tolerant of high soil salt contents, and is distributed from seawater to freshwater areas (Kim, 1975; Min and Kim, 1983). Therefore, it was difficult to infer the exact sequence of hydrarch succession caused by desalination of the reclaimed land.

The other successional classification was the xerosere, in which many species of halophytes and non-halophytes were involved. The pioneer species that follow reclamation were grouped as either annuals or perennials. The Annuals group was composed of *S.*

*herbacea* - *S. japonica* - *A. subcordata* - *S. asparagoides*. The dominant species were *S. herbacea* in wet areas, and *A. subcordata* and *S. asparagoides* in xeric areas. Later, *S. herbacea* was replaced by *A. tripolium* - *C. scabrifolia* - *Z. sinica* - *L. tetragonum* in wet areas, *A. scoparia* in xeric areas. The Perennials group comprised *C. scabrifolia and Z. sinica*, both persistent species. Following the lines of desalination and dehydration, the succession sere at almost every site was [*A. tripolium* - *A. scoparia*] → [*C. epigeios* - *S. viridis*] → [*I. cylindrica* var. *koenigii* - *S. brachyotus* - *S. viridis*] → [*A. indica* - *L. corniculatus* var. *japonicus* - *T. repens*] non-halophytes. In xeric areas, however, the successional sere was [*A. tripolium* - *A. scoparia*] → [*I. cylindrica* var. *koenigii* - *S. brachyotus* - *S. viridis*] → [*A. indica* - *L. corniculatus* var. *japonicus* - *T. repens*] → non-halophytes.

## Interactions between Plants and Soil Environments through the Desalination

Correlation coefficients (CC) between individual factors of MC, EC, organic matter (OM), total nitrogen (TN), bulk density (BD), and available phosphorus (AP) in soil are shown in Table 3. CCs between EC and MC had positive values at almost every site. In contrast, those of EC and AP were positive early on, but negative in the late stages of reclamation. We could conclude that those soils were filled with brackish water, with high AP contents in the early stages of

**Table 3.** Correlation coefficients between the soil factors at the six study sites. Numbers in parenthesis are years after reclamation.

| Factor | Namdong<br>$n=17$ | Hyundai A<br>(1 yr)<br>$n=17$ | Hyundai B<br>(2 yr)<br>$n=51$ | Jangdeog<br>(8 yr)<br>$n=60$ | Mado<br>(12 yr)<br>$n=64$ | Baegseog<br>(30 yr)<br>$n=58$ |
|---|---|---|---|---|---|---|
| MC–EC | 0.369 | 0.622** | 0.431** | –0.240 | 0.309* | 0.456** |
| MC–BD | –0.359 | –0.591* | –0.353* | 0.720** | –0.246 | –0.588** |
| MC–OM | 0.279 | 0.698** | 0.617** | 0.208 | 0.468** | 0.819** |
| MC–T-N | 0.262 | 0.665** | 0.515** | 0.070 | 0.285* | 0.616** |
| MC–A-P | –0.069 | 0.535* | –0.151 | –0.389** | –0.306* | –0.401** |
| EC–BD | 0.386 | 0.444 | 0.244 | –0.395 | 0.258* | –0.361** |
| EC–OM | –0.531* | 0.526* | 0.459** | –0.147 | 0.144 | 0.460** |
| EC–T-N | –0.221 | 0.395 | 0.491** | –0.221 | –0.147 | 0.219 |
| EC–A-P | –0.020 | 0.930** | 0.505 | –0.191 | 0.174 | –0.230 |
| BD–OM | –0.386 | –0.509* | –0.218 | –0.283* | –0.502** | –0.478** |
| BD–T-N | –0.287 | –0.766** | –0.149 | –0.025 | –0.359** | –0.343* |
| BD–A-P | 0.194 | –0.427 | 0.252 | 0.261 | 0.408** | 0.378** |
| OM–T-N | 0.791** | 0.785** | 0.662** | 0.589** | 0.634** | 0.757** |
| OM–A-P | –0.463* | 0.524** | 0.124 | –0.270* | –0.652** | –0.309* |
| T-N–A-P | –0.629** | 0.338 | 0.154 | –0.193 | –0.774** | –0.247 |

MC, moisture content; EC, electrical conductivity; BD, bulk density; OM, organic matter; T-N, total nitrogen; A-P, available phosphorus.

*, significant at 5% level; **, significant at 1% level.

**Table 4.** Correlation coefficients between soil factor and biomass at the six study sites. Numbers in parenthesis are years after reclamation.

| Factor | Namdong<br>$n=17$ | Hyundai A<br>(1 yr)<br>$n=17$ | Hyundai B<br>(2 yr)<br>$n=51$ | Jangdeog<br>(8 yr)<br>$n=60$ | Mado<br>(12 yr)<br>$n=64$ | Baegseog<br>(30 yr)<br>$n=58$ |
|---|---|---|---|---|---|---|
| MC | –0.155 | 0.765** | 0.436** | –0.230 | 0.454** | 0.439** |
| EC | –0.495* | –0.226 | 0.157 | –0.081 | –0.215 | –0.413** |
| BD | –0.220 | –0.326 | –0.099 | –0.075 | –0.106 | –0.343* |
| OM | 0.366 | 0.282 | 0.549** | –0.216 | 0.302* | 0.483** |
| T-N | 0.510 | 0.339 | 0.493** | 0.097 | 0.459** | 0.549** |
| A-P | –0.449 | 0.332 | 0.248 | –0.059 | –0.449** | –0.371** |

MC, moisture content; EC, electrical conductivity; BD, bulk density; OM, organic matter; T-N, total nitrogen; A-P, available phosphorus.

*, significant at 5% level; **, significant at 1% level.

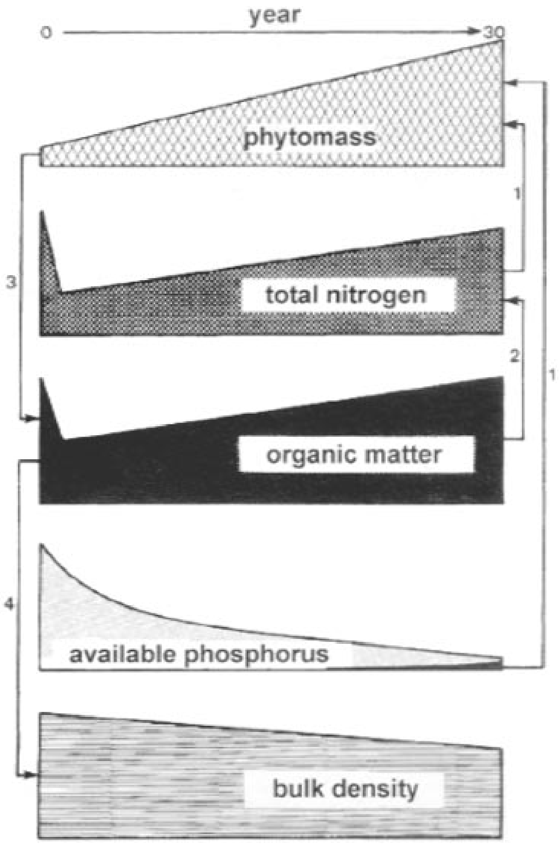

**Figure 2.** Generalized diagram showing the interaction between soil and plants in reclaimed land for 30 years after reclamation. Axis Y and Axis X of polygon mean relative magnitude and elapsed time after reclamation, respectively. 1, uptake by plants; 2, decomposition of organic matter; 3, input of plant body; 4, input of organic matter.

reclamation. The CCs between BD and EC were positive early, but negative in the late stage. In these situations, sediments probably were first hardened by desalination and dehydration, but later were softened by OM input from plants.

BD was negatively correlated with all the other factors. The CCs between BD and either OM or MC were significant at the 5 ~ 1% levels. The main factors affecting BD probably were OM and MC, the former more strongly than the latter. CCs were negative between AP and OM, and between AP and TN. These data clearly demonstrate the relationships between soil factors on reclaimed land.

Soil properties are also influenced by the aboveground biomass (AB) of plants, as shown in Table 4. Positive relationships were found between AB and MC (or TN), but AB and BD (or AP) were negatively related. The positive relationship between AB and MC may be explained because *P. communis* and *T. angustata* grew in wet areas. Their productivity was higher than for any other species, much organic matter was introduced to the soil, and decay rates were slowed by inundation (Kim, 1975; Min and Kim, 1983). In contrast, AB was negatively correlated with AP probably because the AP contents were decreased not only by natural leaching but also by plant absorption.

The interaction between plants and soil is diagrammed in Figure 2. Desalination gave rise to an increase in species number and plant biomass. The increasing biomass decreased soil AP content but increased soil OM and TN contents. Soil OM also induced BD to increase. The plants surveyed in our study interacted with their soil environments for up to 30 years after reclamation.

Received November 17, 1999; accepted March 13, 2000.

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