Slits in Container Wall Improve Root Structure and Stem Straightness of Outplanted Scots Pine Seedlings

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Rune, G. 2003. Slits in container wall improve root structure and stem straightness of outplanted Scots pine seedlings. Silva Fennica 37(3): 333–342.

Root structure and basal sweep were measured on 6-year-old Scots pine (*Pinus sylvestris* L.) trees at two sites with different soil fertility. Each site was planted with seedlings of identical origin after nursery cultivation in either solidwall container types with vertical ribs or in slitwall container types. Neither container design nor container volume affected tree height or stem diameter on the two sites. The transversal area of lateral roots was larger than the transversal area of bottom roots for the two container types at both sites. The proportion of bottom root transversal area to the total root transversal area was larger in the seedlings growing on the low fertility site than in those growing in the high fertility site for both container types. Seedlings cultivated in slitwall containers had a larger root area in proportion to stem diameter and had less root spiralling compared to the trees cultivated in solidwall containers. At the high fertility site, trees from the slitwall container type had straighter stem bases than seedlings grown in solidwall containers. At the low fertility site, differences in basal sweep formation were small between the container types. Reasons for this are discussed.

Keywords *Pinus sylvestris*, solidwall container, slitwall container, root morphology, mechanical instability, stem straightness
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Received 21 January 2003 **Accepted** 1 April 2003

1 Introduction

It is difficult to produce containerised seedlings without root deformation. Deformed roots are more common for container grown pine seedlings compared to seedlings derived from either seed (Rune and Mattsson 1998) or naturally regenerated (Nichols and Alm 1983). It is well known that deformations such as roots spiralling of pines can cause poor stability in the field (Balisky et al. 1995, Lindström 1998). A common consequence of poor juvenile stability is the formation of basal sweep (Rune and Warensjö 2002), which leads to a reduction in wood quality due to compression wood formation (Timell 1986).

The first generation of containers for tree seedling production was introduced in the early 1970's. Most common were solidwall containers made of hardplastic with smooth walls and small bottom drainage holes, and softwall containers (e.g. Paperpot). These designs resulted in spiralling roots (Hultén and Jansson 1978, Lindström and Rune 1999). At the end of the 1970's these containers were replaced by a second generation with vertical ribs on the inside walls to attempt to prevent root spiralling. Subsequent studies have indicated that the ribs reduce spiralling and hence improve tree stability (e.g. Lindström and Håkansson 1995). However, studies have also shown that this container type only confers a limited improvement in root structure in the field (e.g. Lindström 1994).

Development of a third generation of containers started in the early 1980's with different solutions of pruning lateral roots. Examples are box-pruning and pruning by chemicals or slitwall systems where vertical slits allowed improved lateral root growth after planting (henceforth termed slitwalled). Root growth in slitwall containers is controlled either mechanically or by air pruning. Unlike solidwall containers, where roots are directed downwards, slitwall containers allow lateral growth of roots through slits and therefore allow a more 'natural' root system to result. This has been shown to improve juvenile tree stability (Lindström 1998). To date, however, scant attention has been paid to the effect of different rooting patterns on the occurrence of basal sweep in the field.

Species such as spruce form adventitious roots after planting and these can increase stability in the presence of root deformity (Carlson et al. 1980). Pines do not form adventitious roots (Selby and Seaby 1982). Therefore pine may suffer more than spruce from growth in containers of poor design and be more sensitive to forces such as wind, snow and frost heaving after outplanting. The purpose of this study was to examine the structure of root systems derived from two different container types, solidwall containers and slitwall containers and their relations with the formation of basal sweep in young Scots pine (*Pinus sylvestris* L.) trees. As soil fertility can affect juvenile pine stability (Lines 1980, Auburlinder 1982) the root structure and basal sweep formation was studied in two sites with different soil fertility.

2 Material and Methods

Two sites in central Sweden (lat. 60°15´N, long. 16°15´E, alt. 160 m, and lat. 60°17´N, long. 16°14´E, alt. 160 m, respectively) were planted with Scots pine seedlings of the same origin (Hedesunda, lat. 56°32´N, long. 03°32´E, elevation 160 m). In mid-May 1991, seeds were sown in four types of containers representing two different root guidance approaches. The two solidwall container types, Hiko V50™ and Hiko V93™, are conical with vertical ribs on the inside wall and a container height of 85 mm. The container volumes are 50 ml (767 seedlings/m^2) and 90 ml (458 seedlings/m^2). The two slitwall container types, Planta 80™ and Planta 90™, are octagonal in cross-section with vertical slits in the sidewalls and a container height of 70 mm. The container volumes are 45 ml (875 seedlings/m^2) and 80 ml (505 seedlings/ m^2). All containers were filled with peat substrate (Hasselfors K11, Sweden, pH 5.0) mixed with 2 kg/m^3 of dolomite lime. Initially the seedlings were grown in a greenhouse in Garpenberg (lat. 60°15´N, long. 16°15´E) and six weeks after sowing, the seedlings were moved outdoors on pallets elevated 15 cm above the ground.

During nursery growth a complete mineral solution (Ingestad 1979) was added twice a week in the irrigation water according to standard routines (Lindström and Stattin 1994). During the season a total of 40 g · m^{-2} of nitrogen supply was given. Due to the differences in container structure, sup-

Table 1. Average height, diameter and dry weight of roots and shoots (± standard error of the mean) at lifting for one-year-old Scots pine seedlings cultivated in solidwall and slitwall containers of two different volumes. Means followed by the same letter are not significantly different ($P<0.05$) according to Tukey's test. Analyses are based on means of 6 replications with 5 seedlings in each replication.

Container type	Height, mm	Diameter, mm	Root weight, mg	Shoot weight, mg
Hiko V50 (solidwall)	129.5 (2.9) a	2.0 (0.4) b	1223.0 (53.9) b	3451.0 (130.3) b
Hiko V93 (solidwall)	136.5 (4.1) a	2.3 (0.5) a	1809.17 (55.6) a	5199.5 (146.4) a
Planta 80 [a)] (slitwall)	126.0 (3.4) ab	2.1 (0.4) ab	750.2 (26.4) c	3767.0 (145.1) ba
Planta 90 [a)] (slitwall)	115.3 (3.0) b	2.0 (0.5) b	643.2 (30.4) c	4030.3 (180.4) b

[a)] Roots that had penetrated the slits in the container wall were mechanically pruned.

Table 2. Average diameter (20 cm above ground surface), height (± standard error of the mean) and number of tested seedlings and root systems 6 years after planting. Scots pine seedlings nursery cultivated in containers with two principles of root guidance. Data were pooled for volumes in respective container system and site.

Soil fertility	Type of container	Height, cm	Diameter, mm	Number of seedlings	Number of root systems
High	Solidwall	135.3 (9.8)	36.8 (2.7)	192	30
	Slitwall	132.8 (9.9)	35.4 (2.6)	181	25
Low	Solidwall	109.8 (7.4)	22.9 (1.6)	218	23
	Slitwall	104.8 (6.8)	21.2 (1.4)	235	21

plementary irrigation was needed to avoid water stress during cultivation for seedlings grown in slitwall containers. In early November seedlings were put in frozen storage.

Both experimental sites had similar topographic characteristics but at one site, the stand prior to the experiment comprised mainly of old Norway spruce (*Picea abies* (L.) Karst.). According to a site description system developed by Hägglund and Lundmark (1982) the site index, assessed by means of the site properties, is G 28 (dominant height of Norway spruce at a total age of 100 years). The soil type is a silt-rich sandy soil and the site was in this study termed 'high-fertility'. At the other experimental site, the stand prior to the experiment comprised of old Scots pine and the site index is T 22 (dominant height of Scots pine at a total age of 100 years) according to Hägglund and Lundmark (1982). The soil type is a sandy-loam till and the site was in this study termed 'low-fertility'.

Both experimental sites were clear felled in 1990 and soil preparation was carried out in autumn 1991. At the high fertility site soil preparation was carried out by creation of mounds at 2.5 × 2.5 m spacing. The mounds, 10–15 cm high, consisted of mineral soil placed on the humus layer, turned upside down beside the scarified patch. Soil preparation at the low fertility site was carried out by a disc trencher that creates a mound on the inverted humus layer. At the time of outplanting, seedlings cultivated in slitwall containers were pruned mechanically and thereafter, 30 seedlings from respective container system were randomly selected for registration of height, diameter and dry weight of roots and shoots (Table 1).

At the end of May 1992, the high and low fertility sites were planted with seedlings reared in the 4 container types in a completely randomised design. The high fertility site consisted of 18 replications/container type with 12 seedlings/replication totalling 864 seedlings. The low fertility site consisted of 12 replications/container type with 12 seedlings/replication totalling 576 seedlings. Mortality at the high fertility site was high, mainly due to pine weevil (*Hylobius abietis* L.) attacks and after six growing seasons 373 trees remained compared to 453 trees at the low fertility site. Diameter and height of these trees was measured in August 1997 (Table 2), together with the angle of basal sweep (≥5° within 30 cm from the ground) using a digital protractor (Lucas Anglestar, model DP 45, USA).

At the high and low fertility site, 55 and 44 trees respectively were randomly selected and the root systems were manually excavated in order to study the root development (Table 2). Measurements on the root systems followed Lindström and Rune (1999). Root ends were cut to fit in a 10-cm-radius cylinder with a hemispherical base. Measurements of root diameter were made in four quadrants at the point of intersection of roots with the plane of measuring frame. Roots intersecting the cylindrical portion of the frame that correspond to the height of the container were termed 'lateral' roots whereas those intersecting the hemispherical portion were termed 'bottom' roots.

The number of all primary and secondary roots exceeding 1 mm diameter at a distance of 10 cm from the central root axis was determined. A root area index (RAI) describing the symmetry of root distribution in the four defined quadrants, was calculated as the ratio between the quadrant with the largest root transversal area and the total root transversal area. For a symmetric root system the RAI is 0.25, and higher RAI indices indicate a more asymmetrical root system. The number of spiralled roots with a diameter ≥1 mm was counted for each root system. Spiralling was classified as negligible if the number of added turns for spiralling roots was ≤1 turn, as moderate if spiralling was >1 but ≤3 turns and as severe if spiralling was >3 turns or if a single lateral or bottom root had spiralled >1 turn.

The experimental sites reported in the present study vary in site index and method of soil scarification. Each site can be interpreted as a case study and results are therefore presented separately for each site.

Anova was used for analyses of seedling variables prior to outplanting. Data are based on means of 6 replications with 5 seedlings in each replication. Differences were considered significant if $p<0.05$. Tukey's test was used for making multiple comparisons.

For the field trial, analyses of variance (one-way) was used for testing the equality of population means between tree height, diameter, and root area. Student's *t*-test was used to reveal differences in root distribution in four quadrants (RAI). The relationship between stem diameter and root area for excavated root systems was described with the function: $R=e^a \times D_{0.20}{}^b$ where R = root transversal area (mm^2), D = stem diameter at 20 cm height (mm) and a and b = constants. The ratio calculated between root transversal area (mm^2) and stump diameter (mm) for trees cultivated in the four container types at each site was tested using Student's *t*-test. Differences in the proportions of root spiralling and basal sweep measurements between solidwall and slitwall containers were analysed using χ^2 test (Zar 1974).

3 Results

During nursery growth the largest seedlings were obtained in the large solidwall container. Root weight of seedlings reared in slitwall containers were considerable lower than for seedlings reared in solidwall containers (Table 1).

After six growing seasons at respective sites, no significant differences ($P=0.0896$–0.950) were found for diameter, root area, RAI, root spiralling and stem straightness between the two container volumes assessed for each type. Therefore, container volume data was pooled for site results.

No significant differences were found 6 years after planting at the high and low fertility site for height ($P=0.556$ and $P=0.254$), diameter ($P=0.435$ and $P=0.226$) (Table 2) or total root area ($P=0.334$ and $P=0.303$) (Table 3) between Scots pine trees cultivated in solidwall and slitwall containers, respectively. The transversal area of lateral roots was larger than the area of bottom roots for both solidwall and slitwall container grown plants ($P<0.001$) at both sites (Table 3). In addition, the proportion of bottom root area to the total area was larger for seedlings grown at the low fertility site compared to those growing at the high fertility site for both container types. No differences in root symmetry (RAI) were found between container types at either of the sites (Table 4). At the high fertility site, seedlings grown in slitwalled container types showed a more rapid increase in root area with increasing stem diameter than seedlings grown in solidwall containers (Fig. 1) ($P=0.003$). This was not evident at the low fertility site ($P=0.638$).

Table 3. Number of primary and secondary roots and distribution of lateral and bottom roots and root transversal area expressed in total and for lateral and bottom roots (± standard error of the mean) of tested seedlings 6 years after planting. Scots pine seedlings nursery cultivated in containers with two principles of root guidance. Data were pooled for volumes in respective container system and site.

Soil fertility	Type of container	No. of primary and secondary roots			Root transversal area (mm^2)		
		Lateral	Bottom	Total	Lateral	Bottom	Total
High	Solidwall	20.4	1.2	21.7	494.6	23.2	517.8
		(2.3)	(0.5)	(2.4)	(88.3)	(7.0)	(90.8)
	Slitwall	18.8	1.0	19.8	693.3	18.6	711.9
		(1.8)	(0.3)	(1.8)	(137.3)	(10.4)	(142.6)
Low	Solidwall	9.2	2.1	11.3	202.0	38.3	240.3
		(1.2)	(0.5)	(1.1)	(63.2)	(15.3)	(73.0)
	Slitwall	10.5	1.0	11.5	168.9	20.8	189.7
		(1.3)	(0.2)	(1.4)	(41.3)	(10.1)	(44.5)

Table 4. Root area index (RAI)[a] for tested seedlings 6 years after planting. Scots pine seedlings nursery cultivated in containers with two principles of root guidance, and P (*t*)-values. Data were pooled for volumes in respective container system and site.

Soil fertility	Solidwall	Slitwall	P(*t*)
High	0.52 ($n=192$)	0.55 ($n=181$)	0.42
Low	0.57 ($n=218$)	0.58 ($n=235$)	0.80

[a] The ratio between the quadrant with the largest root transversal area and the total root area. For symmetric root system the RAI is 0.25, and higher RAI indices indicate a more asymmetrical root system.

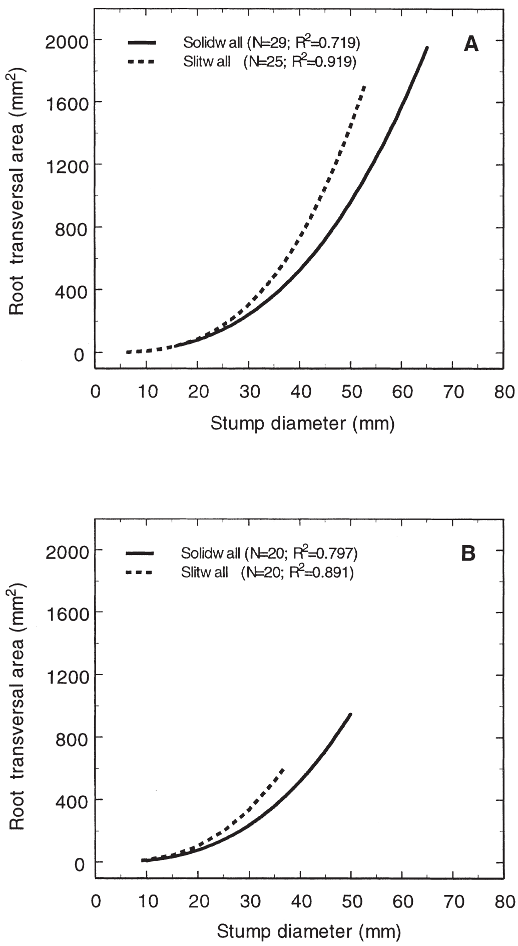

Fig. 1. Relationship between stump diameter 20 cm above ground surface and root transversal area according to the function $R=e^a \times D_{0.20}{}^b$ (R = root transversal area in mm^2, D = stem diameter in mm at 20 cm height, a and b = constants) for 6-year-old Scots pine seedlings nursery cultivated in containers with different principles of root guidance in a high fertility site (A) and in a low fertility site (B). Data were pooled for volumes in respective container system and site.

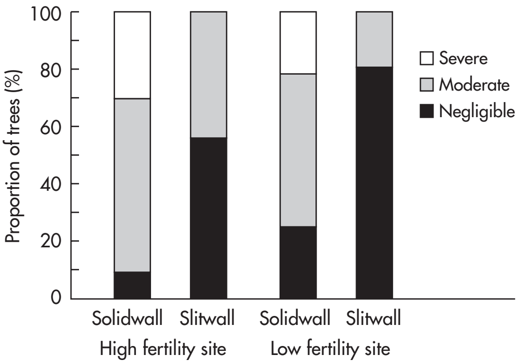

Fig. 2. Proportion (%) of 6-year-old Scots pine trees with different degrees of spiralled roots. The seedlings were grown in containers with two principles of root guidance. The spiralling was classified as negligible if the number of added turns for spiralling roots was ≤1 turn, as moderate if spiralling was >1 but ≤3 turns and as severe if spiralling was >3 turns or if a single root or more had spiralled >1 turn. Data were pooled for volumes in respective container system and site.

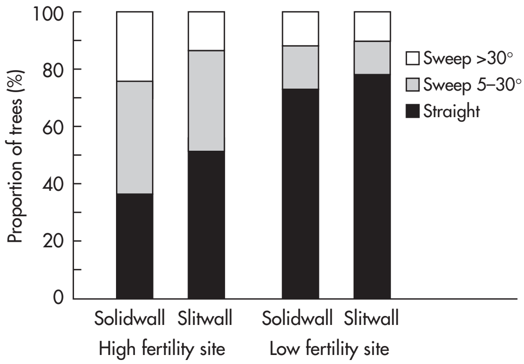

Fig. 3. Proportion (%) of 6-year-old Scots pine trees with straight (<5°) stem base and basal sweep (5–30° respective >30°) within 30 cm from the ground. The seedlings were nursery cultivated in containers with two principles of root guidance. Data were pooled for volumes in respective container system and site.

The frequencies of trees with severe and moderate root spiralling were lower in the seedlings cultivated in slitwall container types than in those cultivated in solidwall container types ($P \leq 0.001$) at both sites (Fig. 2). At the high fertility site, slitwall container type resulted in trees with straighter stem bases ($P = 0.005$) and a lower proportion of basal sweep >30° ($P = 0.008$) than the trees cultivated in solidwall container type. No significant difference concerning these variables where found at the low fertility site ($P = 0.256$ and $P = 0.55$, respectively) (Fig. 3).

4 Discussion

Seedling density and container volume are known to affect growth of seedlings in nursery (Hultén 1980, 1983, Simpson 1994). As expected, the larger solid wall container resulted in larger seedlings in this study whereas the container size effect not was as clear for slitwall containers.

The substrate in a slitwall container runs a higher risk of drying out due to the slits in the container wall. Although precautions were taken to avoid water stress by extra supply of water during nursery growth, we cannot eliminate the possibility that water stress has been committed. This could be a reason for the partly unexpected relations in seedling growth between small and large slitwall containers. The smaller root system in slitwall containers compared to solid wall containers at the time of outplanting is probably mainly due to the mechanical pruning of roots made just before outplanting.

The field results showed that the use of solidwall or slitwall container made no difference to the above ground size of trees at either of the two sites 6 years after planting. This result is supported by Lindström and Persson (1996) who also found no significant differences in growth between trees reared in solidwall and slitwall containers. However, they showed that severe root deformation, which was obtained in softwall containers, could reduce above ground growth.

Different container volumes and concomitant growing densities in the nursery resulted in similar root development 6 years after planting for Scots pine seedlings. This contrasts with the findings of e.g. Girouard (1995) who found increased root deformity in 3–9-year-old Black spruce (*Picea mariana* [Mill.] B.S.P.) seedlings grown in 50 cm^3 containers compared with seedlings grown in 110 cm^3 containers. The seedlings in Girouard's study were grown for two years in the container before outplanting compared to one year in this study. It is known that root deformation increase with increasing time of growth in the container (Grene 1978). Therefore the shorter length of growth in this study may explain why container volume and growing density were of minor importance for root architecture in the field compared to Girouard's study.

Factors known to be of importance for the capacity of a root system to anchor the tree in the soil are total root area (Lindgren and Örlander 1978), the distribution of lateral and bottom roots (Coutts et al. 1990) and root spiralling frequency (Lindström 1998). In this study, the frequency of spiralling roots was found to be more common for seedlings cultivated in containers with solidwalls at both sites. For containerised seedlings it is well known that root spiralling is an effect of a poor container design (Hultén and Jansson 1978) and it is evident from this study that the use of slitwall containers results in improved root morphology.

The bottom root area was proportionally larger for both container types in the low fertility site compared to the high fertility site. This may be due to the differences in soil type. At the high fertility site, the soil density was higher, rendering the substrate less permeable to air and water, which could lead to a more shallowly rooted tree (Köstler et al. 1968, Lähde and Mutka 1974, Nordwall 1994). According to Coutts et al. (1990), a large bottom root area favours tree stability. Studies concerning container grown pine seedlings (Lindström 1990, Halter et al. 1993) have indicated that root deformations may cause mechanical instability. A serious effect of juvenile tree instability is the formation of basal sweep (Rune and Warensjö 2002). In the present study, trees with basal sweep formations were found to be more common at the rich site. One potential site effect may be that trees grown at the high fertility site had a lower proportion of bottom roots and a higher frequency of roots with root spiralling than trees at the low fertility site leading to a reduction in stability. In general, root growth is favoured by soil scarification. Lower soil density, higher soil temperature and improved soil moisture conditions are reported as a result of soil scarification (Örlander et al. 1990, Örlander et al. 1998). High root growth has been found after soil scarification where the humus layer is mixed or buried compared to pure mineral soil (Hallsby 1994). If the humus layer is removed by soil scarification and the seedlings are planted in mineral soil, the nitrogen available to the seedlings may be reduced which may restrain the growth (Nohrstedt 2000). Obviously, soil scarification is important for tree establishment and we cannot rule out the influence of the different site preparation techniques on the occurrence of basal sweep in this study. Basal sweeps has an adverse effect on timber quality (Burdett 1979, Pfeifer 1982) even though basal sweep occurring early during establishment may be compensated with differential growth over time (Lindström and Rune 1999). In spite of the resulting straighter appearance, timber quality may still be compromised e.g. compression wood and eccentric pith.

Trees grown at the high fertility site were on average 20% taller compared with trees grown at the low fertility site. Trees grown in solidwall containers had a small root area in relation to stem diameter, especially at the high fertility site. Martinsson (1986) concluded that a large root area in relation to the aboveground part is usually associated with good stability. Also Sundström and Kaene (1999) concluded that a balanced shoot:root ratio is the most important factor for improved stem form and stability in planted Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco). Auburlinder (1982) concluded that both shoot:root ratio and incidence of basal sweep were positively related to site fertility in stands of maritime pines (*Pinus pinaster* Ait.). For lodgepole pine (*Pinus contorta* Dougl.) Lines (1980) found that fertilization increased shoot: root ratio and decreased stability. Basal sweep formation is not necessary solely linked to the stabilising function of the root system. It may also depend on soil density, frost heaving, method of planting, plant size and snow and wind exposure (Low 1964, Moss 1971, Girouard 1995, Goulet 1995, Cameron and Dunham 1999).

Basal sweep formation seems to be rare for seeded and naturally regenerated pines (Rosvall

1994, Rune and Mattsson 1998). This study indicated that trees with deformed root systems have the highest frequency of stems with basal sweeps. It therefore appears that basal sweep formation may, in part, be determined by the ability of the root to provide adequate anchorage in the soil to offset wind or snow loading. Therefore, root systems of container grown trees should have as few deforming constraints as possible to prevent instability and subsequent basal sweep formation and to this end the slitwall type appears the most favourable between the two containers compared in this study.

4.1 Conclusions

Container design affects root development after planting which can influence the formation of basal sweep. The effect of the container design on subsequent field establishment depends to a large extent on soil type. In this study, basal sweep formations were more common for trees grown at the high fertility site representing a dense soil type. Under these conditions, trees grown in solidwall containers seem to have an increased incidence of basal sweep than trees grown in containers with slitwalls. This study indicates that stem form of Scots pine can be improved by the use of a container type that promotes a more natural root morphology.

Acknowledgements

This study was financed by the Swedish National Board of Forestry and Jacob Wallenberg Foundation. I thank Dr A Lindström, Dr A Mattsson and Dr E Stattin (Dalarna University) for valuable comments on the manuscript. A special thank to Lars Håkansson and Claes Hellqvist (Dalarna University) for help with fieldwork and data processing.

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