Response of Woodland-planted Ramps to Surface-applied Calcium, Planting Density, and Bulb Preparation

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Abstract. Concern about over-harvesting wild populations of ramps (*Allium tricoccum* Ait.) has led to interest in planting ramps as an under-story agroforestry crop. To see if ramps would respond to Ca amendments in an acidic site, we planted three types of ramps bulbs and broadcast slaked lime (3316 kg·ha⁻¹) or gypsum (7704 kg·ha⁻¹) on a Rayne silt loam (fine-loamy, mixed, mesic Typic Hapludults). After 3 years, surface-applied slaked lime raised Ca levels as deep as the 22.5 to 30 cm layer, which showed an increase of 0.34 cmol_c·kg⁻¹, and increased pH in the 2.5 to 5.0 cm layer from 3.96 to 4.67. Gypsum application raised Ca concentration in the 22.5 to 30 cm layer from 0.2 in the control to 0.7 cmol_c·kg⁻¹, but had little effect on pH anywhere in the profile. In plots harvested after 2 years, both amendments increased plant survival and per-plant weight, compared to controls. In plots harvested after 3 years, ramps grown in the slaked lime treatment were heavier than in the gypsum treatment indicating that slaked lime, which raised pH as well as supplied Ca, was probably the better amendment. Single or joined bulbs survived better than bulbs obtained by breaking joined bulbs in two. While more research is needed to overcome limitations to commercial planting of ramps in acidic sites, our data show that Ca application is beneficial to growth and survival of ramps.

Wild leeks (*Allium tricoccum* Ait.), commonly known as ramps, are a traditional food widely appreciated in rural areas of the eastern U.S. Ramps grow in moist, nutrient-rich wooded areas from Minnesota and Quebec to Missouri, Tennessee, and North Carolina (Greenfield and Davis, 2001; Vasseur and Gagnon, 1994). Increased popularity as a gourmet item has resulted in over-harvesting, and with the reduction of natural habitat there has been a decline in wild ramp populations. As a consequence, the Smoky Mountain National Park in North Carolina and Tennessee was closed to ramp harvesting in 2002 (Davis and Greenfield, 2002). Establishment of ramp beds in wooded areas could be an effective way to maintain adequate supplies of ramps (Facemire, 1996). From seed to harvestable plant requires about 5 years of growth (Facemire, 1991). One way to speed up this process is to plant ramp bulbs already 2 or more years old, but little published data are available on bulb management protocols and soil nutrient requirements.

Natural ramp patches are usually found on north or east-facing slopes, which are generally cooler and more moist than west- or south-facing slopes (G. Facemire, personal communication, 2004). Vasseur and Gagnon (1994) reported that ramps in Quebec were

growing well in a soil with 6.45 cmol_c·kg⁻¹ Ca and 0.7 cmol_c·kg⁻¹ Mg. Planting bulbs taken from this area to another area with moist, rich soil resulted in good survival, but planting in nutrient-poor soil with unfavorable moisture regimes generally resulted in high mortality. Nutrient availability was especially important for survival of small, young bulbs.

Low soil pH, often accompanied by Al and Mn toxicity and nutrient deficiency, may also be an important factor affecting ramp growth. Andersson (1993) reported that growth of ramson (*Allium ursinum* L.), considered the European counterpart of North American ramps, was very sensitive to Al. Soil solutions from sites where ramson plants were growing in the wild had a minimum Ca/Al molar ratio of 39 and pH of 4.5 or higher. When plants were grown in acidic flowing nutrient solution with 20 mM Al and a Ca/Al molar ratio of 12.5, Al toxicity symptoms appeared. Onions (*Allium cepa* L.), another member of the same genus, are sensitive to low pH conditions and produced maximum yields at pH 5.8 to 6.5 (Thompson and Kelly, 1957). Davis and Greenfield (2002) noted that ramps are often found in soils with pH of 5.5, and prefer soils with 1760 to 4515 kg·ha⁻¹ Ca. They conducted a study using CaSO₄, limestone, and/or MgO to amend a pH 4.9 soil containing 370 kg·ha⁻¹ Ca (J. Greenfield, personal communication, 2003). Addition of 3363 or 5605 kg·ha⁻¹ Ca raised plant survival from 23% in the treatment without amendment to 35% at the highest Ca level studied. Apparently, at least part of the improvement was not related to soil pH effects because increasing pH from 4.9 to 6.0 using MgO as a liming agent resulted in lower sur-

vival, which would imply that supplying Ca is also important.

Moist sites with an eastern exposure, relatively high pH, and good nutrient availability are relatively uncommon. The problem may have been made worse by removal of Ca from the forest due to repeated timbering in those parts of the Appalachian highlands developed on low-base-status parent material (Jenkins, 2002), and on base-poor igneous and metamorphic rock in Piedmont forests of the southeast U.S. (Huntington et al., 2000).

We decided to determine if addition of Ca-rich amendments would improve establishment of ramps grown in an acidic site. The three most available amendments are limestone (CaCO₃ or CaMg(CO₃)₂), agricultural slaked lime (mostly Ca(OH)₂), and agricultural gypsum (mostly CaSO₄·2H₂O). The most reasonable choices for surface application to rapidly increase Ca concentrations in dystrophic soil profiles are slaked lime and gypsum, because both of these sources of Ca are considerably more soluble than calcitic or dolomitic limestone.

Slaked lime should begin to increase soil pH and precipitate Al in surface soil layers as soon as the applied material dissolves and moves through overlying fresh leaves (L) and partly decayed leaf horizons (Oi and Oe). We do not expect very deep or rapid penetration of Ca into the mineral horizon because hydroxyl anions are consumed as they neutralize Al and H cations associated with soil acidity, and the Ca cations occupy exchange sites previously occupied by the Al and H cations (Shamshuddin and Ismail, 1995).

Gypsum supplies Ca and S, but has little effect on soil pH (Ritchey and Snuffer, 2002) because the sulfate ion is not able to neutralize acidity. Because the sulfate anion does not react strongly with minerals in Appalachian soils (He et al., 1996), there is little retention of sulfate in exchangeable form (Shamshuddin and Ismail, 1995), although at pH levels below 4.5, some sulfate may precipitate with Al as basaluminite (Sposito, 1989). In addition, not much Ca will be sorbed because there is little competitive exchange of Ca with Al and H on the exchange complex. Thus, most Ca in acidic soil treated with gypsum will either be in an undissolved form or in soil solution. Due to the relatively low retention and relatively high levels of Ca and sulfate in solution, leaching is rapid, and soil solution levels of Ca throughout the profile should increase relatively quickly.

Although gypsum does not raise pH, it can still help plant growth to a limited extent. Increasing soil solution concentrations of Ca and S by gypsum addition can 1) increase supply of Ca and S, both of which are needed by ramps as nutrients, 2) increase soil solution Ca/Al ratio, which would slightly reduce toxicity of soluble Al³⁺ through its effect on lowering concentrations of Al³⁺ at root surfaces (Kinraide et al., 1994), 3) decrease the proportion of Al present as Al³⁺ by forming nontoxic AlSO₄⁺, 4) possibly precipitate some Al as basaluminite (Sposito, 1989), and 5) slightly reduce soluble Al levels by leaching AlSO₄⁺ out of the profile (Shamshuddin and Ismail, 1995). One possible disadvantage of gypsum use on nutrient-poor

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forest sites is that it has been shown to promote leaching of Mg from acidic Appalachian soils (Ritchey and Snuffer, 2002), and removal of Mg where levels are already low could cause deficiencies.

We hypothesize that even though gypsum does not raise soil pH, the speed with which it can move into the soil profile would probably provide some benefits to ramps during the first year of growth, given that ramps are planted with the base of the bulb 2.5 to 5 cm below the surface of the soil mineral layer.

Our objectives were to 1) characterize the distribution of Ca, Mg, S, Al, and pH with soil depth 3 years after surface application of gypsum and slaked lime, 2) measure the effect of these amendments on establishment and growth of ramps in an acidic partially cleared forest site in southern WV, and 3) evaluate bulb management and plant spacing effects since little is known about bulb management protocols for initial establishment of ramps in natural wooded areas.

Materials and Methods

To evaluate the effects of Ca amendments and cultural practices on establishment of ramps under less than optimum soil conditions, a partially cleared forest site located on an acidic soil mapped as Rayne silt loam (fine-loamy, mixed, mesic Typic Hapludults) was selected. Vegetation consisted mostly of white oak (*Quercus alba* L.) and scarlet oak (*Quercus coccinea* Muenchh.) with a few red maple (*Acer rubrum* L.). The white pine (*Pinus strobus* L.) under-story previously present was removed during partial clearing. The experiment was located near Beaver, WV at about 37° 46' 30" N and 81° 7' 00" W on a westward-facing site with a slope of 5%.

The experimental area measured 58 × 27 m and contained 12 plots separated by an average distance of 5.5 m. Ramp bulbs were planted 2 and 3 Mar. 1999 in 1.83 × 3.05 m plots distributed in a randomized complete block arrangement with three amendment treatments in four blocks. The ramps were planted so that the base of the bulb (where roots emerge) was about 5 cm below the surface of the mineral soil layer. Within each plot, two spacing-density sub-treatments were established (30.5 × 30.5 cm or 0.093 m² per plant, and 15.25 × 15.25 cm or 0.023 m² per plant). Each density subplot was divided into three sub-subplots with 15 bulbs each. Three plant material bulb type sub-subtreatments were tested: 1) one single

bulb (single), 2) two joined bulbs (joined), and 3) one bulb obtained by breaking joined bulbs apart (split). Mean fresh weights were 1.8 g for single bulbs, 3.1 g for joined bulb pairs, and 1.7 g for split bulbs.

Amendments were applied 5 Mar. 1999 to a 3.05 m by 4.57 m area to include the plot area planted to ramps as well as a buffer zone around the plot. Amendments were applied after planting to avoid inadvertent placement of Ca within the soil profile during the planting operation. We estimated that the amount of extractable Al in the surface 15 cm of mineral soil was equivalent to about 4240 kg·ha⁻¹ limestone. The agricultural grade slaked lime we applied had a calcium carbonate equivalent of 1.28, so we surface-applied 3316 kg slaked lime. We applied 7704 kg·ha⁻¹ gypsum in an attempt to supply the same amount of Ca as was contained in the lime. Control plots received no amendments.

On 1 May 2001, about 2 years after planting, seven ramps in each sub-subplot were harvested. After fresh weights were measured, roots were separated from leaves plus bulbs and both plant portions were oven-dried. On 22 Apr. 2002 (about 3 years after planting), leaves and bulbs (without roots) of remaining plants were harvested, weighed, and oven-dried. Survival rate was calculated as the number of live bulbs encountered in the locations that were harvested divided by the number of bulbs originally planted in those locations. Joined bulbs were evaluated as two bulbs.

Composite soil profile samples were collected 22 to 25 May 2002 from four positions inside the plots where there was minimal soil disturbance from harvests. The profiles were divided into eight layers: the L layer of fresh leaves, the Oi–Oe layer of partially decomposed litter, and mineral soil layers (in cm): 0 to 2.5, 2.5 to 5.0, 5 to 10, 10 to 15, 15 to 22.5, and 22.5 to 30. To minimize possibilities of contamination of samples lower in the profile, we removed the leaf and Oi–Oe samples from a 150-cm² surface area by hand, then used a 7.6-cm-diameter sharpened PVC tube, which we could split open after collection, to extract the 0 to 15 cm samples. After cleaning the sampling hole, we collected the deeper samples with a push tube sampler of 1.9 cm in diameter. Samples from one replication of the gypsum treatment were lost. Soil samples were dried, ground, and analyzed by ICP for neutral 1 M NH₄OAc-extractable Ca, Mg, K, S, and Mn (Thomas, 1982), and for 1 M KCl-extractable Al (Barnhisel and Bertsch, 1982). In addition to measuring cations on the exchange complex,

these extractants also measure soluble cations present in the soil solution at collection. Soil pH was measured in a 1 soil : 1 water (by weight) suspension. Electrical conductivity (EC), a measure of solution cation and anion concentration, was determined in the same suspension as pH.

Analysis of variance and regression evaluations were conducted using General Linear Model statistical procedures (SAS Institute, 1990). Statistical analyses for ramps survival and per-plant dry weight were conducted using a mixed model, with block effects considered as random (Littell et al., 1966). Effects of planting density were evaluated using means over all soil amendment levels and effects of bulb management using means over all soil amendments and plant densities. Differences were considered significant if $P < 0.05$, unless otherwise stated.

Results and Discussion

Soil conditions in control plots

Levels of nutrients measured in May 2002 in control plots, which received no amendment, were similar to those measured in February 1999, just before planting (data not shown).

The soil was strongly acidic (Table 1), and similar to Appalachian highland forest soils analyzed by Jenkins (2002) in that most nutrient cations were located in the organic and 0 to 2.5 cm mineral soil layers. The Ca concentration at the 2.5 to 5.0 cm depth was 0.35 cmol_c·kg⁻¹, which is much lower than the level of 6.5 cmol_c·kg⁻¹ in sites in Quebec, which supported good growth of ramps and is also lower than the level in Quebec where poor ramp growth was attributed to low Ca (2.2 cmol_c·kg⁻¹), P, and N levels (Vasseur and Gagnon, 1994). The Mg concentration at the 2.5 to 5.0 cm depth was 0.18 cmol_c·kg⁻¹. This contrasts to 0.70 cmol_c·kg⁻¹ in sites in Quebec associated with good growth of ramps and 0.20 cmol_c·kg⁻¹ in sites with poor growth. (Vasseur and Gagnon, 1994). Levels of Bray-extractable P evaluated in the 1999 sampling at our site were also low (1.2 mg·kg⁻¹ in the 0 to 15 cm and 15 to 30 cm depths).

The 2.5 to 5 cm layer of our control plots had a pH of 3.96, and contained 5.3 cmol_c·kg⁻¹ KCl-extractable Al. The Al saturation of the effective cation exchange capacity was 87%, and the molar Ca/Al ratio of extractable cations was very low at 0.1. The high Al and low Ca and Mg levels indicate that this site is considerably less fertile than areas where ramps are found growing spontaneously.

Table 1. Mean soil characteristics of four control plot soils measured in May 2002 in a Rayne silt loam soil (Typic Hapludult) in a partly cleared forest of southern West Virginia. Horizon L consisted of freshly fallen leaves and horizon Oi–Oe consisted of partially decayed leaves and organic material.

Layer (cm)	C (g·kg ⁻¹)	N (g·kg ⁻¹)	pH	Al	Ca	Mg	K	S	EC (dS·m ⁻¹)
L	497	12.7	ND ^a	ND	3.00	0.43	0.22	0.26	ND
Oi–Oe	404	18.0	ND	ND	3.77	0.33	0.16	0.28	ND
0–2.5	110	5.3	3.83	5.19	1.46	0.38	0.46	0.49	0.16
2.5–5	58	2.8	3.96	5.28	0.35	0.18	0.23	0.46	0.10
5–10	33	1.9	4.19	3.90	0.23	0.10	0.14	0.69	0.07
10–15	17	1.2	4.27	3.37	0.19	0.07	0.09	0.98	0.06
15–22.5	13	1.0	4.28	3.36	0.17	0.06	0.07	0.97	0.06
22.5–30	11	0.8	4.22	3.80	0.17	0.05	0.06	0.95	0.06

^aND = not determined.

Fig. 1. Effect of slaked lime and gypsum on soil pH (1 soil : 1 water) in mineral soil layers of a forested Rayne silt loam (Typic Hapludults) in southern West Virginia 3 years after surface application. Layers where differences were significant at $P = 0.05$ are indicated by an asterisk.

Fig. 2. Effect of slaked lime and gypsum on exchangeable soil Ca in the Oi–Oe and mineral soil layers of a forested Rayne silt loam (Typic Hapludults) in southern West Virginia 3 years after surface application. Layers where differences were significant at $P = 0.05$ are indicated by an asterisk.

Effects of amendments on soil properties

Soil pH. Three years after surface application, slaked lime had significantly increased pH through the top three layers of mineral soil sampled (0 to 10 cm), compared to control plots (Fig. 1). As expected, gypsum application had no statistically significant effect on pH.

Soil Ca. Compared to the control, slaked lime increased profile Ca levels as deep as the

22.5 to 30 cm layer (Fig. 2). The $0.34 \text{ cmol}_c \cdot \text{kg}^{-1}$ increase in Ca in this deep layer may have resulted from downward movement of Ca ions accompanied by sulfate contained in acidic precipitation, or from movement of un-reacted slaked lime through soil channels.

As expected, gypsum was more efficient than slaked lime in increasing Ca levels deep in the profile, raising soil Ca concentrations

to levels higher than those found in either the lime or control treatments in the 15 to 22.5 cm layer and the 22.5 to 30 cm layer (Fig. 2). This was probably due to limited reaction of sulfate and Ca with soil constituents, which meant that sulfate was free to accompany Ca and facilitate its downward movement.

Soil S. In gypsum-amended plots, levels of S deep in the soil profile were greater than in control plots (Fig. 3). This observation supports the assumption that Ca moved down the profile accompanied by sulfate.

Soil Al, Mg, K, Mn, and electrical conductivity. Levels of Al (in $\text{cmol}_c \cdot \text{kg}^{-1}$) in the 0–2.5 cm layer were 0.1 in the lime treatment, 3.2 in the gypsum treatment, and 5.2 in the control, but were not statistically different at depths below 2.5 cm. Possible explanations for the decrease in Al in the gypsum treatment include 1) neutralization of Al by calcium carbonate impurities in the agricultural gypsum used, 2) precipitation of Al as basaluminite, or 3) leaching of Al with sulfate anions.

The $36 \text{ kg} \cdot \text{ha}^{-1}$ of Mg added to the slaked lime amended plots approximately doubled soil exchangeable Mg levels in each layer of mineral soil in the slaked lime treatment, compared to the control. Magnesium levels in the gypsum treatment were similar to Mg levels in the control treatment. The gypsum amendment contained $18 \text{ kg} \cdot \text{ha}^{-1}$ of Mg, and apparently this was sufficient to counterbalance Mg-leaching effects of surface-applied gypsum observed by Ritchey and Snuffer (2002).

There were few statistically significant effects of amendments on K, EC, or exchangeable Mn below the surface 0 to 2.5 cm layer (data not shown).

Effects of planting bulb weight on survival and harvest fresh weight

There was a wide range in size of planted bulbs. Fresh weights ranged from 0.4 to 4.8 g for single bulbs, from 1.0 to 7.7 g for joined bulbs, and from 0.2 to 5.0 g for joined bulbs that had been split into two. We hypothesized that heavier planting materials would result in improved survival and heavier bulbs at harvest, as was the case for onions (Herison et al., 1993). To evaluate effects of initial bulb weight on survival in single and split bulb planting types, we examined mean initial planted weight of bulbs of plants that survived compared to mean initial weight of bulbs where ramp plants did not survive. Similarly, for joined bulbs we compared mean planted weight where none, one, or two bulbs were harvested. Within planting bulb type, there were no significant differences in weight of planted material between surviving vs. nonsurviving groups in ramps that grew 2 years or in ramps that grew 3 years. We conclude that weight of planted bulbs had no effect on survival in this experiment.

There was a slight positive relationship between fresh weight of planted material and fresh weight of material harvested within planting bulb type as expected (Table 2). Use of lighter weight bulbs at planting resulted in lighter fresh weights at harvest, while planting of heavier bulbs resulted in heavier fresh weights at harvest. The relationship was strongest for joined bulbs harvested in 2001.

Fig. 3. Effect of slaked lime and gypsum on exchangeable soil S in the Oi-Oe and mineral soil layers of a forested Rayne silt loam (Typic Hapludults) in southern West Virginia 3 years after surface application. Layers where differences were significant at $P = 0.05$ are indicated by an asterisk.

Table 2. Statistical significance of correlations between fresh weight of ramps at harvest and fresh weight of bulbs planted in a partly cleared forest in southern West Virginia in March 1999. Material harvested in 2001 consisted of leaves, bulb and roots, while material harvested in 2002 consisted of leaves and bulbs only. Where joined bulbs were planted, correlations were calculated using planting locations where both bulbs survived.

Bulb type planted	Relationship	r^2
Plants harvested in 2001		
Single	Harvested weight = $1.03 + 1.01$ planted weight	0.26
Joined	Harvested weight = $-0.06 + 1.52$ planted weight	0.47
Split	Harvested weight = $1.55 + 0.69$ planted weight	0.12
Plants harvested in 2002		
Single	Harvested weight = $0.75 + 0.57$ planted weight	0.13
Joined	Harvested weight = $1.57 + 0.57$ planted weight	0.15
Split	Harvested weight = $0.62 + 0.76$ planted weight	0.27

Table 3. Main effects of soil amendment, planting density and plant bulb type on plant survival and mean individual plant dry weights (shoot plus bulb) in 2001 and 2002 for bulbs planted March 1999 in a dystrophic acidic woodlot in southern West Virginia.

Treatment	Plant survival		Mean individual plant dry wt (g)	
	2001	2002	2001	2002
Amendment				
Slaked lime	0.72a ^c	0.67a	0.56a	0.36a
Gypsum	0.76a	0.72a	0.49a	0.24b
Control	0.40b	0.24b	0.33b	0.18b
Planting density				
High	0.59a	0.48b	0.44a	0.27a
Low	0.66a	0.61a	0.48a	0.25a
Planted bulb type				
Joined	0.71a	0.57a	0.38c	0.25a
Single	0.63ab	0.58a	0.54a	0.28a
Split	0.54b	0.48b	0.46b	0.25a

^aMeans followed by the same letter within a column treatment group are not significantly different by lsd ($P = 0.05$).

Effects of soil amendment, plant spacing, and bulb type on survival

Survival was measured as the number of live bulbs encountered divided by the number of bulbs planted. Survival in the control treatment without amendment was 0.40 in plants harvested in 2001, and 0.24 in subtreatments

harvested in 2002. Survival rates in the gypsum and slaked lime treatments did not differ from each other, or between years, and averaged 0.72. Both gypsum and slaked lime amendments improved plant survival as evaluated in 2001 and 2002 (Table 3); compared to control, application of the Ca amendments increased

ramp survival of 2-year ramp plants by an average of 84% and increased survival of 3-year ramp plants by an average of 188%. The decrease in survival from 2001 to 2002 in the control treatment was statistically significant by t test. These results are in agreement with observations by Vasseur and Gagnon (1994), who found that ramp survival dropped to 0 after several years in sites with $<2.7 \text{ cmol} \cdot \text{kg}^{-1}$ Ca, in contrast to survival of near 100% in a fertile, moist site.

Survival was little affected by plant spacing after 2 years of growth, but after 3 years of growth, the high density ($15.25 \times 15.25 \text{ cm}$) subtreatments showed reduced survival (0.48 of the material planted, compared to 0.60 for the low density subtreatment).

Effects of bulb type were evident in the 2001 harvest, where joined bulbs had significantly better survival than planting material obtained by splitting joined bulbs apart. In 2002, survival of both single and joined bulbs was better than for splits. This result indicates that planting stock obtained by splitting joined bulbs is not biologically equivalent to planting stock consisting of bulbs growing as individuals.

Effects of soil amendment, plant spacing, and bulb type on mean individual plant dry weight

Both gypsum and slaked lime improved individual plant dry weights (bulb and leaves excluding roots) of ramps that were harvested after 2 years (Table 3). Compared to control, slaked lime application increased weights by 72% and gypsum increased weights by 48%. Ramps harvested after 3 years of growth showed a positive response to slaked lime, but the response to gypsum was less than in the 2-year harvest. Compared to control, slaked lime increased plant dry weight by 100% in the 3-year harvest, while gypsum increased dry matter by only 33% (significant only at $P = 0.14$).

There were no significant effects of planting density on mean individual plant dry weights in either harvest.

Bulb type had significant effects on dry weights of material harvested 2 years after planting. Individual plant weights were highest where single bulbs had been planted and lowest where joined bulbs were planted. Part of this effect may have been due to the larger size of the single bulbs that were planted in 1999, given that mean fresh weight of each planted single bulb was 6% heavier than planting material obtained from breaking joined bulbs apart, and 16% heavier than the mean weight of each individual bulb making up joined bulbs in the joined bulb treatment.

For bulbs that grew 3 years (2002 harvest), there were no significant differences in harvest dry weights among planting bulb types. It is possible that by the third year, initial effects of planting bulb type had become less important, and harvest weight was determined mainly by the soil environment.

Vasseur and Gagnon (1994) observed that lack of soil moisture had a strong effect on growth of ramps. During our experiment, weather was dryer than the 30-year average.

Precipitation was 82% of normal for 1999, 88% of normal for 2000, and 86% of normal for 2001. The effect of cumulative below-average precipitation may have contributed to generalized decreases in mean plant weight observed in the third year, particularly in the control treatment, where high Al levels in soil probably inhibited root growth and the ability to obtain water (Table 3). An additional possibility is that overall soil fertility levels at our site were too low to allow steady increases in plant size from year to year.

We conclude that surface application of gypsum and slaked lime improved base status of an acidic forest soil down to at least 30 cm depth. Ramp establishment and growth in a low nutrient, partially cleared forest site in southern West Virginia benefited from both Ca sources. Gypsum increased soil Ca levels more deeply than slaked lime, but slaked lime increased soil pH and reduced soil Al levels much more than gypsum did. Slaked lime probably was the better amendment. Beneficial effects of slaked lime were still significant in the harvest conducted after 3 years of growth. Single and joined bulbs survived better and produced heavier plants than bulbs obtained by breaking joined bulbs in two. Planting at a 30 × 30-cm spacing resulted in higher survival than in a 15 × 15-cm spacing. While more research is needed to overcome limitations to commercial planting of ramps in acidic sites, Ca application should result in improved survival and growth.

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