ROOT DEVELOPMENT CONTROL MEASURES IN CONTAINERS:

RECENT FINDINGS

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Abstract.--Coating the inside surfaces of containers with cupric carbonate (CuCO3) caused roots of Ponderosa pine *(Pinus ponderosa* Laws.) to stop growth at the container wall. Higher order laterals then proliferated and were arrested. These roots resumed growth radially when the container was removed. Degree of root crowding had little influence on treatment effect. Indole butyric acid (IBA) worked also, but not as well as CuCO3. The CuCO3 treatment was complementary to mycorrhizal inoculation of the growing medium. Combination of the two treatments resulted in bigger trees, more lateral roots, and more mycorrhizal infection than either treatment alone.

Résumé.--Au contact des parois intérieures des récipients enduites de carbonate de cuivre ($CuCO_3$), les racines de pin Ponderosa *(Pinus ponderosa* Laws.) arrêtent de croître. Ensuite, les racines latérales d'un ordre plus élevé prolifèrent mais sont arrêtées de même; elles reprennent leur croissance radiale quand on sort le plant du récipient. Le degré d'encombrement des racines n'influe que peu sur l'effet du traitement. L'acide indole-butyrique est efficace, mais pas autant que $CuCO_3$. Ce dernier agit complémentairement à une inoculation mycorrhizienne du milieu de croissance. La combinaison des deux traitements donne des arbres plus gros, des racines latérales plus nombreuses ainsi qu'une infection mycorrhizienne plus importante que ne le peut un seul d'eux.

INTRODUCTION

The work on control of tree seedling root development in containers, which is discussed in this paper, was stimulated by Burdett's (1978) report, in which the author stated that "lodgepole pine seedlings were grown in styroblocks painted with root growth inhibitor (exterior latex paint containing 100 gm/1 cupric carbonate). This inhibited elongation of lateral roots while in the container, but these roots resumed growth when the tree was removed from the container. Consequently the tree soon acquired a root system form similar to that of a naturally established one." We will not go into detail here as to why these findings may be so important to reforestation, but will simply refer you to all the problems with root deformation of planted trees described in the proceedings of the 1978 Victoria symposium on the subject (Van Eerden and Kinghorn 1978). Suffice it to say that it appeared that Burdett's technique, or an elaboration of it, might enable a nurseryman to produce a tree capable of rapidly sending out lateral roots immediately after planting. This could result in planted trees that reliably grow as

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Note: The use of trade names in this publication does not constitute or imply endorsement by the USDA Forest well as, or better than, seeded trees, and are windfirm.

Consequently, in 1978, the authors set out to:

1. duplicate Burdett's experiments, using Ponderosa pine *(Pinus ponderosa* Laws.), the most widely distributed commercial forest tree species in the western United States;

2. see if some other chemicals or other cupric carbonate concentrations would have similar effects on tree root morphogenesis in containers;

3. acquire knowledge about the treatment effect in relation to the degree of root development in the container;

4. see what interactive effects the treatment had when combined with mycorrhizal inoculation of container growing medium.

In the following discussion of methods and results relating to each of these areas of investigation, the methodology will be discussed only briefly. Full details are given in McDonald (1981).

TESTS OF OTHER CUPRIC CARBONATE CONCENTRATIONS AND OTHER INHIBITORS

Method

In a short-term study the roots of Ponderosa pine seedlings were exposed to various concentrations of cupric carbonate (CuCO3), indole butyric acid (IBA), and trifluralin herbicide (Table 1). This was done by combining the chemicals with exterior latex paint and coating the interior walls of Spencer-Lemaire "Rootrainers" with the solution. The paint was allowed to dry and then the seedlings were reared in the containers as directed by Tinus and McDonald (1979).

After 26 weeks half the seedlings in each treatment (six) were measured (top height, number of needle fascicles, average length of secondary needles, number of roots air pruned, number of roots encountering the wall and turning downward, and root and top dry weights). At the same time the other six trees of each treatment were removed from the containers and planted in a 20 x 20 cm grid pattern in damp vermiculite in a greenhouse bench. After five weeks these trees were carefully removed from the vermiculite. The number and length of roots extending beyond the original root "plug" were measured, and care was taken to distinguish between those growing from the sides and those growing from the bottom of the "plug".

The first measurements were taken to examine treatment effects at time of removal from the container. The second set was taken to determine if treatments actually influenced side root development after simulated outplanting.

Results

Trifluralin, at all concentrations, had pronounced adverse effects on the seedlings; it was not used thereafter.

The highest concentration of CuCO3 (100 g/L) not only reduced root deflections (from an average of 12 per tree to 3 per tree) in comparison with no treatment, but also resulted in significantly bigger trees (48% taller and 74% heavier) (Table 2).

However, the paint-only treatment significantly reduced growth in comparison with that of trees from untreated containers. High concentrations of CuCO3 in the paint overrode this negative carrier effect. Low concentrations of CuCO3 had little effect.

High concentrations of IBA appeared to cause trees to grow better than those reared in the paint-only treatment, but the effect was weak and erratic in comparison with the CuCO3 effect.

Trees treated with CuCO3 (at 100 g/L) and reared in the vermiculite bench for 5 weeks after container removal had 27% of

Table 1. Chemical root inhibitor treatments

Chemical/paint treatment	Concentrations (g/L)					
No treatment	-	-	-	-	-	-
Paint only	-	-	-	-	-	-
Trifluralin	70.88	14.18	2.84	0.56	-	-
$CuCO_3$	100.00	10.00	3.00	1.00	-	-
IBA	50.00	5.00	0.05	0.005	0.005	0.0005

Table 2. Comparison of size and root deflections of Ponderosa pine seedlings from copper-painted containers (mean of six trees).

$CuCO_3$ concentration (g/L paint)	Height (mm)	Shoot dry wt (g)	Root dry wt (g)	Roots deflected
0.1	44.2	0.49	0.35	12.2
1.0	48.7	0.60	0.39	7.5
3.0	54.8	0.92	0.54**	9.0
10.0	54.8	0.81	0.48	9.7
100.0	65.2*	1.00**	0.61*	3.7*
No paint	58.7*	0.78	0.50	) Not
Paint only	46.8	0.51	0.35	)measured

*,** Significant (5% probability) or highly significant (1% probability) differences, respectively from paint-only (t-test)

their roots as side roots in comparison with 8% for untreated trees, three times more side root length than untreated trees, about the same total egressed root length (side and bottom) as untreated trees, and significant increases in height growth over untreated trees (Table 3).

Conclusions

A few generalizations can be made from this first study:

1. Treatment of the containers with the higher concentrations of CuCO3 (and, to a lesser extent, IBA) resulted in a greater proliferation of side roots of Ponderosa pine following greenhouse transplanting. Lower concentrations were relatively ineffective.

2. The latex paint carrier may be phytotoxic, but the effect is overridden by the CuCO3 or IBA treatment at higher concentrations. Another carrier might be better.

3. Treflan (trifluralin), at the concentrations tested, is too phytotoxic for use in this manner.

4. Our findings using CuCO3 with Ponderosa pine were similar to those of Burdett (1978) with lodgepole pine *(Pinus contorta* Dougl. ex Loud.).

TESTS WITH CuCO3/IBA AND VARIOUS MECHANICAL TREATMENTS

Plants kept in containers too long will form undesirable, constricted root systems from which they may never recover when planted in their permanent location (Harris et al. 1971). These negative effects have long been observed (Knight 1809). Armson (1978) has pointed out that three things really determine the nature of the root system generated in a container: (1) the length of time the tree grew in the container, (2) the rate of seedling growth, and (3) the nature of the container. Ideally, seedlings should be reared in the container only until there is sufficient root development to hold the growing medium together (Carlson and

Table 3. Post-planting data for Ponderosa pine seedlings treated with $CuCO_3$ (6 trees/treatment).

$CuCO_3$ concentrated (g/L paint)	Mean side roots as % of total roots	Mean length of side roots (cm)	Mean total root length (cm)	Mean root collar diameter (cm)	Mean stem height (cm)
No paint	7.8	19.3	248.5	2.8	58.0
0.0	9.4	12.0	64.0**	3.0	59.3
1.0	4.7	3.7*	78.8**	2.2	38.7*
3.0	12.1	19.1	158.0	3.0	64.3
10.0	12.0	25.7	214.3	3.3	63.8
100.0	27.1	61.2**	226.0	3.3	70.0*

*, ** Significant (5% probability) or highly significant (1% probability) differences, respectively, from no-paint treatment.

Nairn 1977). However, we know that this is often operationally impractical. A root morphology control procedure may be doubly important if it results in a better root system (than that of a tree from an untreated container) when the tree is left in the container longer than desirable.

Method

Ponderosa pine seedlings were reared in treated Ray Leach super cells. Four container treatments were used: (1) no treatment, (2) $CuCO_3$ in latex paint at 50 g/L painted on the inside of the cells, (3) IBA at 5 g/L in paint as in (2), (4) five mechanical treatments consisting of various patterns of slots and holes cut into the walls of the cells. The seedlings were grown to a common state of top development. Budset was then induced and root growth was continued for 1, 2, 3, or 4 months before being stopped completely. Following a cold storage period, 10 trees of each container treatment/root development combination were measured (stem diameter, top height, number of roots deflected downward at the container wall, and number of roots at the drainage hole). Another 10 trees were transplanted into 7 L pots filled with moist peat for continued growth in a shadehouse. These transplanted trees were allowed to grow for two months, then were removed from the pots. The peat was carefully removed from the roots extending beyond the original container root plug volume. The side and bottom roots of these trees were then measured (number and fresh weight), as were stem heights and root collar diameters.

Results

Upon removal of the seedlings from the Leach cells it was found that the added time allowed for root development had no significant effect on any of the measured parameters. However, when all the trees in a container treatment were compared, regardless of time allowed for root development, the copper-treated trees had a highly significant reduction in root deflections at the container wall in comparison with those from containers with no treatment. Trees grown in mechanically treated containers had a significant reduction in root deflection, hut the trees were also stunted. Average survival in mechanically treated containers was 39%. Survival in containers with no slots or holes was 93%. Containers with slots or holes allowed the growing medium to dry out under a normal greenhouse irrigation regime.

Seedlings transplanted from containers to pots were compared, one treatment/root development combination to another, in a two-way analysis of variance routine (ANOVA). Container treatments (IBA, $CuCO_3$, slots) had highly significant effects on nearly all growth parameters. Duration of root development period following top growth cessation had little effect over all. This would suggest that (1) the degree of root development differential was insufficient to induce an effect or (2) the treatment ($CuCO_3$) ameliorated the effect of root crowding in the containers.

Conclusions

The correlation with $CuCO_3$ treatment, fewer root deflections at the root-container wall interface, and enhanced side root development following removal of the trees from the container, observed in previous work, was reproduced in this test. Again, $CuCO_3$-treated trees grew bigger than those in other treatments.

The synthetic auxin analog, IBA, was again a weak substitute for $CuCO_3$. The application method apparently does not keep this powerful root growth inhibitor at the root-container wall interface in sufficient amounts.

Finally, there were no differences in root egress rates of the seedlings grown to four different degrees of root development. There is some question as to whether enough root compression was achieved to acquire a real effect, but if there was, these results mean that the $CuCO_3$ treatment effectively retarded root growth distortion because of crowding. More work is needed to see if this is indeed true.

TESTING EFFECTS OF CUPRIC CARBONATE TREATMENT-MYCORRHIZAL INOCULATION INTERACTION

The preceding work, and Burdett's work, indicate that cupric carbonate, used as described, brings about changes in root system morphogenesis in containerized lodgepole and Ponderosa pine.

The $CuCO_3$ treatment results in a proliferation of lateral roots which arise from the inhibited primary laterals. This may provide a root system more susceptible to infection by mycorrhizal fungi in the container (Hatch 1933). On the other hand, it is possible that the $CuCO_3$ treatment would inhibit formation of mycorrhizae. Inoculation of growing medium in treated and untreated ($CuCO_3$) containers and measurement of the development of mycorrhizae on seedlings grown in the medium would resolve the question. If the results were positive it could mean that the combined effect of mycorrhizal inoculation and the $CuCO_3$ treatment would result in an enlargement of the seedlings' nutrient absorbing root surface area (additive effect) (Bjorkman 1970).

Method

Two species of known mycorrhizal fungi, *Suillus granulatus* (L. ex Fr.) O. Kutze isolate #133, and *Pisolithus tinctorius* (Pers.) Coker and Couch isolate #75-20, were prepared as inoculum, according to Marx and Bryan's procedure (1975), by Steven Grossnickle at the Forest Tree Physiology Laboratory at Colorado State University. The washed mycelial fungal inoculum was combined, at a rate of 10% (v/v), with a peat/vermiculite growing medium. Inoculated and uninoculated growing media were used to grow both Ponderosa pine and lodgepole pine seedlings in Spencer-Lemaire "Rootrainers". Some of the containers were treated with cupric carbonate, and some were not (Table 4). This resulted in a 2 (tree species) x 2 (container treatment) x 3 (mycorrhizae treatment) factorial experiment.

The tree seedlings were grown to the point at which the root-growing medium matrix could easily be removed intact from the container. Budset was then induced, and the trees were removed and measured (height, root-collar diameter, number of roots deflected, and number of short roots infected and not infected with mycorrhizal fungi).

Results

The data were summarized, and a three-way ANOVA, comparing container treatment, tree species, and species of fungus, was calculated on each of the measured parameters.

Trees grown in copper treated containers were somewhat bigger with respect to stem height and diameter than those grown in untreated containers (Fig. 1 and 2), as were the trees grown in inoculated medium (plain containers) in comparison with those grown in uninoculated medium (25-40% larger). Trees subjected to the combined treatments (copper and mycorrhizae) often had greater height and diameter, especially in Ponderosa pine, than when either treatment was used alone. In no case was stem height or caliper reduced by the combined treatment.

The cupric carbonate treatment greatly reduced root deflections at the container wall and numbers of roots reaching the bottom of the container (Fig. 3 and 4). This occurred whether the medium was inoculated or not in both tree species.

The copper treatment alone resulted in increased numbers of short roots and incidental mycorrhizal infection (Fig. 5 and 6). The copper-mycorrhizal inoculum combinations were very effective in increasing the number of short roots and percentage of mycorrhizal roots for Ponderosa pine, but were less effective or neutral for lodgepole pine.

Table 4. Summary of treatments in the cupric carbonate-mycorrhizal infection interaction experiment.

Mycorrhizal inoculum treatment	Container treatment: None	Container treatment: $CuCO_3$ (50 g/L)	Total no. of trees
	- - - - - 10 trees each species	- - - -	
None	PP/LP*	PP/LP	40
P. tinctorius	PP/LP	PP/LP	40
S. granulatus	PP/LP	PP/LP	40
Total trees	60	60	120

*PP = ponderosa pine, LP = lodgepole pine

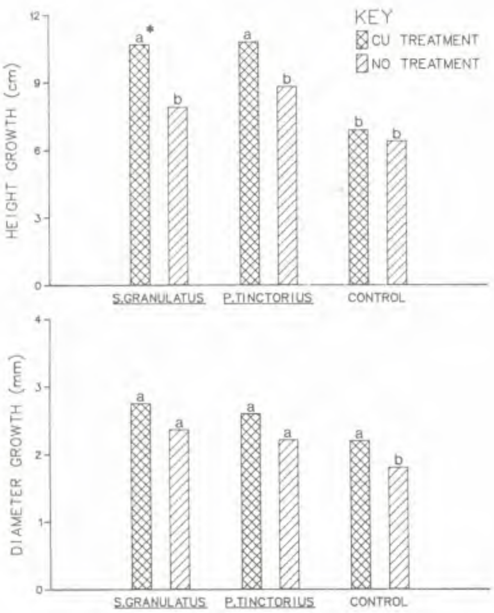

Figure 1. Height and diameter growth of *P. ponderosa* with mycorrhizal fungus-cupric carbonate interactions. (Means within a given copper-mycorrhizal treatment with a common letter are not significantly different at α = 0.05 as determined by Tukey's mean separation test.)

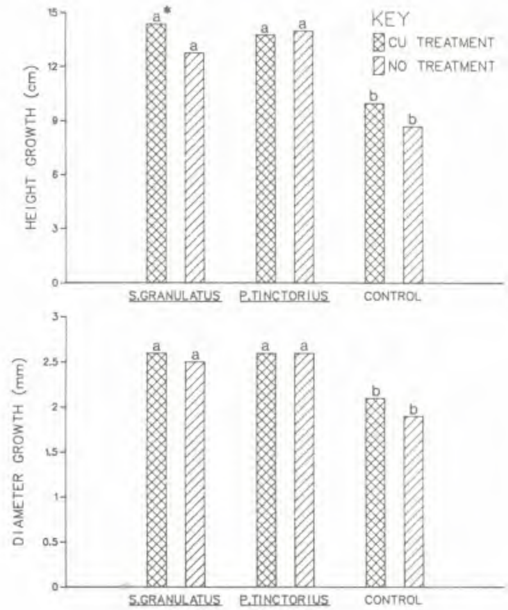

Figure 2. Height and diameter growth of *P. contorta* with mycorrhizal fungus-cupric carbonate interactions. (Means within a given copper-mycorrhizal treatment with a common letter are not significantly different at α = 0.05 as determined by Tukey's mean separation test.)

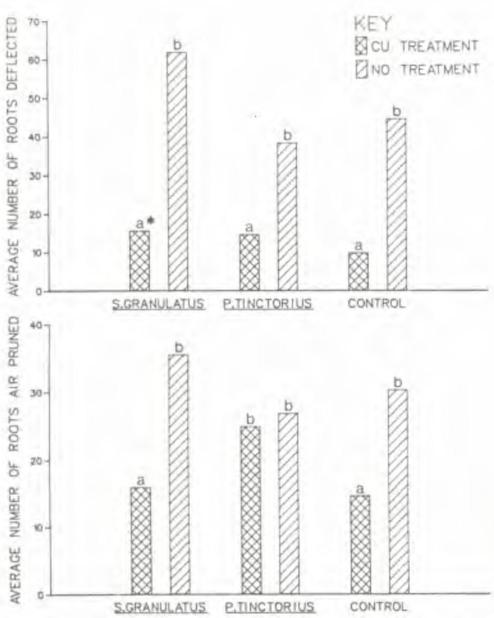

Figure 3. Root development characteristics of *P. ponderosa* with mycorrhizal fungus-cupric carbonate interactions. (Details as in Figure 1.)

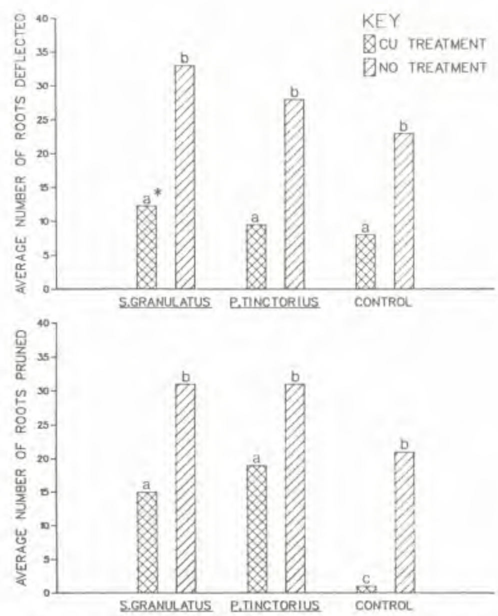

Figure 4. Root development characteristics of *P. contorta* with mycorrhizal fungus-cupric carbonate interactions. (Details as in Figure 2.)

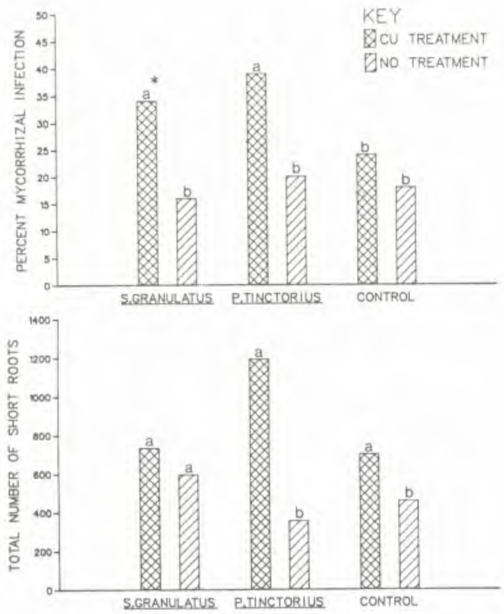

Figure 5. Percent mycorrhizal infection and total number of short roots of *P. ponderosa* with mycorrhizal fungus-cupric carbonate interaction. (Details as in Figure 1.)

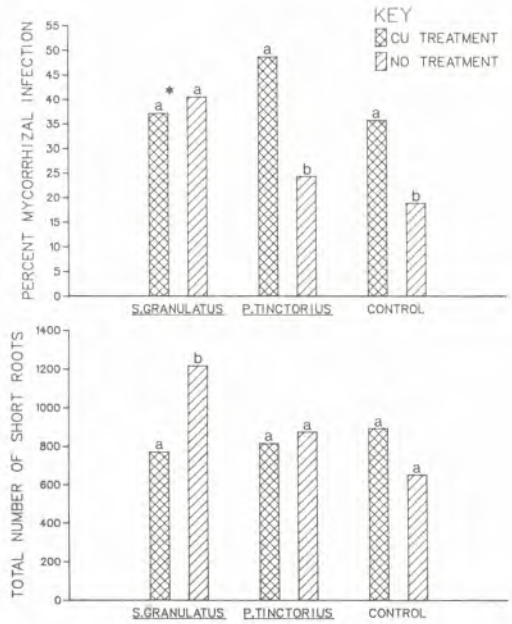

Figure 6. Percent mycorrhizal infection and total number of short roots of *P. contorta* with mycorrhizal fungus-cupric carbonate interaction. (Details as in Figure 2.)

Conclusions

The cupric carbonate treatment generally had beneficial effects on tree morphology (bigger trees, fewer root deflections) and, at the same time, no detrimental effects on the fungal association (percentage of mycorrhizal roots). Indeed, the proportion of mycorrhizal roots was usually much higher where trees were copper-treated. Lodgepole pine appeared to be more readily infected than Ponderosa pine. However, there were some differences in performance of the fungi in association with the different tree species.

This was a small test. Preliminary indications were most encouraging, but more work is needed to confirm these findings.

GENERAL SUMMARY AND CONCLUSIONS

Our findings with cupric carbonate and Ponderosa pine are in agreement with those of Burdett (1978) with lodgepole pine. This validation is based largely on root egress from the root plug following simulated outplanting. The message is clear: coating the interior of containers with acrylic latex paint and cupric carbonate (at concentrations of 50 to 100 g/L of paint) does cause lateral root growth to be arrested at the root-container wall interface. This subsequently leads to a proliferation of higher order laterals which are similarly arrested. These arrested root tips resume growth when the seedling is removed from the container and planted. Consequently, a much higher proportion of the roots emerge from the sides of the root plug than is usually seen when untreated containers are used.

The cupric carbonate treatment caused Ponderosa pine seedlings to be taller and heavier in these tests.

Container type used appears to have little or no influence on the $CuCO_3$ treatment effect.

The synthetic auxin analog, IBA, was effective in high concentrations, but was not as effective as $CuCO_3$. The problem seems to be in keeping IBA at the root-wall interface where it can be effective. A carrier other than latex paint may be better.

The carrier, latex paint, was phytotoxic. However, the $CuCO_3$ effect overrides this phytotoxicity so that this paint can be used until a better carrier is found.

Mechanical treatments (holes, slots in the containers) were disappointing. Trees became stunted or died because the containers tended to dry out in the greenhouse.

The effect of added root crowding on root morphology seemed to be ameliorated by the CuCO3 treatment. While more study on this is needed, these results could be very important where containerized seedlings cannot be planted on schedule.

Seedlings grown in copper-treated containers and in growing medium inoculated with mycorrhizal fungi generally were bigger and had a greater percentage of mycorrhizal roots than comparable seedlings grown in untreated containers and uninoculated medium. The combined treatment was usually better than either treatment alone.

When seedlings were removed from created containers the interior coating of inhibitor was usually left intact. CuCO3-paint mixture coatings may be useful for more than one crop of trees, but this was not tested.

Field plantation tests under way in Canada (by Burdett) and the United States (by the authors) will help determine the long-term effects of the treatment on growth and stability of these pines. In five years or so the results should indicate how valuable the enhanced side root development is. We suspect that the treated trees will grow faster and be more windfirm than untreated trees.

We would urge those of you interested in this procedure to try it now on a small scale. It is simple to do and needs to be tried on other species of trees and at other locations.

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