A dormancy extension technique for biotechnical streambank stabilization in warm regions

Ming-Han Li, Harlow C. Landphair, Michael A. Arnold, Kenneth Mullin, Karen E. Eddleman

Abstract

Researchers identified four challenges to applying biotechnical-streambank stabilization in warm regions. These challenges are strongly correlated to plant dormancy and planting period. Prompted by these challenges, researchers investigated the applicability of using the cold storage method to extend the dormant condition of live black willow (Salix nigra) cuttings for later planting. Black willow cuttings were harvested in February 2001 and stored in a refrigerator at 4.4 °C (40 °F). These cold-stored cuttings had survival rates of 81.3, 43.6, and 43.8% when they were planted in the field in March, April, and May 2001, respectively. These rates are considered satisfactory in biotechnical engineering. A cost analysis suggests that using cold storage in field conditions is feasible.

Keywords: Biotechnical-streambank stabilization; Dormancy; Black willow

1. Introduction

Biotechnical streambank stabilization has gained popularity among governmental agencies in the United States in recent years (USDA/NRCS, 1996; Allen and Leech, 1997). While its use is common in the northern United States, its use in warm regions of the United States is still rare.

To explore the use of biotechnical streambank stabilization as an alternative to traditional methods, the Texas Department of Transportation (TxDOT) initiated a research project in 1998, investigating the applicability of biotechnical stabilization techniques. Initially, the applicability of biotechnical techniques was to be evaluated by the design, construction, and monitoring processes of demonstration projects being completed by local TxDOT district and area offices. An important task of the TxDOT research project was to develop technical guidance and selection criteria of biotechnical techniques. During the design process of the biotechnical demonstration project, researchers defined four challenges associated with warm region application.

As a result of the challenges defined in the design process, researchers revised the research project objective to evaluate the applicability of using cold storage methods to extend the dormancy period of live black willow cuttings. Black willow cuttings were harvested in February 2001 and stored in a refrigerator at 4.4 °C (40 °F). These cold-stored cuttings had survival rates of 81.3, 43.6, and 43.8% when they were planted in the field in March, April, and May 2001, respectively. These rates are considered satisfactory in biotechnical engineering. A cost analysis suggests that using cold storage in field conditions is feasible.
storage to extend plant dormancy for biotechnical applications in warm regions. The cold storage treatment (storage at 4.4 °C) was applied to live dormant cuttings and a series of field plantings were conducted.

This paper introduces the challenges and explores the research needs stemming from streambank stabilization projects using biotechnical techniques in warm regions, and further outlines the associated dormancy extension experiment and results. The findings of the study will become the basis for how cuttings should be handled to extend the construction period in warm regions.

2. Challenges of warm region application

During the design process of biotechnical demonstration project, the first task was to conduct biotechnical engineering case studies. It was found that there were many successful cases in the northern United States and Canada but much less in the southern United States. From this initial finding and the process of implementing the biotechnical demonstration project, four challenges were defined.

2.1. Plant physiological limitations

A plant becomes dormant because of changes in environments (Lang et al., 1985), normally decreasing temperature and day-length (Wareing, 1969). Plant dormancy is important to biotechnical techniques because, to be effective, stakes must be harvested and planted immediately during the dormant period (Hoag, 1995; Gray and Sotir, 1996; Allen and Leech, 1997; Schiechtl and Stern, 1997). Use of dormant cuttings allows more time for the cuttings to produce roots before energy is diverted to leaf production, and therefore, can yield a high survival rate (Crowder, 1995). This is challenging in warm areas where winters are short. As shown in Fig. 1(a), west coast, south and southeast of the United States are categorized as Plant Hardiness Zones 8, 9, and 10 (Cathey, 1990), and in general, plants in these zones become completely dormant in January and break dormancy from February to early March, depending on the latitude. This short dormant period provides a very narrow project implementation time.

2.2. Climatic constraints in warm regions

Stabilizing streambanks requires access to the bottom of a stream, which can be complicated due to frequent stream flow during rainy, warm winters. In TxDOT’s case, Texas’ diverse climatic pattern is attributed to its broad territory covering from latitude 25°50′N at the extreme southern turn of the Rio Grande River on the south line of Cameron County to latitude 36°30′N along the north line of the Panhandle. As a result, for example, the January daily mean minimum temperature ranges approximately from 10 °C (50 °F) in Brownsville to −9.4 °C (15 °F) in Dalhart (data from NOAA-CIRES Climate Diagnostics Center). However, most of TxDOT streambank erosion problems occur in the southeast region and most metropolitan areas such as Austin, Dallas/Fort Worth, Houston, etc., where many bridge crossings are located. Unless flow diversion devices are used, probability is high that the plant dormant period, ideal for biotechnical construction, will be missed. If a flow diversion is proposed, the construction will not only be more expensive but also involve severe disturbance of a stream channel. In the United States, construction activities that disturb a stream channel are strictly regulated and require a slow and complicated permitting process. Consequently, the use of flow diversions for streambank stabilization projects is not normally preferred.

2.3. Construction schedule conflicts

When streambank problems occur near infrastructure such as bridges, utility lines, sewerage lines and so on, concerns over right-of-way purchase or access often require several governmental or private entities to resolve those issues. As such, a project schedule can be easily delayed when any of the parties involved fails to complete its mission. This construction schedule conflict is further complicated with the short dormant period in warm regions.

2.4. Shortage of qualified contractors

A survey of erosion control contractors in the United States conducted in 1999 indicates that very...
few warm regions contractors had experience with biotechnical applications. Contractors in the northern regions have specialized in the biotechnical engineering area. This finding could be attributed to the aforementioned absence of biotechnical cases in the southern United States, as well as, challenges of applying biotechnical techniques in warm regions.

Given these challenges, successful biotechnical streambank construction within a 2-month dormant period offers little promise without utilizing an alternative method such as plant dormancy extension.
3. Methods

The investigation of dormancy extension was conducted to evaluate whether harvesting and storing plant cuttings for later planting is practical in warm regions. The test site was located at a field laboratory in Bryan, Texas, USA. According to the “USDA Plant Hardiness Zone Map” (Cathey, 1990), as illustrated in Fig. 1(b), Bryan is within Zone 8b with the average annual minimum temperature range between -6.7 and -9.4 °C (15–20 °F), which is considered relatively warm.

Black willow (Salix nigra) was used for the experiments. Black willow is one of the widely used plants in biotechnical engineering because:

- it is native to North America (see Fig. 2 for black willow’s native range),
- it is easy to propagate by stem cuttings (McKnight, 1965), and
- its root system is dense (Gray and Sotir, 1996).

Cold storage at 4.4 °C (40 °F) was used to treat harvested black willow cuttings. This test was conducted to repeat the similar cold storage method performed by other scientists (Cram and Lindquist, 1982; Platts et al., 1987) to investigate whether the similar method can also be applied in warm regions. Further, the cold storage treatment was intended to be economical and practical for field application. Treatments that require addition of fertilizer or chemical substances to stimulate root growth were not used. Live cuttings were harvested on 14 February 2001 when black willows were still dormant and then stored in a walk-in refrigerator that maintained a constant temperature of 4.4 °C (40 °F). While stored in the refrigerator, cuttings were wrapped and covered by black plastic bags to block any light source (Fig. 3). The cut ends were soaked in water to maintain vitality. Before being planted, cuttings were first removed from the refrigerator and soaked in an outdoor pond for approximately 3–5 days. This pre-planting soaking was applied because it was...
economical and effective in enhancing survival (Hoag, 1993; Schaff et al., 2002). Cuttings were then planted in an embankment of a 33% gradient. Placement conditions for each installation were identical in soil type, orientation, sun exposure, and elevation. Three sets of installation were conducted on 6 March, 3 April, and 10 May, 2001, respectively. The installation process is presented in Fig. 4.

For each installation of cuttings, researchers followed planting procedures of brushlayering described in the literature (Gray and Sotir, 1996; Bentrup and Hoag, 1998). A graphic illustration of brushlayering is presented in Fig. 5. Only one layer of brushlayering was built in the embankment for this study. Cold-stored cuttings were randomly distributed for those three sets of installation in March, April, and May. The diagnosis of cutting size (diameter and length) using the post-hoc multiple comparison test with the Tukey’s procedure concluded that there is no practical difference among different installation sets. The quantity, diameter and length of cuttings installed...
in each test type are presented in Table 1. During installation, cuttings were handled with care to minimize damage. Refilled soils were moistened during planting. Cuttings were installed with approximately 0.9–1.2 m of stems inside the embankment and were separated by plastic net for easy monitoring (Fig. 6). All planted cuttings were monitored through March 2002.

4. Results and discussion

4.1. Cold storage treatment

The cold storage applicability was determined by comparing the survival rate of treated cuttings with the satisfactory survival rate of 40–70% reported in the literature (Gray and Sotir, 1996). A survival rate of 40–70% 1 or 2 years after planting was considered satisfactory. For this reason, researchers used the range of 40–70% as the test thresholds for applicability. A survival rate falling under 40%, between 40 and 70%, and above 70% is labeled as “not satisfactory”, “satisfactory”, and “very satisfactory” respectively. In March 2002, the survival rates of cuttings installed in March, April, and May 2001 were 81.3, 43.6, and 43.8%, respectively, which indicates cutting installations in March, April, and May appear to be very satisfactory, satisfactory, and satisfactory, respectively (Table 2).
To investigate the effects of installation timing, cutting diameter, and cutting length, as well as the interaction between these factors on survival, the survival results of the cold storage experiment were further analyzed using the logistic regression. The fitted logistic regression model (the fitted logit model) generated by SAS is:

\[
\text{Logit}(\hat{P}_{\text{Survival}}|\pi) = 3.7049 - 0.1878 \times \text{diameter} + \beta \times \text{installation month}
\]

where \(\text{Logit}(\hat{P}_{\text{Survival}}|\pi)\) is the natural logarithm of \(\frac{\pi_{\text{Live}}}{1 - \pi_{\text{Live}}}\), \(\hat{P}_{\text{Survival}}|\pi\) is the predicted probability of the cutting survival odds, \(\pi_{\text{Live}} = \hat{P}_{\text{Survival}}|\pi\) which is the probability that a cutting survives, \(\beta = 1.1159\), when installation month is March, \(-0.4252\), when installation month is April, and \(-0.6907\), when installation month is May.

The Hosmer and Lemeshow goodness-of-fit statistic (chi-square) is 4.6851, and the corresponding \(P\)-value with 8 degrees of freedom is 0.7906. This indicates that the model fits well.

The fitted logit model indicates that the survival rate decreased when cutting installation occurred later in the season. The reason why the cutting survival in the March installation (81.3%) was higher than those in the April (43.6%) and May (43.8%) installations could be related to the weather. As shown in Fig. 7, the cutting survival rate decreases as the monthly temperature increases. Cuttings installed in March obtained sufficient rains (157.2 mm = 6.19 in.) and were under a mild temperature of approximately 12°C (53.6°F) (Figs. 8 and 9). While the survival rate is high (81.3%) in March, it drops in April and May when the mean monthly temperatures jump from 12.7°C (54.8°F) in March to 21.7°C (71.1°F) in April, and to 25.3°C (77.5°F) in May. Probably, cuttings installed in March yielded a higher survival rate (81.3%) because they had a more suitable growing condition (mild temperatures and adequate water supply) than those planted in April and May. As shown in Fig. 9, the temperature of 15–20°C (59–68°F) seems to be a threshold for the cold storage treatment to be considered “very applicable” (survival rate higher than 70%). Temperatures above 15–20°C (59–68°F) tend to suppress survival approximately from 80 to 40%. Which factor, either monthly rainfall or temperature differences, had more influence on cutting survival in April and May cannot be determined without more investigation. However, the survival rates of

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Live/dead counts</th>
<th>Survival rate</th>
<th>Applicability</th>
</tr>
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<tbody>
<tr>
<td>March installation</td>
<td>80</td>
<td>65/15</td>
<td>81.3%</td>
</tr>
<tr>
<td>April installation</td>
<td>78</td>
<td>34/44</td>
<td>43.6%</td>
</tr>
<tr>
<td>May installation</td>
<td>80</td>
<td>35/45</td>
<td>43.8%</td>
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Table 2
Survival rate of each test set one year after planting
April and May installations are very close regardless of the significantly different rainfall depth between April (6.1 mm = 0.24 in.) and May (122.2 mm = 4.81 in.) (see Fig. 8).

Another finding from the fitted logit model is that the survival rate decreased as the cutting diameter increased. The relationship between π_{live} of the March installation and the cutting diameter is plotted in Fig. 10. The diameter of cold-stored cuttings installed in March ranged approximately from 10 to 29 mm. The dashed curve shown in Fig. 10 is the theoretical relationship of diameter <10 mm and diameter >29 mm extrapolated using the logit model. This extrapolated relationship is not conclusive because no data can support it in the study. In particular, when diameter is approaching zero, the survival rate near 100% is obviously unreasonable.

4.2. Application potential

Researchers conducted a cost analysis of cold storage application in field conditions, and results indicate this method is practical. Trailers with self-contained, diesel-powered refrigerated units are available for lease. A typical 48-feet trailer can store approximately 23,520 cuttings, which can treat about 150m (500 ft) of streambank using brushlayering with four lifts. Trailer rental would cost about US $1250 dollars per month plus fuel (2001 figure in south Texas). If the truck is used for three months, the estimated cost of rental and fuel is about US $5000. For a typical streambank stabilization project of US $100,000-$150,000, the cost is no greater than 5%, which is reasonable.

5. Conclusions and recommendations

Dormancy extension utilizing cold storage appears to be a practical solution to the challenges of warm region biotechnical streambank stabilization. Cold-stored cuttings that were harvested in February 2001 had a survival rate of 81.3, 43.6, and 43.8% when they were planted in March, April, and May 2001, respectively. This indicates that the survival rates of cold-stored cuttings are satisfactory. The results from the cold storage treatment encourage continued research efforts that would further extend the knowledge of plant dormancy and increase biotechnical engineering application in warm regions. For example, research and technology focusing on different plant species can be conducted to identify more workable plants for warm region biotechnical uses. Other variables such as supplemental watering and fertilizer are also suitable research topics to strengthen the knowledge base generated from this study. With these research efforts, using live cuttings to stabilize streambanks may have great applicability in warm regions.

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