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Invasive Species Biology, Control, and Research

Part 1: Kudzu (*Pueraria montana*)

Patrick J. Guertin, Michael L. Denight, Dick L. Gebhart, and Linda Nelson

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Abstract: A 2007 Report to Congress documented a crucial factor in the loss of Army training land: uncontrolled vegetation growth. Of the 53 installations surveyed for the report, 30 reported that approximately 12 percent of their training lands were unusable for certain types of training. Uncontrolled vegetation was a source of such problems as an inability to conduct mounted and dismounted maneuver training, interference with equipment used in line-of-sight training, safety issues, and damage to equipment and structures. Of the 11 plant species (or groups) identified by installations as "uncontrolled vegetation," six were invasive plants, of which the two invasive plants most commonly identified were Kudzu (*Pueraria montana*) and Multiflora Rose (*Rosa multiflora*). This work provides a snapshot of current research and scientific knowledge related to the invasive plant species Kudzu, its impact on the Army, and a concise representation of control technologies for military land managers.

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Preface

This study was conducted for Office of the Assistant Chief of Staff for Installation Management (ACSIM), Environmental Division under Project A896, "Base Facility Environmental Quality," Army Invasive Species Priority Control and Management. The technical monitor was Bill Woodson, DAIM-ED-N.

The work was managed and executed by the Ecological Processes Branch (CN-N) of the Installations Division (CN), Construction Engineering Research Laboratory (CERL). The CERL principal investigator was Patrick J. Guertin. Alan Anderson is Chief, CEERD-CN-N, and Dr. John T. Bandy is Chief, CEERD-CN. The associated Technical Director was William d. Severinghaus, CEERD-CV-T. The Director of ERDC-CERL is Dr. Ilker R. Adiguzel.

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Unit Conversion Factors

Multiply	By	To Obtain
acres	4,046.873	square meters
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
feet	0.3048	meters
gallons (U.S. liquid)	3.785412 E-03	cubic meters
inches	0.0254	meters
miles (U.S. statute)	1,609.347	meters
ounces (U.S. fluid)	2.957353 E-05	cubic meters
yards	0.9144	meters

1 Introduction

Background

A 2007 Report to Congress documented a crucial factor in the loss of Army training land: uncontrolled vegetation growth. Of the 53 installations surveyed for the report, 30 reported that approximately 12 percent of their training lands were unusable for certain types of training. The report cited uncontrolled vegetation as a source of such problems as an inability to conduct mounted and dismounted maneuver training, interference with equipment used in line-of-sight training, safety issues, and damage to equipment and structures (Office of the Assistant Secretary of the Army 2007).

Of the 11 plant species (or groups) identified by installations as "uncontrolled vegetation," six were invasive plants, of which the two invasive plants most commonly identified were Kudzu (*Pueraria montana*) and Multiflora Rose *(Rosa multiflora)*. Both species were introduced from Asia into the United States and were used extensively for conservation purposes in the 1930s through 1950s. Since that time, it has been widely recognized that both species are highly invasive in many areas of the Eastern United States.

Objectives

The objective of this work was to provide a snapshot of current research and scientific knowledge related to the invasive plant species Kudzu (*Pueraria montana*), its impact on the Army, and control technologies. The effort is intended to satisfy two goals: (1) to provide control and research information for ERDC-CERL direct funded program development, and (2) to provide a concise representation of control technologies for military land managers.

Approach

This work began with a literature review of pertinent materials related to control technologies for Kudzu (*Pueraria montana)* from sources including (but not limited too): scientific literature, government/university extension services, and Department of Defense, Army and ERDC technical and programmatic documents. This was supplemented with representative

data from ongoing research to demonstrate potential future developments and opportunities in control technologies.

Scope

Information presented in this report was current at the time of publication. Invasive weed control methodologies, points of contact, and similar information may change over the course of time as scientific developments progress.

Mode of technology transfer

Information from this report will be disseminated as an ERDC/CERL report to military personnel and other interested parties. This report will also be made accessible through the World Wide Web at:

http://www.cecer.army.mil

2 Overview of Kudzu (*Pueraria Montana*)

Plant information

Name: *Kudzu Pueraria montana* (Lour.) Merr. var. *lobata* (Willd.) Maesen & S. Almeid.

Synonymy: *Pueraria lobata* (Willd.), *P. tunbergiana* (Sieb. & Zucc.) Benth.

Family: Fabaceae (Leguminosae)/Pea Family.

U.S. Department of Agriculture (USDA) Symbol: PUMOL.

Tier 1 Installations: Fort Bragg, Fort Hood, Fort Benning, Fort Polk, Fort Campbell and Fort Stewart.

Tier 2 Installations: Fort Pickett, Camp Atterbury, Camp Blanding, Fort Knox, Rucker, Fort Chaffee, Fort AP Hill, Fort Indiantown Gap, Fort Dix, and Fort Jackson.

Nativity: Introduced for all reporting installations.

State Noxious Status: Kudzu and its entities are listed in some form of noxious or controlled plant in Connecticut, Illinois, Florida, Kansas, Kentucky, Massachusetts, Mississippi, Missouri, Oregon, Pennsylvania, Texas, Washington, and West Virginia.

Biology

Description

Kudzu (*Pueraria montana*) is in the Family *Fabaceae (Pea Family, legume)*. Kudzu is a perennial, high-climbing, deciduous woody vine, with tuberous roots and brown stems that can grow as long as 20 m. Leaves are alternate, long petioled, with three leaflets. Leaf surfaces are green and hairy on both surfaces. Flower structures are purple, up to 2.5 cm across and occur in short stalked clusters. Fruiting structures are brown pods (bean-like) containing multiple seeds that present in the Fall (Foresth and

Innis 2004). Seeds can survive several years in the seed bank before germination.

Kudzu rapidly fixes carbon to growth of extensions and leaf material instead of woody support structures, using surrounding trees, etc. for support (Foresth and Innis 2004). This growth form allows for rapid plant expansion that can easily overtop trees and surrounding vegetation.

Reproduction

Kudzu reportedly reproduces readily through vegetative spread (Foresth and Innis 2004). Vegetative reproduction occurs when stems come into contact with the ground, roots will develop at stem nodes. When plants senesce or stems are broken due to disturbance these connections become new plants. In the United States, sexual reproduction is limited by fungal pathogens or limited availability of pollinators. Limited data suggest that sexual reproduction is higher in the southern part of the plant's North American range (Foresth and Innis 2004).

Introduction into the United States

Kudzu was introduced into the United States at the 1876 Centennial Exposition in Philadelphia, PA. (Miller and Boyd 1983). Initially introduced as an ornamental, by the 1930s it was widely used for erosion control in the Southeast United States. A lack of natural pathogens and predators, coupled with Kudzu's ability to grow at rapid rates made the plant a nuisance species by the mid-1950s and caused it to be Federally listed as a noxious weed in 1977 (Everest et al. 1999).

Habitat

P. montana occurs in untended fields, forests, roadsides, pastures and a variety of similar sites. Its ability to fix nitrogen gives the plant a competitive advantage in disturbed or low quality sites (Witkamp et al. 1966). Kudzu's deep roots makes it drought resistant. It can grow in altitudes up to 2000m, and in wide range of soil types although it performs poorly on poor sandy soils and poorly drained heavy clays. It grows best on well-drained fertile loams. In total, Kudzu is estimated to occupy over 3 million hectares in the eastern United States (Foresth and Innis 2004).

Range

Current range

Kudzu has a minor presence in New England (Frankel 1989), and is occasionally found across the Mid-Western states (Wiedenmann 2001). The plants most severe infestations occur in the piedmont regions of Mississippi, Alabama, and Georgia. Figure 1 shows Kudzu's range of distribution.

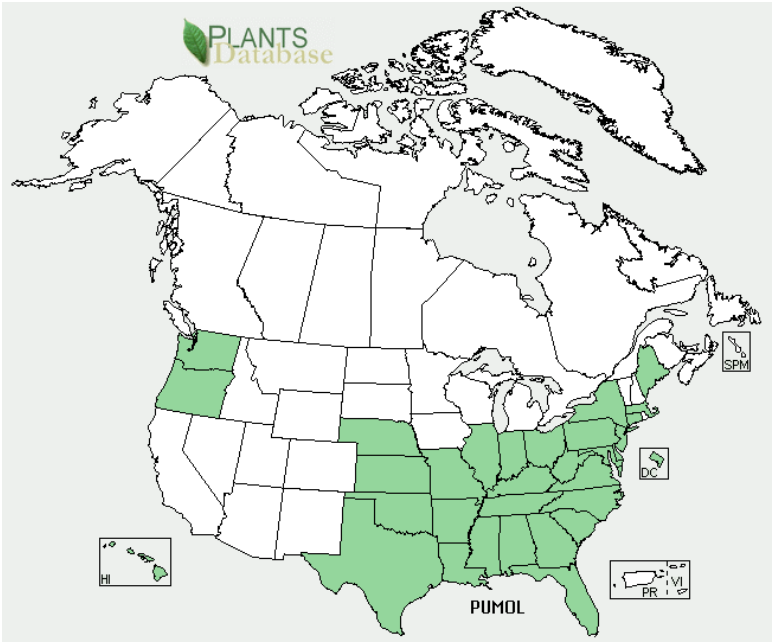

Figure 1. Current Distribution of *Pueraria Montana* in the United States (USDA, NRCS 2004).

Kudzu affects, or may potentially affect Army training lands in a number of locations; Kudzu has either been reported or has a high probability of occurring on 14 Army and two National Guard Tier 1 and 2 installations (DeNight and Busby 2007; Guertin and Tess 2006). This report considers only Tier 1 and 2 installations because those locations support the majority of training. The plant may also occur on several Tier 3 installations, especially in the Southeast. Tier 1 Installations are: Fort Bragg, Fort Hood, Fort Benning, Fort Polk, Fort Campbell and Fort Stewart. Tier 2 Installations: Fort Pickett, Camp Atterbury, Camp Blanding, Fort Knox, Fort Rucker, Fort Chaffee, Fort AP Hill, Fort Indiantown Gap, Fort Dix, Fort Jackson. The majority of these installations are in the Southeast.

Future range

It is common knowledge the Kudzu is a highly invasive in North America. Consequently, it is no longer planted for soil erosion or similar uses. With

numerous Federal and State prohibitions on cultivation; Kudzu is limited to vegetative expansion and to a minor degree through sexual reproduction. Given this, the plant would not be expected to expand rapidly outside its current range. Still, given its ability to rapidly spread within its current infestations, localized spread could be quite extensive. The current estimate of Kudzu spread within the Eastern Unites States is 50,000 hectares a year (Foresth and Innis 2004).

If current scientific theories on global change are accurate, long term trends in Kudzu spread may easily surpass 50,000 hectares a year. Anticipated changes in the Eastern United States include higher temperatures, higher CO_2 levels, and increased natural habitat fragmentation (Rogers and McCarty 2000). Kudzu's growth rate responds positively with increases in CO_2 (Sasek and Strain 1988 1989). Higher temperatures and their effects (including longer growing seasons and a warmer northern growing range) favor Kudzu's aggressive vegetative reproduction characteristics. Additionally, higher light zones of forest edges and disturbances associated with habitat fragmentation favor Kudzu.

3 Control and Management

Kudzu's large tuberous root structures and its ability to quickly refoliate after disturbance, make it extremely hard to exterminate. Eradication becomes more difficult with time as the plant develops large roots that store starch, which makes them more resilient to control (Miller and Boyd 1983; Foresth and Innis 2004).

Control strategies that frequently defoliate the plant and stress/deplete its roots are needed for success. Defoliation during the growing season will reduce plant vigor and stress starch reserves. Defoliation in the fall is important as Kudzu allocates few resources to root storage during the growing season; it allocates a majority of these resources near the end of the growing season.

Depending on the age and size of infestation, eradication could take as long as 10 years (Virginia Department of Conservation and Recreation 2001).

Mechanical

It is possible to control Kudzu through mowing and similar mechanical means. However, these methods of control can be difficult, and time and labor intensive. Moreover, Kudzu's roots and reproductive strategies are resilient to this disturbance (Foresth and Innis 2004). For successful eradication, Kudzu's extensive rooting structure and large tubers must be depleted. Additionally, cut materials must be removed and destroyed to counter the plant's ability to root from stem nodes and seed structures. To accomplish this, mowing must occur on a monthly basis for at least 2 years. Mechanical control can be cost and resource prohibitive for large tracts of land.

Burning

Burning during the fall and winter months in conjunction with chemical or mechanical treatments can be useful in promoting the seed germination of desirable plant species. Fire is unsuitable as a primary control method because Kudzu quickly sprouts from its root system and can easily reach prefire conditions in a short period of time (Radar and Harrington 1999).

Chemical

Kudzu's reproductive biology makes chemical control a potentially expensive method for control/eradication. The plants ability to root from stem nodes and the fragile nature of these nodes may require chemical applications for up to 10 years established population (Quimby, Jr. et al. 2003; Thomas 2000; Miller and Boyd 1983).

A wide array of chemicals is available for control. Chemical selection is largely based on user situation. Many good sources for chemical control recommendations exist, including university extension offices and state natural resource management agencies. Table 1 lists information reprinted from the University of Georgia, Warnell School of Forestry and Natural Resources, Center for Invasive Species and Ecosystem Health (http://www.bugwood.org). The table lists information covering many chemical agents and their applicability to a wide range of land management/Kudzu control scenarios. Many of these scenarios are similar to the land management needs of military installations encounter. Herbicides should be applied according to the manufacturer's Specimen Label approved by the U.S. Environmental Protection Agency (USEPA) and within the laws and regulations of all appropriate governing authorities.

Biological control

Insects

Insect herbivory and seed predation have a significant occurrence in Kudzu populations within the United States (Foresth and Innis 2004). Insects include a wide range of native and naturalized species (Britton et al. 2003), including sawflies, borers, weevils, and scarabs. In addition, two insect species from China (*Gonioctena tredecimmaculata* and *Ornatalcides trifidus*) have been studied in quarantine in the United States as potential biocontrol agents for Kudzu (Frye et al. 2007). However, both of these species have been shown to feed on soybean (*Glycine max* L.) and a native woodland plant, hog-peanut (*Amphicarpaea bracteata* L. Fernald). In host-range tests. Frye et al. (2007) concluded that the high economic importance of soybean in the United States will make it difficult to justify importing these insects for biological control of Kudzu. To date, there are no insect biological control agents approved for release in the United States to control Kudzu.

Table 1. Chemical agents and applicability to land management/Kudzu control scenarios.

Situation	Herbicide Formulation	Application Rate	Remarks and Precautions
Young Pine Stands	Metsulfuron methyl (Escort)	4 oz. per acre	May be applied over-the-top of pines which have been established for at least 1 year in the field. Use 30 gal of water per acre and add a non-ionic surfactant to ensure thorough wetting. Make application after full leaf expansion through September. Retreat with broadcast or spot treatments in subsequent years as needed.
	Metsulfuron methyl (Escort) + Imazapyr (Arsenal)	1 to 2 oz. per acre + 10 to 16 oz. per acre	For treatment of 1-year-old pines, use the 1 to 2 oz. rate of Escort + 10 oz. of Arsenal. Add a non-ionic surfactant (0.25%v/v). Apply in midsummer directing spray away from pine foliage when possible. For treatment of 2- to 4-year-old pines, use the 1 to 2 oz. rate of Escort + 16 oz. of Arsenal. Add a non-ionic surfactant ¼ to ½ percent in solution). Apply in early to midsummer directing spray away from pine foliage when possible. Some stunting of pine growth may occur with these treatments.
	Clopyralid (Transline)	21 oz. per acre	For use in spot applications in forestry on sites adjacent to right-of-ways or industrial areas. Add nonionic surfactant (¼ to ½ in solution). Apply in early to midsummer before Kudzu blooms, and apply in at least 100 gallons of water per acre to ensure thorough coverage. Backpack application: mix 4 oz. of Transline + 4 oz. of a nonionic surfactant in 4 gal of water.
Older Pine Stands	Triclopyr (Garlon 4) + Diesel fuel or Basal Oil	4 percent Garlon 4 in diesel fuel or basal oil	Spray on Kudzu vines that are running up tree trunks or hanging from limbs. Apply in winter to early spring before Kudzu growth begins. Pine trees 6 in. in diameter breast height should not be injured if mixture is sprayed on the bark. Do not spray into the foliage or smaller branches of pines. Hardwood stems are susceptible to this mixture.
	Clopyralid (Transline)	21 oz. per acre + 1 qt. per acre	If damage to adjacent trees and other woody plants can be tolerated, 1 qt. of Garlon 4 can be added to the 21 oz./ac rate of Transline in 100 gal of water to improve long term control. Backpack application: 4 oz. Transline + 4 oz. Garlon 4 + 4 oz. of a non-ionic surfactant in 4 gal of water.
	Metsulfuron methyl (Escort) + Glyphosate (Accord)	3 oz. per acre + 2 qts per acre	Apply to Kudzu growing in understory. Use a non-ionic surfactant, wait until full leaf development by Kudzu, apply through September. Direct spray away from pine foliage. Some stunting of pine growth may occur.

Situation	Herbicide Formulation	Application Rate	Remarks and Precautions
Streamsides, gullies, sensitive areas	Dicamba + 2,4-D (Banvel 720)	2-3 gals per acre	Do not spray herbicide directly into water or allow runoff to contaminate surface water. Do not apply in the root zone of desirable plants. Apply in August and September.
Open areas	Picloram (Tordon 101 M)	1-2 gals per acre	Broadcast herbicide in sufficient water to thoroughly wet the Kudzu mat. Apply in late May to September.
	Picloram (Tordon K)	0.5-1 gal per acre	Broadcast herbicide in sufficient water to thoroughly wet the Kudzu mat. Apply in late May to September.

Goats

Goats prefer broad leaf plants over grasses growing within the same area. Studies have found that repeated grazing over 2 to 4 years is sufficient to eliminate Kudzu populations (Miller and Boyd 1983; Luginbuhl et al. 1996; Randall 1996). Studies at North Carolina State University report that goat dietary habits shifted plant community components towards favorable grasses and legumes while eradicating Kudzu (Luginbuhl et al. 1996). The North Carolina results were the result of animal stocking rates of 30 goats/ha.

Although goat grazing is an effective means of controlling Kudzu in small areas, obtaining sufficient herds and funds to cover costs associated with herd maintenance may be prohibitive for treatment of large tracts of land. Additionally, high levels of hoof traffic may produce erosion concerns in some environments.

Fungal and bacterial agents

To date, the scientific literature identifies two agents, one fungal (*Myrothecium verrucaria* and *Colletotrichum gloeosporiodes*) and one bacterial (*Pseudomonas syringae* pv. p*haseolicola)*, that have been studied as possible bio-controls for Kudzu. All three of these pathogens are native to the United States however, only *Myrothecium verrucaria* has shown potential as a practical control strategy against Kudzu.

Myrothecium verrucaria (Albertini and Schwein.) Ditmar: Fr. (Moniliales)

This fungus has a wide range of hosts; among them are leafy spurge (Yang and Jong 1995), and sicklepod (*Senna obtusifolia* [L.] Irwin and Barneby)(Walker and Tilley 1997). Field tests in Mississippi demonstrated that the fungus attacks leaves and stems of Kudzu and that 95 to 100 per-

cent control could be achieved within 14 days of inoculation. In inoculation studies, a surfactant was needed to obtain good infection (Boyette 2000). Research by Weaver and Lyn (2007) demonstrated that *M. verrucaria* is compatible with the herbicides aminopyralid, metsulfuron, and low rates of flyroxypyr and thus may be incorporated into an integrated management program for Kudzu. Currently, this fungal pathogen is being developed as a bioherbicide for Kudzu and other invasive vines (Weaver and Lyn 2007). A potential drawback with *M. verrucaria* is that it produces secondary metabolites or mycotoxins known as macrocyclic trichothecenes that are highly toxic to mammals (Boyette et al. 2007; Anderson and Hallett 2004; Quimby, Jr. et. al. 2003). However, these mycotoxins reportedly are not produced *in planta* (Weaver and Lyn 2007). Research is currently ongoing to eliminate or reduce mycotoxin production of *M. verrucaria* using inhibitors, mutant selection, and cultural methods (Hoagland et el. 2007; Abbas et al. 2001). These findings may improve the probability of EPA registration and commercial development of *M. verrucaria* as a bioherbicide for Kudzu.

Pseudomonas syringae pv. Phaseolicola

The bacterium that causes “halo blight” in beans also affects Kudzu. The blight will cause mortality in Kudzu seedlings under 10 weeks old; however, the disease is not fatal to mature plants, which can readily recover (Zidak and Backman 1996).

Colletotrichum gloeosporiodes (Penz.) Penz. and Sacc. in Penz. (Sphaeriales)

A strain of this widely-distributed fungal pathogen was isolated from Kudzu in Georgia. The fungus attacks both leaves and vines, and produces asexual spores in a pycnidium. Field studies showed a synergistic effect when combined with the herbicide Dicamba (Farris and Reilly 2000).

Mission impacts

Kudzu forms large lush green tangles of foliage that can cover large areas of ground and extend high into tree tops. Kudzu can directly impact the training mission in that vegetative cover interferes with dismounted troop movements and training equipment that requires a direct line of sight (i.e., lasers). Foliage can easily cover tree stumps, ditches, and other obstacles that could cause damage or injury to equipment or personal traversing an area. An example of this is the loss of a helicopter landing site at Fort Pickett, VA. where Kudzu had overgrown uneven ground in the area mak-

ing landings hazardous (Personnel Communication. 20 May 2008, Amy O. Hayne, VAARNG-FM-E).

In addition, Kudzu's vining stems can tangle in axles and other equipment impeding vehicle movement. Damage to vines from these activities can assist the plant in further spread with an area as it facilitates the plants major mode of reproduction.

Indirectly, Kudzu can impact the training mission through its ability to damage sensitive habitat and degrade installation infrastructure. Although no studies have been conducted to quantify a problem, Kudzu occurs on several installations that have threatened or endangered species (TES) (Guertin and Tess 2006). Kudzu's aggressive growth form will dominate habitats; altering soils, plant structure and species composition. This leads to a real possibility of damaging environments that support TES populations. In turn, this may affect training as TES preservation can directly conflict with lands for training. Additionally, Kudzu vines and foliage can engulf parking lots, buildings, power lines, and other infrastructure. The plant forms dense vegetative mats that trap moisture and may accelerate the deterioration of concrete and masonry. The vines can also interfere with the operation of power lines and similar structures.

University/agency research/control points of contact

A wide array of institutions, both university and government, have experience in Kudzu control and research. For current control technologies university extension offices and state natural resource offices in the locality of interest should be contacted.

A list of notable Points of Contact for various control/research issues follows.

Long-term research (genetics)

Dr. Rodney Mauricio
University of Georgia

Dr. Rodney Mauricio is currently involved in a 5-year study to look at genetic basis for invasiveness of species introduced from China. The study includes Kudzu. UGA-China PIRE Home Page

Myrothecium verrucaria as a biocontrol:

Douglas Boyette
USDA-ARS
Southern Weed Science Research Unit,
P.O. Box 350, Stoneville, MS 38776; phone (662) 686-5217.

General Kudzu control

Dr. James Miller
U.S. Forest Service
Auburn University, AL
334-826-8700

Dr. Miller has almost 20 years experience in research and control of Kudzu. He has written on several control topics including chemical, mechanical, and goats.

Goat control

Dr. Errol G. Rhoden 303 Milbank
Tuskegee Institute
Tuskegee, AL
334/727-8435

4 Summary

This work has provided a snapshot of current research and scientific knowledge related to the invasive plant species Kudzu (*Pueraria montana*), its impact on the Army, and a concise representation of control technologies for military land managers.

Kudzu was introduced into the United States at the 1876 Centennial Exposition as an ornamental plant. By the 1930s it was widely used for erosion control in the Southeast United States. A lack of natural pathogens and predators, coupled with Kudzu's ability to grow at rapid rates made the plant a nuisance species by the mid-1950s and caused it to be Federally listed as a noxious weed in 1977.

P. montana is a hardy plant; it occurs in untended fields, forests, roadsides, pastures and a variety of similar sites. Its ability to fix nitrogen gives the plant a competitive advantage in disturbed or low quality sites and its deep roots makes it drought resistant. In total, Kudzu is estimated to occupy over 3 million hectares in the eastern United States.

Successful control strategies must frequently defoliate the plant and stress/deplete its roots. Effective control of Kudzu requires persistent effort and a determined management plan that may include one or a combination of several methods:

1. Mechanical control
2. Fire management
3. Chemical control (herbicides)
4. Biological control (fungi or insects)
5. Prescribed grazing.

Kudzu can directly impact the training mission in that vegetative cover interferes with dismounted troop movements and training equipment that requires a direct line of sight (i.e., lasers). Foliage can easily cover tree stumps, ditches and other obstacles that could cause damage or injury to equipment or personal traversing an area. Kudzu's vining stems can tangle in axles and other equipment impeding vehicle movement. Damage to vines from these activities can assist the plant in further spread with an area as it facilitates the plants major mode of reproduction.

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14. ABSTRACT

A 2007 Report to Congress documented a crucial factor in the loss of Army training land: uncontrolled vegetation growth. Of the 53 installations surveyed for the report, 30 reported that approximately 12 percent of their training lands were unusable for certain types of training. Uncontrolled vegetation was a source of such problems as an inability to conduct mounted and dismounted maneuver training, interference with equipment used in line-of-sight training, safety issues, and damage to equipment and structures. Of the 11 plant species (or groups) identified by installations as "uncontrolled vegetation," six were invasive plants, of which the two invasive plants most commonly identified were Kudzu (Pueraria montana) and Multiflora Rose (Rosa multiflora). This work provides a snapshot of current research and scientific knowledge related to the invasive plant species Kudzu, its impact on the Army, and a concise representation of control technologies for military land managers.

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