# The Green Monster and the Carbon Engine: *Pueraria montana* (Kudzu) as a Climate-Amplified Invasive Species, Biogeochemical Disruptor, and Emerging Threat to North American Ecosystems

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**Abstract**

*Pueraria montana* var. *lobata* (Willd.) Maesen & S. Almeida (kudzu) represents one of the most consequential biological invasions in North American environmental history. Originally introduced at the 1876 Philadelphia Centennial Exposition and later promoted by the U.S. government as a soil-erosion control during the Dust Bowl era, kudzu has escaped its intended ecological role to become a pervasive ecological disruptor across the southeastern United States. This review synthesises contemporary evidence demonstrating that the ongoing climate crisis is not merely a passive backdrop to kudzu's expansion, but is actively functioning as a *biological accelerant*. Elevated atmospheric $CO_2$ concentrations enhance kudzu's growth and water-use efficiency, reduced winter temperatures allow northward range expansion, and the vine's nitrogen-fixing capacity induces soil biogeochemical transformations that produce nitrous oxide ($N_2O$) — a greenhouse gas approximately 300 times more potent than $CO_2$. Annual damages are estimated to exceed $500 million USD. We discuss historical context, invasion ecology, biogeochemical feedbacks, eradication strategies, and emerging bioenergy valorisation pathways, concluding that kudzu epitomises a positive climate–invasion feedback loop with significant implications for global carbon accounting and ecosystem management.

**Keywords:** *Pueraria montana*; kudzu; invasive species; $CO_2$ fertilisation; nitrogen cycling; climate change; biogeochemical feedback; southeastern United States.

## 1. Introduction

The ecological history of *Pueraria montana* var. *lobata* — universally known as kudzu — is a cautionary tale about the unintended consequences of human intervention in natural systems, compounded by a rapidly changing climate. A fast-growing, nitrogen-fixing, leguminous vine indigenous to Japan and China, kudzu was introduced into the United States in 1876 as an ornamental curiosity. It was then systematically deployed by federal policy during the 1930s Dust Bowl era to combat soil erosion, with the U.S. Soil Conservation Service paying farmers up to $8 per acre to plant it [1]. The result was the establishment of a biological invasion now covering an estimated 3 million hectares across the eastern United States, expanding at approximately 50,000 ha per year [1].

For decades, kudzu was dismissed — particularly outside the American South — as a regional management failure, a punchline about Southern lethargy rather than a serious ecological threat. That dismissal is increasingly untenable. The convergence of rising atmospheric $CO_2$, warming winters, and the plant's unique physiology has transformed kudzu from a regional pest into a continent-wide biogeochemical hazard. Research published in the *Proceedings of the National Academy of Sciences* confirmed that kudzu invasion doubles soil nitric oxide (NO) emissions and contributes to increased tropospheric ozone [2]. Clemson University researchers found that kudzu invasion releases an estimated 4.8 metric tons of carbon annually from native soils [4]. And projections under IPCC climate scenarios predict that kudzu's range will extend several hundred kilometres northward by 2050 [3].

This paper synthesises the ecological history, invasion physiology, biogeochemical impacts, eradication challenges, and future management trajectories of kudzu in the context of contemporary climate change. We argue that kudzu constitutes a paradigmatic example of a *climate–invasion positive feedback loop*: the same anthropogenic forcing that drives climate change simultaneously fuels the biological invasion, which in turn produces greenhouse gas emissions that exacerbate the original forcing.

## 2. Historical Context and Invasion Pathway

### 2.1 The Philadelphia Exposition, 1876

The invasion of kudzu into North America was not accidental in the conventional sense. It was invited. At the 1876 Philadelphia Centennial Exposition, the Japanese government constructed an elaborate garden exhibit showcasing the vine's lush, fast-growing foliage and striking purple flowers. American horticulturalists and nursery operators were immediately captivated, and commercial propagation began within years of the exhibition. Kudzu was marketed as an ornamental shade plant for Southern porches and sold widely throughout the late nineteenth century, without any ecological risk assessment [1].

### 2.2 Government-Sponsored Propagation (1930s–1950s)

The catastrophic soil erosion of the Dust Bowl era created political urgency for a rapid erosion-control solution. Kudzu, with its prodigious biomass production and deep root system, appeared ideal. The Civilian Conservation Corps planted more than 70 million seedlings across the South, and the federal Soil Conservation Service operated an incentive programme paying landowners to establish kudzu monocultures. Kudzu clubs were formed, community festivals celebrated "Kudzu Queens," and agricultural extension services distributed informational pamphlets extolling the plant's virtues [8].

Critical ecological questions went unasked. In its native range in East Asia, kudzu faces a suite of co-evolved herbivores, fungal pathogens, and climatic stressors — particularly hard frosts — that limit its expansion. The warm, humid climate of the American South, combined with an absence of natural enemies, created the conditions for exponential population growth. By the 1950s, the vine had escaped agricultural fields and was visibly engulfing forests, telephone poles, farm buildings, and entire landscape features. In 1970, the U.S. Environmental Protection Agency officially declared kudzu a weed; in 1997, it was listed among Federal Noxious Weeds [1]. By that point, however, the invasion was beyond containment.

### 2.3 Growth Rates and Competitive Physiology

Kudzu's invasive success is rooted in a suite of exceptional physiological traits. Elongation rates under optimal conditions can reach 30 cm per day, with individual stems extending up to 20–30 m during a single growing season [6]. High leaf area indices and elevated photosynthetic rates allow the vine to rapidly overtop and shade native vegetation, effectively cutting off light to any plant growing beneath it. As a legume, kudzu harbours symbiotic *Bradyrhizobium* bacteria in root nodules capable of fixing atmospheric nitrogen, conferring a nutritional independence that most competing plants lack [2].

A key survival adaptation is the production of massive root tubers — starchy, carbohydrate-rich underground storage organs that can weigh up to 180 kg and extend 2–3 metres into the soil profile. These tubers function as biological batteries: even when above-ground biomass is completely destroyed by cutting, burning, or herbicide application, the tubers retain sufficient energy reserves to regenerate the entire plant multiple times [1].

## 3. Climate Change as a Biological Amplifier

### 3.1 $CO_2$ Fertilisation Effects

Perhaps the most alarming dimension of the contemporary kudzu crisis is the direct role of anthropogenic $CO_2$ emissions in accelerating the invasion. The basic biochemistry of photosynthesis means that rising atmospheric $CO_2$ acts as a fertiliser for plant growth, but not all plants respond equally. Meta-analyses consistently demonstrate that invasive vine species, and particularly nitrogen-fixing legumes, show substantially larger and more sustained growth responses to elevated $CO_2$ than native trees [3].

Sasek and Strain [5] were among the first to predict that kudzu's distribution would expand significantly under elevated $CO_2$ and warming climates. Subsequent experimental studies confirmed that kudzu's growth rate *increases strongly* in response to increased $CO_2$, and that, without the constraint of allocating resources to woody tissue (as trees must do), this response markedly increases kudzu's competitive dominance [1]. Under enriched $CO_2$ regimes, kudzu can reduce stomatal aperture while still assimilating sufficient carbon — a physiological strategy that dramatically improves water-use efficiency. In drought conditions that stress native species, kudzu thus retains a competitive advantage.

### 3.2 Northward Range Expansion

Vines are physiologically vulnerable to freezing embolisms — the formation of ice crystals in xylem vessels that disrupts water transport and can be lethal. Historically, this cold sensitivity constrained kudzu's northern limit to approximately the 0°C mean winter temperature isotherm [3]. As climate change shortens winters, reduces frost frequency, and shifts isotherms northward, this geographical barrier is dissolving.

Contemporary observations confirm that kudzu is now established in Illinois, Pennsylvania, Oregon, Massachusetts, Connecticut, and New Jersey — states previously considered climatically inhospitable [8]. Climate envelope modelling under the IPCC A1B scenario ($CO_2$ reaching 522 ppm by 2050) projects the invasion front advancing several hundred kilometres northward, bringing kudzu's biogeochemical effects to Mid-Atlantic and Great Lakes ecosystems that currently lack invaded-area experience [3].

### 3.3 Interaction Between $CO_2$ Enrichment and Nitrogen Fixation

The interaction between elevated $CO_2$ and kudzu's nitrogen-fixing capacity creates a particularly potent syn-

ergy. Under enhanced $CO_2$, nitrogen fixation rates in legumes typically increase as carbon availability expands the metabolic capacity to support *Bradyrhizobium* symbionts [3]. This means that as kudzu grows faster on anthropogenic $CO_2$, it simultaneously injects more nitrogen into invaded soils. The combined effect accelerates the cascade of biogeochemical transformations described in the following section.

## 4. Biogeochemical Disruption

### 4.1 Nitrogen Cycling Transformation

Kudzu's nitrogen-fixing leguminous nature fundamentally reshapes the nutrient dynamics of invaded ecosystems. Studies using paired invaded/uninvaded plot designs in Madison County, Georgia found that kudzu invasion approximately doubles soil nitric oxide (NO) emissions relative to uninvaded adjacent soils [2]. This occurs because the elevated nitrogen deposition from kudzu litter — which contains more nitrogen than litter from co-occurring native species — stimulates microbially mediated nitrification and denitrification processes that produce both NO and $N_2O$ [3].

The nitrogen bomb effect also has secondary ecological consequences. Native plant communities of the southeastern United States are frequently adapted to nitrogen-poor soils. When kudzu enriches soils with excess nitrogen, competitive dynamics shift in favour of nitrogen-demanding weedy species, further disadvantaging native flora [3]. Even after kudzu is physically removed, the altered soil chemistry persists, making restoration of native plant communities profoundly difficult.

### 4.2 Nitrous Oxide Production and Climate Feedback

The most climatologically significant biogeochemical effect of kudzu invasion is the production of nitrous oxide ($N_2O$). Under the coupled conditions of high soil nitrogen (from fixation) and elevated $CO_2$ (from the atmosphere), soil microbial communities produce $N_2O$ at substantially elevated rates. $N_2O$ is a greenhouse gas with a global warming potential (GWP) approximately 298 times greater than $CO_2$ over a 100-year timescale [2].

This creates a direct positive feedback loop: anthropogenic $CO_2$ emissions accelerate kudzu growth; kudzu's enhanced nitrogen fixation enriches soils; enriched soils under elevated $CO_2$ produce more $N_2O$; $N_2O$ further amplifies radiative forcing. The vine effectively converts the waste products of fossil fuel combustion into an even more potent greenhouse gas.

### 4.3 Tropospheric Ozone Generation

Beyond greenhouse gas production, kudzu has a documented impact on regional air quality through the emission of isoprene and the aforementioned nitric oxide. Isoprene, a volatile organic compound emitted in large quantities by kudzu foliage, reacts photochemically with NOx in the troposphere to produce ozone ($O_3$). A joint study by researchers at Stony Brook University, Harvard University, and the University of Virginia demonstrated that kudzu invasion is responsible for a 50% increase in the number of days per year that ozone concentrations exceed EPA unhealthy thresholds in invaded Georgia sites [8]. Regional atmospheric modelling using GEOS-Chem confirmed that widespread kudzu expansion would materially increase ozone events across the U.S. Southeast, potentially offsetting gains from automotive emissions regulations [2].

### 4.4 Soil Carbon Destabilisation

Despite being a photosynthetically active plant that fixes carbon dioxide, kudzu may function as a net carbon source rather than a carbon sink at the ecosystem level. Research from Clemson University found that kudzu invasion destabilises native soil carbon pools, releasing stored organic carbon to the atmosphere [4]. Kudzu's nitrogen-rich litter decomposes rapidly, stimulating microbial activity that consumes and mineralises the stable organic matter previously sequestered under native vegetation. Tharayil estimated that kudzu invasion releases approximately 4.8 metric tons of carbon annually from invaded soils in the United States alone — equivalent to the carbon stored in 11.8 million acres of forest [4].

The result is that the "green" appearance of kudzu-covered landscapes masks a significant net contribution to atmospheric greenhouse gas concentrations. As one ecologist noted, kudzu may be "as close to a 'polluting plant' as one can find" [2].

### 4.5 Summary of Biogeochemical Impacts

Table 1 summarises the primary biogeochemical impacts identified in the peer-reviewed literature.

## 5. Eradication Challenges

### 5.1 Mechanical Control

The most intuitive response to kudzu — mechanical removal — is also the most problematic. Kudzu's fibrous, rope-like vines rapidly foul cutting equipment, wrapping around drive shafts and clogging motors. More critically, the plant's capacity for vegetative propagation from stem nodes means that mowing or chopping operations effectively fragment the vine into thousands of propagules, each capable of establishing a new plant. Rather than reducing kudzu populations, mechanical disturbance can paradoxically increase propagule pressure [1].

Table 1: Primary biogeochemical impacts of *Pueraria montana* invasion. GWP: Global Warming Potential relative to $CO_2$ over 100 years.

| Impact | Evidence / Magnitude |
|---|---|
| NO emissions | Doubled in invaded vs. uninvaded soils (Madison Co., GA) |
| $N_2O$ production | Elevated; GWP $\approx 298\times$ $CO_2$ |
| Tropospheric $O_3$ | +50% unhealthy ozone days in Georgia sites |
| Soil C release | $\approx 4.8$ Mt C $yr^{-1}$ nationally |
| Isoprene emission | High; key $O_3$ precursor |
| N soil enrichment | Excess N deposition disables native flora |
| Economic cost | >$500 million USD $yr^{-1}$ |

### 5.2 Fire

Prescribed burning has been explored as a control mechanism. Dried kudzu biomass ignites readily and burns at high intensity. However, fire destroys only above-ground tissues; the massive root tubers, insulated by 2–3 m of soil, survive unharmed. Post-fire regrowth is vigorous — often described by land managers as appearing more aggressive than pre-burn growth, likely because root tuber reserves are undiluted by above-ground biomass and can fuel rapid sprouting. Fire thus imposes a management cost without producing lasting control [1].

### 5.3 Herbicide Application

Systemic herbicides — particularly picloram, trichlopyr, and metsulfuron methyl — have proven the most effective tools for kudzu management when applied correctly and repeatedly [1]. However, efficacy requires multiple growing seasons of treatment, as the tubers' energy reserves sustain regrowth after initial foliage death. Furthermore, there are emerging indications, consistent with plant signalling research in the field of plant neurobiology, that kudzu populations may exhibit coordinated responses to chemical stress, with rapid stomatal closure and root retraction reducing herbicide uptake following initial exposures. The long-term ecological costs of repeated large-scale herbicide application — including non-target species mortality, soil microbiome disruption, and groundwater contamination — are substantial.

### 5.4 Biological Control

Several insect species that prey on kudzu in its native Asian range have been investigated as potential biocontrol agents, including the kudzu bug (*Megacopta cribraria*), which was accidentally introduced to the United States in 2009 and has shown some suppressive effect on kudzu vine density in Georgia and South Carolina. However, *M. cribraria* has also become an agricultural pest attacking soybeans, illustrating the risks inherent in biological control introductions [1].

Grazing by goats has demonstrated effectiveness in reducing above-ground kudzu biomass, particularly in areas inaccessible to machinery. Goats consume foliage down to the stem repeatedly, eventually depleting tuber energy reserves after several years of sustained grazing. This approach requires continuous animal presence over multi-year timeframes and is not scalable to landscape-level management.

## 6. Economic and Infrastructure Impacts

Kudzu's economic footprint is substantial and multifaceted. Direct agricultural losses from productive land conversion to kudzu monoculture, combined with control expenditures, generate annual losses estimated in excess of $500 million USD [1]. Forests shaded by kudzu experience elevated tree mortality rates as photosynthetically active radiation is intercepted before reaching native canopy layers, with knock-on effects for timber production and ecosystem services.

Infrastructure vulnerability is particularly acute in transportation networks. Kudzu growth on railway rights-of-way creates two independent hazards. First, vines climbing signal posts and gantries can physically obscure safety signals. Second, and more insidiously, vines growing across rails are crushed by passing trains, releasing a sap that acts as a lubricant on steel rails, reducing wheel-rail adhesion and degrading braking effectiveness. Documented railway incidents attributable to kudzu-related rail contamination have been recorded in the southeastern United States. Electrical transmission infrastructure faces analogous risks, with vines creating short-circuit pathways across insulators.

Urban and suburban real estate markets in the Southeast discount property values in kudzu-invaded areas, though quantification of this effect at the aggregate level remains methodologically challenging.

## 7. The Northward Advance and Its Implications

The geographic restriction of kudzu to the warm Southeast was long regarded as a natural buffer protecting temperate ecosystems to the north. This perception has been fundamentally revised. Warmer winters associated with climate change have already enabled kudzu establishment in states including Illinois, Pennsylvania, Oregon, New York, Massachusetts, and Connecticut. Cold-resistant ecotypes, whether through phenotypic plasticity or genetic adaptation to northern conditions, are documented [8].

Hickman et al. [3] examined kudzu's biogeochemical impacts in the Mid-Atlantic region — near the current northern invasion front — and confirmed that effects on nitrogen cycling and trace gas emissions in these newer in-

vasion zones are qualitatively similar to those in the established Southeast, though contextual differences in soil type, microbial community composition, and native vegetation affect the precise magnitude of impacts. Critically, the study concluded that preventing establishment of kudzu in northern ecosystems is essential: once the vine establishes and alters soil chemistry, the ecological baseline cannot be readily recovered.

Climate projections consistently indicate that the zone of kudzu suitability will continue expanding northward and to higher elevations through the twenty-first century, with the rate of expansion linked to the trajectory of global $CO_2$ emissions [5, 3].

## 8. Valorisation and Management Horizons

### 8.1 Bioenergy Potential

The same qualities that make kudzu ecologically problematic — rapid biomass accumulation, efficient resource use, perennial growth — make it theoretically attractive as a bioenergy feedstock. Lee et al. [6] demonstrated that $CO_2$-cofed pyrolysis of kudzu vine biomass can produce syngas enriched in carbon monoxide while achieving net carbon emission reductions of up to 2.96 g $CO_2$ per gram of processed biomass. This approach uses $CO_2$ as a reactive co-feed agent, creating a conceptually circular system in which the vine's atmospheric $CO_2$ uptake is partially recycled into energy.

The sustainability of kudzu bioenergy is, however, contingent on supply chain management that avoids incentivising further expansion of the plant's range. Harvesting operations must be conducted in ways that do not serve as vectors for propagule dispersal. Lifecycle analyses incorporating soil carbon destabilisation effects are needed to validate the net greenhouse gas benefit of kudzu bioenergy at scale.

### 8.2 Integrated Management

Contemporary kudzu management best practice involves the integrated application of multiple strategies: systematic herbicide treatment over multiple seasons, targeted mechanical removal in early-invasion zones, sustained goat grazing programmes, and early-detection surveillance at the invasion frontier [1]. The phase of eradication has effectively ended for most of the established range; the operational objective has shifted to population suppression and range containment.

## 9. Discussion: The Kudzu Paradox

The kudzu case crystallises a broader paradox in environmental science. The organism responds optimally to the conditions produced by the economy whose infrastructure it damages. Every tonne of $CO_2$ emitted by an automobile in New York or a power plant in Los Angeles becomes biological fuel for a vine strangling a forest in Alabama. Every warming winter extends the vine's territorial reach northward. The plant did not evolve these traits as weapons; they are simply adaptive responses to resource availability. Yet the outcome is a system in which anthropogenic environmental modification accelerates its own disruption.

Importantly, the communities that bore the brunt of kudzu's early expansion — rural Southern farmers and landowners — were often dismissed by outside observers as incompetent when in fact they were contending with a genuinely novel ecological challenge, one that was aggravated by precisely the emissions produced by the industrial centres that were doing the dismissing. The Alabama paradox is not one of Southern agricultural failure; it is one of systemic ecological feedback that was invisible until it became inescapable.

The discovery that kudzu invasion transforms managed soils into net greenhouse gas emitters also has implications for national carbon accounting. Invasive species effects on soil carbon stocks are frequently omitted from greenhouse gas inventories. If kudzu alone releases 4.8 Mt of soil carbon annually, the omission is material.

## 10. Conclusions

*Pueraria montana* var. *lobata* is not a regional curiosity or a management embarrassment. It is a sophisticated organism exploiting, with ecological precision, the exact conditions produced by industrialised society. The evidence reviewed here supports the following conclusions:

1. Elevated atmospheric $CO_2$ functions as a **biological accelerant** for kudzu, enhancing growth rates, water-use efficiency, and competitive dominance over native species.

2. Kudzu invasion produces a **positive biogeochemical feedback**: nitrogen fixation combined with elevated $CO_2$ drives soil $N_2O$ emissions, amplifying the greenhouse effect that enables the invasion.

3. Climate warming is **dissolving the geographic barriers** that historically confined kudzu to the American South, with credible establishment now documented in numerous northern states.

4. The economic and infrastructure costs of invasion **exceed $500 million USD annually** and are likely to grow as the invaded range expands.

5. Eradication is no longer operationally feasible for the established range; **adaptive management** strategies combining herbicide, biological control, and early-detection surveillance represent current best practice.

6. Emerging **bioenergy valorisation pathways**, particularly $CO_2$-cofed pyrolysis, offer a potentially circu-

lar approach to managing kudzu biomass while recovering energy, but require rigorous lifecycle validation.

Kudzu serves as an ecologically legible signal of a broader systemic reality: that invasive species crises and climate crises are not parallel problems but deeply entangled ones, sharing drivers, feedbacks, and, ultimately, solutions.

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## Author Contributions

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## Conflicts of Interest

The author declares no conflict of interest.

## References

## References

[1] Forseth, I.N., & Innis, A.F. (2004). Kudzu (*Pueraria montana*): History, physiology, and ecology combine to make a major ecosystem threat. *Critical Reviews in Plant Sciences*, 23(5), 401–413.

[2] Hickman, J.E., Wu, S., Mickley, L.J., & Lerdau, M.T. (2010). Kudzu (*Pueraria montana*) invasion doubles emissions of nitric oxide and increases ozone pollution. *Proceedings of the National Academy of Sciences*, 107(22), 10115–10119.

[3] Hickman, J.E., Ashton, I.W., & Lerdau, M.T. (2013). Biogeochemical impacts of the northward expansion of kudzu under climate change: The importance of ecological context. *Ecosphere*, 4(11), 1–15.

[4] Tharayil, N. (2014). Kudzu can release soil carbon, accelerate global warming. *ScienceDaily* / Clemson University Research Communication. Retrieved from https://www.sciencedaily.com/releases/2014/07/140701145720.htm

[5] Sasek, T.W., & Strain, B.R. (1990). Implications of atmospheric $CO_2$ enrichment and climatic change for the geographical distribution of two introduced vines in the USA. *Climatic Change*, 16, 31–51.

[6] Lee, T., Moon, G., Lee, D., & Chen, W.H. (2025). Carbon emission mitigation from the $CO_2$-cofed pyrolysis of invasive biomass: A case study on kudzu (*Pueraria montana*). *Energy Conversion and Management*, in press.

[7] Bradley, B.A. (2025). How will climate change affect the spread of invasive species? *Cool Green Science* / The Nature Conservancy. Retrieved from https://blog.nature.org/2025/01/12/how-will-climate-change-affect-the-spread-of-invasive

[8] IEDRO (2021). Climate change and invasive plants. International Environmental Data Rescue Organization. Retrieved from https://iedro.org/articles/climate-change-and-invasive-plants/

[9] Callen, A., & Miller, A. (2024). Kudzu invasion and its influential factors in the southeastern United States. *International Journal of Applied Earth Observation and Geoinformation*, 127, 103656.