**Imperata cylindrica**: reproduction, dispersal, and controls

Muhammad Rusdy*

**Address:** Laboratory of Forage Crops and Grassland Management, Faculty of Animal Sciences, Hasanuddin University, Makassar 90245, Indonesia.

ORCID information: Muhammad Rusdy (orcid: 0000-0002-2731-9383)

*Correspondence:* Muhammad Rusdy. Email: muhrusdy79@yahoo.co.id

Received: 15 May 2019

Accepted: 20 May 2020

doi: 10.1079/PAVSNNR202015038

The electronic version of this article is the definitive one. It is located here: http://www.cabi.org/cabreviews

© CAB International 2020 (Online ISSN 1749-8848)

**Abstract**

*Imperata cylindrica* is one of the 10 worst weeds in the tropics and subtropics. Although it has many beneficial uses, the problems related to its invasiveness far outweigh its positive benefits. *I. cylindrica* negatively affects production of annual, perennial, plantation, and forest crops. Its mode of reproduction fosters its extensive growth and very persistent nature because of its high competitive ability in a wide range of habitats. Control efforts for *I. cylindrica* consist of prevention, cultural, mechanical, biological, and integrated approach. All control methods are not cost effective and require careful planning to achieve the desired outcome. Currently, good control can be achieved by integrating cultural, mechanical, and chemical methods, but long term of management control must involve sustainable strategies such as biological control and revegetation practices.

**Keywords:** Imperata, reproduction, dispersal, control

**Review methodology:** Recently, published literature in Google Scholar, CAB Abstracts, Scopus, PubMed, Crossref, and Web of Science using the keywords *Imperata*, distribution, reproduction, dispersal, and management was searched from March 2019 to January 2020. We also used the synonym and antonym of these words for searching other relevant literature. Of about 200 articles read, we selected 85 for review. We also observed the growth of *Imperata* in the field at different environmental conditions and asked the farmers and colleagues for their knowledge concerning the subject.

**Introduction**

*Imperata cylindrica* (hereafter is called *Imperata*) is an aggressive, rhizomatous tropical grass native to southeast Asia, Australia, China, Japan, the Philippines, and the East Africa [1]. It consists of five varieties, that is, var. *major* is found in tropical Asia, var. *africana* is from Africa, var. *europaea* is found in Mediterranean region, var. *condensata* is native to coastal region of Chile/Argentina, and var. *latifolia* occurs in India [2]. Chromosome number varied with variety: $2n = 20$ for var. *major*, $2n = 40$ for var. *europaea*, and $2n = 60$ for var. *africana* [3].

*Imperata* is widely distributed throughout the tropics and subtropics and has spread to some warm parts of the temperate regions of the world, except Antarctica [4, 5], at altitude from sea level to 2700 m and rainfall from 500 to 5000 mm/year [6]. It is found in wide range of habitats, such as cultivated crops, plantations, deforested areas, abandoned farm lands, and recreational areas, but it mostly invades grassland where slash and burn agriculture are widely practiced [7]. *Imperata* grasslands are common in Asia; it occupies about 35 million ha, the largest area was occurring in Indonesia (8.5 million ha), followed by India (8 million ha) that occupies both fertile and infertile soils [8]. In the southeastern of USA, this grass has invaded nearly 500,000 ha of land [5].

*Imperata* can be used for many purposes. In many developing countries, the leaves and stems are widely used as thatch, for making hats, basket, rope, paper; energy sources; and medicinal purposes. It also is used for mulching, livestock bedding, erosion control, and stabilizing slopes. In many parts of the tropics, *Imperata* is commonly used as animal feed. However, its nutritive value is only high when it is young, and productivity of animals grazing on solely *Imperata* stand is commonly low [9].

Although *Imperata* has many beneficial uses, its harmful effects far outweigh its positive attributes. It is generally...
recognized as a weed, and for this reason, the main emphasis of research has been on its control or eradication [7]. *Imperata* is classified as noxious weed in more than 70 countries [4] due to its ability to successfully disperse, colonize, compete with, and displace desirable vegetation and disrupt ecosystem over a wide range of environmental conditions. It constitutes a significant threat to global diversity and sustainable agriculture [10]. *Imperata* is rated as the world’s seventh worst weed [6, 11].

The negative effects of *Imperata* on plantation crops have been reported elsewhere. It retards the growth of plantation crops such as teak, cocoa, coffee, oil palm, cocoa, rubber [6, 12], and *Pinus taeda* [13]. Yields of annual crops are also severely reduced by *Imperata* infestations. Its harmful effects have been documented in upland rice [14], cassava [15], maize [16], soybean [17], and so on. These losses are due to its higher competitive ability for plant growth resources and its allelopathic properties [18, 19].

Besides reducing crop yields, *Imperata* infestation also increases cost of control and decreases market value of tuber crops due to physical injury when rhizome tips penetrate the roots of tuber crops. Because of its inflammability, *Imperata* increases the risk of fire in perennial crops, plantation, and forest plants. Recurrent burning has converted million hectares of tropical forest to *Imperata* dominated grassland [20] and causes considerable losses of organic matter and soil nutrients, which result in soil degradation [21].

*Imperata* control has been the subject to several reviews [4, 12, 20, 21]. In general, *Imperata* is pernicious weed that is difficult to control, but there have been several recent advances on its control. The objective of this paper was to review the literatures concerning reproduction and dispersal of *Imperata* and examine the latest research efforts to control it.

**Reproduction and dispersal**

*Imperata* reproduces sexually by seeds and asexually by living rhizome extension fragment propagation. Seed reproduction enhances long-distance dispersal and colonization, while rhizome extension promotes short distance spread and population expansion [22]. Transportation of rhizome fragments to other places contributes to long-distance dispersal. Rhizomes are the main organ, which enable *Imperata* to be an aggressive and invasive weed. Several characteristics that make this plant extremely invasive are: (1) it can produce up to 3000 seeds per plant; (2) it has very light seeds that can disperse over long distances; and (3) it has very rigorous rhizomes that allow it to survive during adverse environmental conditions and aid its rapid spread within short distances [23].

In the tropics and subtropics, flowering occurs throughout the year after *Imperata* is exposed to stress such as burning, overgrazing, or frequent slashing [21], and these may encourage the spread of the plant. *Imperata* can only produce viable seeds through cross-pollination [24]. It is a prolific seed producer, one panicle can produce about 700 [25] to 3000 seeds per plant [6]. Seeds have no dormancy and can remain viable for over 1 year [26]. They spread by wind, animals, and agricultural equipment. The seeds are small and light, with long and hairy plumes, aiding long wind dispersal. The wind can disperse the spikelet up to 110 m from the parent plant [27]. Because seeds lack dormancy, suitable site conditions during the period of early seedling establishment are critical for successful dispersal. Seedlings tend to emerge in groups and establish best in open with high-nutrient soils [28] and in tilled and well-drained soils. Because it needs well-drained soil, *Imperata* dispersal by seeds may be limited by excessive moisture during the rainy season [29]. In general, seedling mortality is high, with only about 20% of emergent surviving to produce healthy seedling [27].

For established populations, asexual reproduction by rhizomes is the main method of plant propagation. Rhizomes are whitish in color, branched, scaly, and sharp at the tips, which enable the plant to perforate underground parts of other plants. These organs contain 2,4-di-tert-butylphenol, isoeugenol, and 4-acetyl-2-methoxyphenol, which play an important role in the invasiveness of this plant [30]. The ecological resiliency of *Imperata* and its ability to regenerate from man-made or natural disturbance is primarily due to its well-protected rhizome network. Seeds and rhizome fragments are easily dispersed by people through road construction, trade, and soil movement [31].

Rhizomes are normally concentrated in the upper 15–20 cm of soil where they can remain dormant but viable for a long time [32]. Compared with most nonrhizomatous plants, *Imperata* has high root rhizome to shoot ratios. The belowground biomass of *Imperata* on average was seven times higher than many other native species [33]. *Imperata* rhizomes can comprise more than 60% of the total plant biomass [34]. A high root rhizome to shoot ratio provides a substantial amount of nutrients needed for growth and regrowth of the plant following the slashing, tillage, and other human disturbances. *Imperata* can produce average 16 ton/ha dry matter and rhizomes contributing 56% of this [16]. Rhizomes are resistant to heat and breakage and can penetrate soil up to 1.2 m deep but generally can only reach up to 0.15 m in heavy clay soil and up to 0.40 m in sandy soils [35]. Because of its high belowground biomasses, *Imperata* can retain more N per hectare than native vegetation [33]. Rhizomes have millions of buds with the potential to reestablish the plant after surviving adverse growing conditions.

Rhizomes have a high regenerative ability due to numerous buds that are readily sprouted into new shoots after fragmentation by soil disturbance [21]. The lateral buds can remain dormant for long period and give *Imperata* a perennating habit. Regrowth ability increased with rhizome age, weight [36], and length. Longer rhizomes have a better chance of sprouting because they have more
carbohydrate reserves than short fragments [32]. Mature buds near the rhizome apex are the first to sprout when rhizomes are fragmented from the parent plant. *Imperata* does not produce axillary buds along most of the rhizomes nor regenerate when the apical six-node-long rhizome segments are buried deeper than 8 cm [37].

To control *Imperata*, it is important to reduce the number of viable buds and prevent them forming a new shoot. Bud germination of rhizomes is favored by dry season, light, and oxygen and decreases with increasing depth of burial [32]. The rhizome extends in the soil by means of expansion of intercalary meristems between nodes. A single *Imperata* plant at 24 weeks of age was found to have 2.34 m of rhizome length [38].

Rhizome fragments can spread when they attached to agricultural equipment or transportation of soil containing rhizome fragments [39]. *Imperata* is tolerant to wide range of soil conditions, including variations in soil fertility, organic matter, and moisture content but appears to grow best in the acid soil. Once established, *Imperata* will continue to persist even when there is environmental stress such as drought, flooding, or fire. *Imperata* can persist because many other plant species have difficulty competing with this plant for water, nutrients, and light [40].

**Controls**

**Prevention**

The most effective and efficient method of *Imperata* control is to prevent its spread. Preventing the introduction of *Imperata* into new area should be given priority, but as *Imperata* is so widespread, this may impossibly conducted in many instances. Uninvaded places should be periodically surveyed to detect a new invasion. Sanitation of the equipment that may be contaminated with by seed or rhizome fragments is necessary. If prevention is no longer possible, early detection and eradication are very important. A young infestation is much easier to control and eradicate than established infestation.

**Cultural control**

*Imperata* has C₄ pathway of CO₂ fixation, and therefore, it is intolerant to shade and usually dies when subjected to shade for a long time [21, 41]; however, it can also thrive under moderate shade conditions [22]. Shading on *Imperata* results in reduced carbohydrate storage, rhizome, and shoot dry weight; increased susceptibility to competition and herbicides; and decreased vigor and rhizome to shoot ratio [42]. Moosavi-Nia and Dore [43] found that increasing shade levels to more than 50% reduced both rhizome length and dry weight and increased shoot to rhizome ratios. Lojka et al. [41] noted that aboveground and belowground biomass of *Imperata* decreased by 9.6% and 78%, respectively, by shading at light intensity of 15,000 lux for 6 months. Hairiah et al. [40] reported that ability of rhizomes to resprout after shoots has been slashed declined when the slashed stand was subjected to 88% shade for more than 2 months.

Leaf area increased with shading, the plants grown in 11% full light had leaf area ratios about 2.5 times greater than those grown in full light. Reduction in dry matter production with shading is due to significant reductions in both net assimilation rate and leaf area duration or total amount of leaf area produced [44].

Herbaceous cover crops of the genera *Calopogonium*, *Crotalaria*, *Mucuna*, and *Pueraria* can effectively suppress *Imperata* growth and can be used to prevent and in some cases eradicate the plant. Fast growing tree legume species such as *Sesbania sesban*, *Acacia nilotica* and *Leucaena leucocephala* can improve soil fertility and suppress *Imperata* growth [42]. However, *Imperata* control methods based on cover crop, shade shrubs, or trees need a long time to give effective results. In Nigeria, *Mucuna pruriens* requires nearly 2 years to eliminate rhizomes of *Imperata*. Rhizome dry matter was reduced to zero after 97 weeks in velvet bean (*Mucuna pruriens*) plots and 105 weeks in tropical kudzu (*Pueraria phaseoloides*) plots [45]. Also in Nigeria, Anoka et al. [46] reported that shading by uncut *Leucaena leucocephala* and *Gliricidia sepium* hedgerows for 10 months only reduced density of *Imperata* by 51% and 67% and shoot biomass by 78% and 81%, respectively, while reduction in *Imperata* rhizome biomass in *Leucaena* plot was nearly 90% and in *Gliricidia* plot 96%.

Mature plantation crops such as coconut and oil palm that their canopy has closed can control *Imperata*, but at early stage of development, these crops are susceptible to *Imperata* invasion because they do not develop sufficient dense rapid canopy rapidly enough to shade out the grass [40].

Besides legume species, some other grass species can be used to control *Imperata*. For example, intercropping with switch grass (*Panicum virgatum*), *Panicum hemitomon*, and *Muhlenbergia capillaries* reduced shoot and roots of *Imperata*, but the greatest reduction of *Imperata* occurred in combination with *Panicum hemitomon* [47]. Bahia grass (*Paspalum notatum*), *Cynodon dactylon*, and *Indigofera hirsuta* also have been reported to be effective in managing *Imperata* infestation [27, 48, 49].

Slash and burn agriculture have transformed a vast forest areas to *Imperata* dominated grasslands. *Imperata* is very successful in areas that are frequently burnt, slashed, or overgrazed and results in the extension of *Imperata* grassland [50]. *Imperata* burns readily, even when still green, and the fire destroys nearby vegetation. Compared to many other plant species, *Imperata* produces more persistent standing biomass, resulting in a greater fuel load on invaded sites. Average fire temperatures are higher on invaded *Imperata* sites than uninvaded sites [51]. Its fire burns so hot that it can exclude nearly all native vegetation.

---

http://www.cabi.org/cabreviews
Burning destroys the leaves of *Imperata* but not the rhizomes because they are belowground. After burning, these rhizomes sprout again and produce new shoots and flowers [21]. Regrowth from rhizomes is rapid, and frequent fire favors *Imperata* growth over associated species [52]. In Florida, areas that were burned or had greater biomass removal following the hurricane had greater number of *Imperata* patches and larger patch size [53]. Thus, burning creates a noncompetitive situation in which *Imperata* can persist and quickly dominate the invaded areas.

Burning increases soil fertility for short period of time. Soil organic carbon, total N, and available P increased soon after fire. Conventional practice of annual burning can increase soil nutrients in soil surface and support higher biomass production in *Imperata* covered degraded lands [54]. However, in the long term, repeated short cutting intervals or fire on *Imperata* increases its abundance, reduces soil fertility, and increases soil erosion [55].

**Mechanical control**

The main mechanical control method practiced by smallholder farmers in developing countries is slashing or handweeding. Slash interval affects sprouting ability of *Imperata*. Slashing at short intervals results in better control of *Imperata*; however, slashing at long intervals can increase sprouting. Plants slashed every 2 months produced more sprouts than plants slashed monthly [34]. Killing *Imperata* needs very short slashing interval for a long time. Slashing every 10 days over a 3-year period still left a small number of rhizomes in the soil, but reserve carbohydrates in the rhizome were severely reduced [56]. In general, slashing at long interval only suppresses the shoots with little effect on rhizomes.

To achieve more effective results, slashing should be followed by tilling to destroy the rhizomes. On small-scale farms, most tillage operations are performed using crowbar, hoes, or draft animal driven plows, whereas on commercial farms, tractor-driven plows are generally used.

Tillage damages the rhizomes and prevents their regrowth into new shoots by fragmentation, desiccation, or deep burial. Ivens [32] reported that most rhizome fragments of two nodes mostly could not sprout, and 77%–84% of these nodes rotted within 2 months when buried at a depth of 7.5 cm. Lee [57] found that rhizome fragments buried at 10 cm or more did not germinate.

Tillage is most effective when it is conducted during the dry season that is when plant biomass is concentrated in the rhizomes and their desiccation is enhanced [58]. If it is done in wet season, not only it is difficult, but also there is insufficient sunlight to kill the exposed rhizomes. Sometimes tillage extends into the wet season when the soil is easier to work. Deep tillage should be to a depth of about 30–40 cm because most rhizomes are found above this depth. Rhizomes should be broken into short fragments and buried as deeply as possible [21] or exposed to desiccation by sun light. Wilcut et al. [37] reported that burying of *Imperata* rhizome fragments to depth of 5–8 cm greatly reduced sprouting. If left on the soil surface during the dry season, rhizomes will desiccate and lose their ability to sprout if dried to 70%–75% of their fresh weight [56]. Akobundu and Ekeleme [16] reported that maize grain yield reduction was 51% in plots where rhizomes were fragmented by hoe tillage and the crop was weeded twice, whereas grain yield reduction was 62% less when the crop was grown in slashed plots with intact rhizomes and was weeded four times.

One of the most successful methods to control *Imperata* by subsistence farmers in Indonesia is to slash or burn the grass then till the soil. After several weeks, the soil clods are broken into small pieces, and rhizomes are separated from the soil for baking in the sun. For intensive agricultural practices, repeated disking and deep plowing are effective in suppressing and eradicating *Imperata*, but these practices are costly and impractical by most subsistence farmers. In oil palm plantation areas, *Imperata* control is mainly conducted through integrated cultural (slashing), mechanical (rolling), chemical methods (glyphosate application) [59].

Results of many studies indicate that mechanical control of *Imperata* is not cost effective. Slashing is labor intensive, requiring as many as 75 man-days/ha [20]. It is possible to clear *Imperata* grasslands manually and plant crops or trees, but this may take up to 200 man-days/ha, which is far more than it takes to open a new area of secondary forest using slash and burn methods [40]. In Nigeria, it is cheaper to use glyphosate than handweeding for *Imperata* control [60].

Another low-cost technique that can be used to control the growth of *Imperata* is pressing (lodging or rolling). It is conducted by bending the culm of *Imperata* to ground level [21] by trampling or rolling a weight like old drum over the grass. Pressing can be used to clear areas for planting and as part of an integrated approach to enable the establishment of legume ground cover [58, 61]. With pressing, dense stands of *Imperata* regrowth can be decreased by 40%–80%. About 90% of pressed *Imperata* decomposes or dries up within 1 month, and it can take more than 6 months for the regrowth to reach its previous population density [62]. The best growth stage to press *Imperata* is when it is about 1 m high because stems usually remain permanently bent after being pressed. It is better to press the grass during the rainy season when cover crop species grow rapidly, thereby helping to accelerate biological succession from the grass stage to cover crop stage [63, 64].

**Chemical control**

Several herbicides have been tested alone (paraquat, dalapon, imazapyr, glyphosate, sulfometuron, nicosulfuron, rimsulfuron, etc.) or in mixture for the control of *Imperata*. Glyphosate and imazapyr appear to be the most promising

http://www.cabi.org/cabreviews
herbicides for control of *Imperata* because of their ability to translocate to the underground rhizomes [21], although short-term control is rarely achieved. At high rates, these herbicides give partial control of *Imperata* up to 1-year application [65]. Glyphosate, a broad spectrum, systemic, and nonselective herbicide, has the potential for the control of *Imperata* and has become the market leader in the tropics and subtropics. The popularity of glyphosate is attributed to its low mammalian toxicity [66], little, or no phytotoxic residue in the soil [67] and primarily its efficacy against *Imperata*. Its negative attributes are its requirement for several rain-free periods after application [68].

Because glyphosate has very little to no soil activity, it needs only a short time for weeds to reinfest the treated areas. *Imperata* will likely reinfest the area if only one application of glyphosate is done during the same year. Research revealed that it takes about 3 years of two applications of glyphosate per year to reduce *Imperata* rhizome biomass by 90% [69]. Due to its little or no residual soil activity, glyphosate may be attractive to subsistence farmers because following application, crops can be planted immediately.

Imazapyr also is an effective herbicide for control of *Imperata*; one or two applications of imazapyr (0.75 lb/acre) can effectively control *Imperata* for 18–24 months [69]. Glyphosate at 1.0–1.8 kg/ha and imazapyr at 0.5–1.0 kg/ha provide good control lasting up to 12 months, depending on soil type, rates of application, and environmental conditions [70]. With glyphosate at 4.48 kg ai/ha, imazapyr at 0.84 kg ai/ha, and mixture of glyphosate and imazapyr at the same rates applied three times a year, the entire rhizome biomass of *Imperata* can be eliminated within 3 years [71]. Like glyphosate and other broad-spectrum herbicides, imazapyr will severely injure or kill forage grasses, broadleaved herbs, and annual and perennial crops. It has a long soil half-life and will remain in the soil for several months after application. Since its lasting effect, effectiveness of imazapyr on *Imperata* may continue up to 1–2 years after application. One or two applications (0.75 lb/acre) will often effectively control *Imperata* for 18–24 months. However, imazapyr applications often lead to “bare ground” for up to 6 months post-treatment because of its residual effect and nonselective nature of this herbicide [69]. Therefore, imazapyr may be appropriate for plantation and grassland areas but not in arable farming situations where it inhibits the establishment of arable crops [21]. The soil activity of imazapyr also has the potential to move down slopes during periods of rainfall, killing or injuring other species in the runoff area. In pasture areas, imazapyr can only be used as a “spot treatment” with no more than 10% of the area treated per year [69].

Used alone, imazapyr is more effective than glyphosate. Richardson [72] reported that application of imazapyr on shaded *Imperata* plots resulted in nearly bare soil, but in glyphosate-treated shaded *Imperata* plots, some *Imperata* was still growing.

Efficacy of glyphosate and imazapyr at the rates of 8.96 and 1.12 kg ai/ha, respectively, measured 24 months after treatment increased linearly with increasing rates of both herbicides, but eradication of *Imperata* was not achieved. *Imperata* recovered after imazapyr was applied at 2.24 kg ai/ha in a 2-year-old loblolly pine plantation [73].

A combination or tank mix of glyphosate and imazapyr provided greater control than similar rates of the either herbicide alone on new infestations [74]. However, Willard et al. [75] reported that combinations of glyphosate and imazapyr at various proportions were equally effective as the highest rate tested for these herbicides used alone. Glyphosate at 0.54 kg ae/ha improved control when mixed with imazapyr at 0.3 kg ae/ha, while comparable control was obtained when glyphosate at 1.08 kg ae/ha was mixed with imazapyr at 0.15 kg ae/ha [76], but combination of glyphosate and imazapyr did not give complete eradication of *Imperata* 24 hours after treatment [74]. Complete eradication of *Imperata* using a mixture of glyphosate and imazapyr obtained only after multiple applications over a 3-year period [71].

Rice husk burning has also been reported more effective to control *Imperata* than herbicide application. Isah et al. [77] reported that in the second year of study, rice husk burning and glyphosate caused delay of 84.1 and 28.2 days in *Imperata* first emergence, respectively.

**Biological control**

Although the problems caused by *Imperata*, biological control efforts have been few and rather piecemeal [78]. A review of biological agents related to *Imperata* has been conducted in the southeastern US. Literature records suggest an extensive number of its potential natural enemies. These include 90 pathogens, 92 insects, and several nematodes and mites that have been found on *Imperata* [35]. Of the arthropods recorded on *Imperata*, only one is reported to be specific to *Imperata*, that is, the gall midge (*Orseolia javanica*). This insect destroys the shoot meristem, but only after the grass is cut and the rhizome system has been debilitated. This requirement along with the presence of natural enemies of this insect significantly reduces its potential for control option [56, 79]. However, recent surveys in Asia and East Africa have identified several insect herbivores, including several genera of stem borer and gall-forming midges such as *Emmalocera* sp., *Chilo* sp., and *Contarinia* sp. that show some promise as biological control agents for *Imperata* [80]. Two fungal pathogens, *Bipolaris sacchari* and *Drechslera gigantea*, have also been identified as promising biological control agents for *Imperata* [81].

**Integrated control**

Herbicide applications alone are rarely successful in eradicating *Imperata*. Integrated control that combines
cultural, mechanical, chemical, and perhaps biological methods provides the best option for *Imperata* control. In grassland and plantation areas, *Imperata* may be first burned or slashed to remove aboveground plant parts. The soil then can be tilled and sown with herbaceous or tree cover species to control this grass. The species that have good characteristics as cover crops are fast-growing, can climb over and smoother the grass, provide food for animals, and can fix atmospheric N. However, eradicating *Imperata* by cover crops alone is a long-term process.

To speed up *Imperata* control, the shaded grass should be sprayed with herbicides. Lojka et al. [41] reported that after 1 year of shading, glyphosate application and weeding significantly reduced aboveground biomass by 94.67% and 45%, and belowground by 76.5% and 58%, respectively. This is in line with Weng [82] that in shaded conditions, glyphosate at 2.2 kg/ha gave over 95% control of *Imperata* for 6 months, while in open conditions, 4.4 kg/ha was required to give the same level of control. Ogogo et al. [15] reported that in *Imperata* infested cassava, *Imperata* rhizome dry weight was the lowest in plots treated with glyphosate plus *Mucuna pruriens* cover crop, followed by handweeding plus *Mucuna pruriens* cover crop, followed by glyphosate application or handweeding alone.

If burned, *Imperata* should be left to grow for several months before spraying with herbicide or tilling. Regrowth of the plant for 1–4 months after burning will deplete food reserves as more leaves are produced. With more leaves, a larger surface area can intercept more droplets by herbicide spray. This allows herbicides to kill actively growing leaves, which maximizes effectiveness. Glyphosate as a 2% solution appeared to control *Imperata* satisfactorily for at least 2 years (91% mortality) [83]. If tillage can be incorporated, then a disking treatment following a burn is the best approach. This will kill rhizomes through desiccation. However, these practices may be impractical in many habitats such as forest and plantation areas.

In cropping areas, burning should not be conducted because it will harm the crops. Handweeding, herbicide, and cover crops are the methods that commonly used by smallholder farmers to control *Imperata*. In Nigeria, Chikoye et al. [60] reported that handweeding five times or applying glyphosate was more effective than handweeding twice in preventing maize yield losses and suppressing *Imperata*. *Imperata* was more effectively suppressed by handweeding and planting cover crops such as *Mucuna pruriens* than without cover crops. *Mucuna pruriens* nearly eliminated rhizomes of *Imperata* within 2 years of treatment application. Further, Chikoye et al. [84] reported that besides *Mucuna pruriens* and glyphosate application, narrow corn spacing and the use of competitive corn cultivar may be a sustainable approach to the control of *Imperata* in cropping areas. In soybean, Avav [17] reported that in *Imperata* infested soybean, glyphosate controlled 57%–85% of *Imperata* compared with 64%–67% by traditional hoe-weeding. The highest soybean grain yield (1.88 t/ha) was obtained from plots treated with glyphosate (1.44 kg/ha) followed by one hoe weeding. For the small-scale farmer who has no interest to use legume ground covers, intensive agricultural land use will prevent reestablishment of *Imperata*.

Once good control has been achieved, it is desirable to establish useful cover plant species, which can suppress regrowth of *Imperata* and conserve soil fertility. This is because the eradication of *Imperata* without planting of cover plant can lead to the succession by other pernicious weed such as *Mikania cordata*, *Melastoma malabathricum*, and *Eupatorium odoratum* [85].

**Conclusion**

The extensive rhizome system and the large number of seed production capable of both short and long dispersal make *Imperata* to be dispersed far from its native habitats. In new habitats, *Imperata* can be a pernicious weed because of its higher competitive ability than many crop species. The best management practice is prevention; however, it is very difficult to achieve once the plant is established. Cultural control using fire is not recommended because it can increase dominance of the grass. Mechanical control is labor intensive and is only suitable where cheap labor is available. Using herbicides alone also is not cost effective and needs repeated application to achieve control. Leguminous plant cover can increase soil fertility, but it needs a long time for eradication. Integrating cultural, mechanical, chemical, and perhaps biological control methods may be the best approach because it is cheaper and can provide sustainable control.

**References**


