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Review Article

Ecological Consequences of Invasive Weeds: Zimbabwean Experience: A Review

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Abstract

Invasive weeds may be defined as troublesome or unsightly plants growing in abundance in both upland and aquatic situations where they are not wanted. The establishment of invasive species cause elevated destruction of waterways, disrupted fire regimes, and the loss of biodiversity in many natural and agrarian ecosystems. *Tithonia diversifolia* is one of the largest, aggressive colonizers especially in sun-exposed abandoned sites. The impact of this weed result in economic loss through controlling and abandonment of agrarian land. The menace of *Tithonia diversifolia* is reaching alarming proportions in many parts of the world, especially in Zimbabwe where they have led to serious ecological and economic losses. Invasion of both upland and aquatic ecosystem by weeds, has undergone serious ecological changes including over-exploitation of its natural resources and land degradation of both agrarian and natural ecosystem, and invasion by *Tithonia diversifolia* among others. *Tithonia diversifolia* The presence of the invasive weed was viewed as a universal threat to crop farming and ranching enterprises because invasive weeds alter forage quantity or quality for livestock and therefore reduce net revenue. The invasive nature of *T diversifolia*, its ability to produce a large biomass and possession of an extensive root system has made it a good candidate for remediation of polluted environments. This invasive weed has been implicated in allelopathy as it produces a myriad of phytochemicals such as alkaloids, flavonoids, phenols, saponins, tannins and terpenoids there by creating its novel niche. *Tithonia diversifolia* after Invasive weeds have the potential for exploitation animal feed, human food, soil additives, fuel production, wastewater treatment, source of raw materials and habitat to many organisms. This paper reviews the ecological consequences of invasive weeds with examples from some selected fields and special reference to *Tithonia diversifolia*.

Keywords

Ecosystem, Invasive, Weeds

1. Effects of Invasive Weeds on Ecosystem Services

The destruction done by the establishment of invasive plant species includes reduced flow in waterways, disrupted fire regimes, and the loss of biodiversity in many natural and agrarian ecosystems [84]. Tithonia diversifolia is one of the largest, aggressive colonizers especially in sun-exposed abandoned sites [73]. The impacts result in economic loss

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through controlling and abandonment of agrarian land and natural ecosystem [32]. The author further revealed that non-native invasive species are a major cause of ecosystem degradation and impairment of ecosystem service benefits. Invasive species result in high risk of invasion of riparian areas because they are among the most human-disturbed ecosystems in the world. These species might be upland or aquatic weeds like Echonia crassips. Forested riparian areas serve as a provider of ecosystem services and are vital to streams and rivers as they increase habitat complexity and available resources for organisms of many trophic levels [1]. An understanding on the biology of Tithonia diversifolia is going to be a stepping stone towards coming up with weed management strategies.

It has been estimated that the cost for controlling invasive plant species worldwide is in excess of $120 billion per year whilst 75 percent of production time is spent in controlling invasive weeds [62]. As revealed by the study by [47] invasive weeds are capable to change water rights, water quantity, or quality associated with the spread of aquatic invasive such as water hyacinth. A similar study by [44] also revealed that weeds harm crops, competing them for surviving resources resulting loss that can be as high as 24%. The author further postulates that weeds can affect the crops by production allelopathic effect as well as competing for water, nutrients and light. When these two effects occur concomitantly, the harm becomes even greater. It is against this background that the study intends to determine the allelopathic effects of Tithonia diversifolia on germination and growth of crop seeds including the staple crop of Zimbabwe.

Ecosystem services are the inherent and tangible provisions supplied by and for natural systems that have direct impacts to humans [6]. The value of ecosystem services include: direct consumptive use values such as food, fibre, fuel, and pharmaceuticals; indirect use values such as nutrient cycles, disease resistance, or resilience to disturbances; direct no consumptive use values such as waste decomposition and air purification; and pure existence use values such as educational value, cultural importance, or aesthetic beauty [84]. The means by which ecosystems provide these values go beyond simple primary productivity to include the maintenance of stable food webs and soil fertility, structural components such as soil and community composition, and biodiversity itself, which all can be affected by invasive plant species [62]. The invasion by T diversifolia compromise these beneficial services thereby impacting standard of living for the general populace. Its understanding is crucial as it is going to impact naturalist and environmentalists with practical knowledge about the ecological consequences of Tithonia diversifolia on the ecosystem hence they are going to be put in action towards coming up with strategies to reduce its spread across the country.

2. Invasion of Agro System by Alien Plants

The life-history strategy or trait package exhibited by alien species affect their competitive performance or ecological adaptability, while environmental conditions, disturbance regimes, habitat degradation and the structure of native communities (e.g., patterns of species richness, evenness and functional composition) are external forces controlling invasion success [10]. The intrinsic and external factors collectively define the potential for successful invasion and delimit its ecological context, the geographic coverage and potential damage to native biodiversity. Successful invasions only arise when non-native species can overcome external forces [14]. Competitive ability, niche construction, phenological niche separation and phenotypic plasticity are some of the traits that contributes to successive invasion of a particular area, Tithonia diversifolia produces some allelochemicals and defoliates its leaves that suppresses growth and establishment of other species in proximity [30]. These factors explain why a small fraction of introduced alien species become invasive regardless of ecosystem type or habitat integrity [78].

Successful invasion of tropical plant species usually relies on the key life-history traits across all life-cycle such as vegetative reproduction, copious seed production, dormancy and effective seed dispersal, high germination success in a wide range of environmental conditions, fast growth and high phenotypic plasticity [48]. The above sentiments were also supported by [52] who observed that more often than not, invasive species have a high rate of reproduction, producing many offspring that essentially take over a particular area.

2.1. Competitive Ability

It is a one of the long-standing hypothesis regarding invasive potential of species which shows that invaders are strong competitors for limited resources and have strong competitive ability [63]. According to [33] invaders have a larger competitive interference ability than natives in the invaded site. In support of the above statements [70] cited that one of the major ways of competition is that invasive weed can produce number of allelochemicals from underground and above ground parts which have phytotoxic effects on neighboring plants. Competition ability may not be a trait that confers advantage in all environments it should be a dominating force when resources are abundant compared to sites where resources are less abundant [72]. The research investigates species composition in Tithonia diversifolia infested area and a distance further in order to determine its competitive ability. The stress gradient hypothesis to invasion shows that competitive ability may be an attribute that confers invasion potential in sites with higher resource abundance [50]. This hypothesis is conversely, even very strong competitive ability for a resource will not overcome essential resource limitation and may not provide benefit in

an environment with low resource abundance [41]. This implies that species with strong competitive ability have a large invasive potential in areas where there is resource to compete for sites with relatively high resource abundance. Competition can be largely regarded as a strong trait that can facilitate invasion of niche with resource competition. There is a strong positive correlation between competitive ability and invader population density in the recipient site so that there is greater interaction between individuals [22]. The situation is converse in resource poor sites since the population might be very low enough that interaction between individuals is not a major factor influencing community dynamics as a result strong competitive ability will not provide benefit to a potential invader [27]. A combination of competitive ability hypothesis and the relationship in site environmental and biotic characteristics will result in Invasion Syndrome 1 [45]. Invasion Syndrome 1specifies that sites with relatively high resources should have higher density and low enemy impact and should be susceptible to invasion by species with highly competitive ability [16]. This is evidenced by high population of Tithonia diversifolia in natural region one and two, these regions are characterized by high rainfall associated with fertile soils. The weed may grow faster than crops and successfully compete for available nutrients, water, space and sunlight [2] hence, the weed is a strong competitor in limited resources.

2.2. Niche Construction

The hypothesis is based on the ability of species to change their environment this might be facilitated through alteration of nutrient dynamics [63]. Tithonia diversifolia produces abundant litter which enhances its growth and persistence, the litter has the ability to liberate allelochemicals though decomposition resulting in impeding germination and growth of other plants in proximity and rendering full colonization of an invaded area. The hypothesis strongly emphasis that species with the ability to modify their environment in a manner that preferentially benefits conspecifics should have more invasive potential than species without that ability [22]. According to [33] niche construction ability is lost if resource abundance is high hence it only provides substantial benefits in low resource condition. The author further stated that if the environment is not stressful there is no benefit to being able to alleviate environmental stress. Niche construction maybe an attribute that only increases a species invasive potential in sites with low resource abundant [25]. A combination of niche construction and the relationships in site environment and biotic characteristic result in Invasion Syndrome 2 [23].

2.3. Phenotypic Plasticity

The hypothesis shows that invaders have a higher potential of ecological plasticity than native species in invaded sites and those invaders have a larger plastic response or fitness traits in response to variable resources than native species in the invaded environment [68]. The hypothesis is in contrary with the invasion of Australia by Parkinsonia aculeana the benefit of phenotypic plasticity is as a result of environmental dependent [68]. According to [28] non-native species with high phenotypic plasticity should have high invasive potential in areas with fluctuating of viable resources. Tithonia diversifolia is often excellent at surviving and reproducing in disturbed environment and are capable to colonize and dominate in these conditions. A combination of phenotypic plasticity and the relationships in site environmental and biotic characteristics result in Invasion Syndrome 3 [63]. The author further stated that a site with moderate or fluctuating resource should have moderate diversity and high enemy impact and should be vulnerable to invasion by species with high phenotypic plasticity. Tithonia diversifolia seeds are long life standing seeds with very little or no predators this could due to speculations its allelochemical have some insecticidal effects that repels some predators.

2.4. Phenological Niche Separation

The hypothesis shows that alien species invasion potential increases when its phenology is temporally distinct from native phenology [81]. [63] indicated that they are several dynamics that exist for invader phenology to be separated from native phenology that includes vacant niche (wherein the invader grows and reproduces at times of the year when natives are not active), priority effects (wherein the invader begins growth earlier than natives) or the invader might have a longer niche breath (length of growing season or fruiting period) as compared to natives. T diversifolia is an evergreen perennial weed which is capable to manufacture its own food during winter season whilst most native species are under dormancy condition. The hypothesis is similar to the hypothesis by [7] vacant niche hypothesis of invasion wherein an invader is thought to be successful when it utilizes resources that are not utilized by the resident native community. When an alien species has been introduced into the site where it has a phonological niche separation from the resident community may avoid any resistance to invasion due to the resident species on the site. It is against this background that the resident species are not active and it provide little competition or enemy impacts. Tithonia diversifolia has a phenological niche separation hence it is able to invade any site with environmental conditions that suit its life history. Invasion Syndrome 4 states that if a species is introduced into the site where it has a phenological niche separation from natives will not have to content with interference from the biotic community at a site (diversity or natural enemies) and may invade where ever site environmental conditions suit its life history [24].

2.5. Allelopathic Effects of *Tithonia diversifolia*

Allelopathy is derived from the Greek word 'allelon' which means 'of each other' and 'pathos' which means to 'suffer'. Thus, allelopathy literarily means the injurious effect of one upon the other [4]. Tithonia diversifolia is believed to possess allelo-chemicals, a study by [54] in Kenya indicates that it contains allele-chemicals that inhibit growth of cow peas. The review is similar to that which was conducted by [18] that shows that Tithonia diversifolia has both growth- inhibiting and growth-stimulating properties. Inversely research by [60] shows that treatment with both aqueous and methanolic extracts of T. diversifolia increased proline concentration significantly for the first five days. The author further cited that aqueous extract of T. diversifolia increased protein concentration from 5th to 30th day. In a similar study [37] observed that aqueous shoot extracts of T. diversifolia applied onto the soil after three woody plant species, Monodora tenuifolia, Dialium guineense and Hildegardia barteri had been planted, and the effects of the treatments were evaluated after 10 weeks. The extract treatments resulted in reductions in the shoot length, leaf area and number, and chlorophyll content of all of the woody plants [19]. The author further indicated that aqueous shoot extracts of T. diversifolia extract-dependently suppressed the growth of radicles and plumules of maize (Zea mays L.) seedlings, the germination of lettuce (Lactuca sativa L.) and Bidens pilosa, and the germination and growth of Tridax procumbens. Fresh shoot aqueous extract of T. diversifolia may contain allelochemical that performed both stimulatory and inhibitory functions [61]. In contrary with [48] who cited that although T. diversifolia was not observed to have any effect on the germination of Zea mays, it did inhibit the radicle and the plumule lengths of the seedlings. In particular, no research has been done on the potential allelopathic influence of T. diversifolia on the growth of maize, sorghum, cow peas, soya beans, sunflower and rapoko grass crops. To do this, it was better to comprehend and evaluate the allelopathic/allelochemical effects of T. diversifolia in a controlled environment [73]. Therefore, this study intends to evaluate the allelopathic effects of T. diversifolia aqueous extract on germination, length of the radicle and plumule and effects on stem girth.

Other studies done in Zimbabwe has shown that *Cyperus rotundus* has some effects allelopathic interaction on development and growth as a complex process that affects all development and growth aspects that includes protein, hormone and chlorophyll synthesis, cell division, cell wall structure, membrane growth and germination of Sorghum [85]. Cited by [44] allelopathy is one plant's directly affecting another plant's growth either positively or negatively, exuding chemical plant extracts. Many phytotoxic chemical substances are known to be exuded by plants to suppress emergence or growth of the other plants.

Allelopathy has the potential to affect all ecological factors, under present condition, weed invasion is the most important reason of crops yield reduction. According to [82] leaves and leaf residuals, roots, pollens and flowers, epidermis, stem, seeds and fruits have active allelopathic properties that can cease growth. [44] revealed that extracts of Lactuca sativa, Xanthium occidentale and Cirsium japonicum inhibited root growth of Medicago sativa L. Modern research indicates that allelopathic activity can induce positive or negative impact on the target plant depending on the concentration of the allelochemical and the plant species involved [20]. As supported by the study by [13] plant interaction in allelopathy might lead to either stimulation or inhibition of growth. Allelopathic interactions that exist among plants usually lead to the dominance of one species, with the other species getting damaged under natural conditions [75].

Pinpointing intrinsic functional traits associated with invasiveness to profile successful invaders has been a long-lasting quest in invasion ecology [17]. Allelopathy is an important process that demonstrates inhibitory or stimulatory effect on neighbouring plants and succeeding crop due to the release of allelochemicals into the surrounding environment [71]. The author further stated that allelopathic properties of plants can be beneficial due to the potential reduction of weeds, but they can also be undesirable and harmful to other successive crop of rotation. Traditionally invasion success was studied by focusing on either the intrinsic biological characteristics conferring invasiveness or characteristics of the resident community favoring invasion, however allelopathy had also contributed to the invasiveness of weeds [64]. Numerous researches about allopathic effects, dormancy and dispersal of other invasive weeds were conducted; however, no research has been done about the wild sunflower (Tithonia diversifolia) focusing its effects on maize, sorghum, cow peas, soya beans, sunflower and rapoko grass in Zimbabwe.

2.6. Allelopathic Effects of Tithonia Diversifolia on Humans and Environment

Past study indicated that phytotoxicity of aqueous extracts of T. diversifolia towards annual rye grass generally increased, at 25 ℃ over a 32-day period [73]. Their impact on human activities can be associated with livestock production, including interfering with grazing practices, lowering yield and quality of forage, increasing costs of managing and producing livestock, slowing animal weight gain, reducing the quality of meat, milk, wool, and hides, and poisoning livestock. Rye grass is one of the palatable nutritious species in livestock production In addition, infestations can reduce recreational land values and the spiny species can cause human health problems [43]. In a similar study by [74] who revealed that phytotoxic effects include inhibition to seed germination and growth including retardation in morphological/ physiological activities of recipient plants by the allelochemicals.

Although they are some negative impacts by T. diversifolia the weed can be harvested all parts of the plants can been used as folk medicine for a wide range of diseases and aliments,

through topical administration to treat abdominal pain, wounding, dermatosis, and muscular disorder; and through oral administration to treat infection, malaria, fever, hepatitis, and diabetes [37]. Thus, the plants have a broad spectrum of medicinal values. On the other hand, T. diversifolia aggressively expands its habitat into agricultural and non-agricultural areas, becoming a serious farmland weed and disturbing native plant communities as an invasive plant species [77]. The species has shown allelopathic potency on the germination and growth of several other plant species [37]. Allelopathy may play an important role in the invasion of T. diversifolia Allelo-chemicals usually interfere with major physiological processes such as respiration, photosynthesis, water balance and stomatal functions, stem conductance of water, xylem element flux, membrane permeability, cell-division, changes in protein synthesis and inhibition of fodder for livestock [80] this has a detrimental effect on livestock production. Some invasive weeds like Parthenium hysterophorus has being cited as a serious threat to natural and agroecosystems as it brings changes in soil quality and affects biodiversity of natural habitats and crops negatively in the invaded regions [74].

The allelopathic effects can occur through different plant parts such as leaves, stems, roots, and seed [85]. The author further stated that leaves of O. alpina possess the most effective source of allelopathy because they are the primary site of photosynthesis and the production of secondary metabolites. In addition, leaves are the most dominantly decayed plant residues/litter that could affect the adjacent crops in an agroecosystem. The study is therefore intending to determine the most effective part of T. diversifolia that suppress germination and growth of other plants in the ecosystem.

2.7. Environmental Conditions Suitable for Invasive Species

Invasive species are capable to thrive under environmental conditions of relatively resource abundant and resource fluctuations [46]. They are generally capable of surviving in a variety of different locations, habitats and conditions [57]. The author further indicated that most invasive weeds are not subject to natural predators and diseases that would help to keep their population under control. Some species require relatively undisturbed habitats, while others thrive in disturbed areas. According to [38] most terrestrial invasive species do better in disturbed habitats. The author further postulates that the current land use of any particular area has a significant influence on species survival hence invasive species are capable to survive over a range of land use patterns, wetlands, forest and field environment. Different species has different genetic makeup that makes them adapt to thrive in a given environmental condition [63]. Tithonia diversifolia is capable of successfully establishing and colonizing marginal areas with erratic moisture. Given that the weed is capable to thrive in various environmental conditions, research was conducted in Zimbabwe to explore growth characteristics of Tithonia diversifolia under different types of soil and moisture resume.

2.8. Dispersal of Invasive Weeds in Zimbabwean Ecosystem

According to (Shumba, 2010) exotic species introduced for commercial or ornamental purposes have escaped from target areas and replaced the original tree biodiversity. This has led to wide dissemination of Tithonia diversifolia into Zimbabwe, [73] postulates that the weed was introduced into Zimbabwe as an ornamental plant and due it its dispersal capability it spreads rapidly. Invasive species are introduced into new areas through a number of argents wind, water and animals. Some plants produce seeds that are spread by wind [38], that can be determined by the size of the seed dust like are capable to disperse long distance. Similar research by [12] who reveals that through wind, plant propagules, either seeds or fruits, can attain long dispersal distances. The author further stated that in these cases, propagules are either minute in size, i.e. “dust” seeds, and thus easily lifted in air, or are provided with hairy, frequently pappus-like appendages reducing their terminal velocity. Apart from propagule traits, parent plant traits are also determinant of dispersal ability through wind [39]. These include release height and fruiting phenology and wind speed or orientation thresholds for propagule abscission which can facilitate release under the most favorable seasonal or daily wind conditions for increasing dispersal distances [9]. The research determines the role of wind mechanism and dormancy in dispersal of Tithonia diversifolia in the ecosystem. Some seed of weeds have various appendages that facilitates their dispersal for example Biden pilosa had some hooks that attach themselves to articles of clothing or vehicles and then be transported well outside the currently infested area [29]. Tithonia diversifolia produces numerous, smaller, lighter seeds which allow for dispersal over large areas by wind [53], Exotic plantations occupy about 156 000ha of which over 90% is in the eastern districts of Zimbabwe this is also supported by the research which cited that Tithonia diversifolia prefers high moisture content (Shumba, 2010). Specific examples are Acacia mearnsii in the eastern highlands, Pinus patula in the Nyanga National Park and Psidium cattlensis in Chirinda Forest [18]. In contrary some indigenous species such as Acacia nilotica and Dichostrychus cinerea have been reported to invade degraded sites and pasture lands swamping the natural vegetation this had a serious impact on demand for livestock products which will be scarcity [7].

Given the above literature T. diversifolia possess some traits for invasiveness. Although a number of researches cited some normative effects of Tithonia spp its biology and ecological consequences is yet to be known in Zimbabwe, hence an understanding on the biology, allelopathic properties and ecological consequences will provide a practical knowledge to naturalist and environmentalist. This will be a stepping

stone towards coming up with weed managent strategies to argument productivity and sustainability of the environment.

2.9. Seed Dormancy, Dispersal and Weed Seedbank of Tithonia Diversifolia

A seed is a dormant or resting stage in the life of a plant and the stage of the life cycle at which dispersal and colonization of new areas occurs. Tithonia diversifolia produces numerous, smaller, lighter seeds which allow for dispersal over large areas by wind [53], however if cuttings are buried horizontally into the soil they often sprout, contributing to the densification of stands of this species. Weed seedbank consists of new seeds recently shed by a weed plant and older viable seeds present on the surface or in the soil that have persisted for several years [51]. The number of seeds produced by a plant, the number of seeds it fathers with the pollen it produces and the proportion of these offspring which survive to reproductive maturity are factors which determine how many descendants left by a genotype expressing a particular life history pattern [75]. Dormancy is a necessary evil in the life cycle of plants it facilitates dispersal in space and time. Weed seed dormancy, dispersal and seed bank are essential tools for continuity existence of weed flora [51].

3. Conclusion

This review focuses on invasion biology and ecological consequences of invasive weeds in the ecosystem paying much attention on *Tithonia diversifolia*. *Tithonia diversifolia* is likely to be a problem in areas with fluctuation of resources through niche construction, competitive ability, phenological structure, ecological plasticity and allelopathic properties. Allelopathy proves to be a strong tool that facilitates invasive plants to colonize new niche and that wind and dormancy plays an important role in dispersal and survival of *Tithonia diversifolia* seeds in the ecosystem. The concept of allelopathy can be employed in the organic management of weeds and reduce our heavy reliance on synthetic herbicides. The concept of allelopathy can be employed in the organic management of weeds and reduce our heavy reliance on synthetic herbicides.

Author Contributions

Musabayana Zivanayi: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing

Mandumbu Ronald: Supervision

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Conflicts of Interest

The authors declare no conflicts of interest.

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