academicJournals

Vol. 6(11), pp. 790-796, November, 2014
DOI: 10.5897/IJBC2014.0763
Article Number: 01A6A0C48644
ISSN 2141-243X

http://www.academicjournals.org/IJBC

International Journal of Biodiversity and Conservation

Full Length Research Paper

Invasive weed risk assessment of three potential bioenergy fuel species

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Received 30 August, 2014; Accepted 30 October, 2014

Bioenergy crops are potential renewable sources of bio-diesel which have low emission profiles, environmentally beneficial, and capable of substituting petro-diesel. However, since most of them are introduced or are not native, it is essential to reduce the ecological and economic consequences of invasive pest introductions and the potential invasiveness of species not yet introduced. The Australian Weed Risk Assessment (WRA) is a plant screening method and has the highest accuracy. The objective of this study was to conduct an agronomic and invasive weed risk assessment of three potential bioenergy fuel species namely: moringa (*Moringa oliefera),* physic nut *(Jatropha curcas),* and castor bean (*Rincinus communis)* for the Caribbean Islands. The WRA gave overall scores for moringa (0), jatropha (13) and castor oil (13). Based on their climatic adaptation and distribution, jatropha *(5)* and castor oil (5), the dispersal mechanism score was high (5) for both of them. The study revealed that jatropha and castor bean should not be considered as bioenergy crops within the ecological limits of the study, and that moringa should be further evaluated as bioenergy crop against invasiveness, given its agronomic potential as a high yielding oil crop.

Key words: Weed risk assessment, *Moringa oliefera, Jatropha curcas, Rincinus communis, bioenergy plants.*

INTRODUCTION

The International Energy Agency has identified the development of renewable energy sources as a key element to mitigate climate change (Schmid, 2012) and solution to the volatility of petroleum prices (Haque et al., 2011). It has stimulated the growth of bioenergy plant species for co-generation, or as ethanol and bio-diesel (Raghu et al., 2006; CAST, 2007; Bridgemohan 2008). The efficient production and processing of bioenergy crops are seen as suitable source energy for fossil fuel-based (Gaunt and Lehmann, 2008).

Several bioenergy spp. have exhibited desirable traits such as high yield, low inputs requirements, wide ecological

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adaptability, do not compete with food production or food grade oils, and are ideal for preventing desertification and erosion (Francis et al., 2003; Low and Booth, 2008). The bio fuels produced from these crops have high calorific value and improved lubricity (Lalas and Tsaknis, 2002) and lack sulphur and consume CO_2 (Choi et al., 1997; Szybist et al., 2005; Concieca et al., 2007). Some bio energy crops like jatropha (*Jatropha curcas),* have some toxicity which is sensed by animals and therefore not foraged (Devappa et al., 2012).

Several bioenergy species including moringa (*Moringa oliefera),* physic nut *(Jatropha curcas),* and castor bean (*Rincinus communis)* are adapted to the Caribbean (Bridgemohan, 2008). Moringa is adapted to semi-arid and humid conditions (Palaniswamy, 2004; Ramachandran et al., 1980), marginal soils (Palada and Chang, 2003) and has good oil yield potential (Sukarin et al., 1987). The monoecious jatropha (Dehagan and Webster, 1979) like castor bean are drought resistant shrub (Ghosh et al., 2007) and grow well on infertile soils without competing or interfering with food production activities (Sukarin et al., 1987).

There is a possibility that bioenergy species may have characteristics that may make them adaptable to the different ecological conditions and explode as invasive plants. As such, it is prudent that they should be assessed against the potential risk that the species might become invasive (Krivánek and PyĺeK, 2006).

Bioenergy plants can be selected and bred from nonnative taxa which have few resident pests, tolerate poor growing conditions, and produce highly competitive monospecific stands-traits that typify much of our invasive flora (Barney and DiTomaso, 2008; Davis et al., 2010).

The Australian Weed Risk Assessment (WRA) system has been used to categorize the risk of plants becoming invasive (Pheloung et al., 1999). It has been modified for application to other locations (Gordon 2008), and was used to evaluate the potential invasiveness of species proposed as biofuels in Florida (Salisbury 2008; Gordon et al., 2011). It is a plant screening method developed for regulatory purposes against invasive plants and has high accuracy (Leung et al., 2002; Daehler et al., 2004; Krivánek and Pyĺek 2006). It has been sufficiently tested both for screening of new species or species already in cultivation that may become invasive (Low and Booth 2008; Salisbury 2008; Gordon et al., 2010).

The WRA has been used to specifically assess invasion by bioenergy crop (Barney and DiTomaso, 2008; Buddenhagen et al., 2009; Koop et al., 2012; Quinn et al., 2014). They all found the model suitable and concluded given the economic and ecological impacts of invasive species, including the carbon expended for mechanical and chemical control efforts, cultivation of taxa likely to become invasive should be avoided.

The objective of this study was to conduct an invasive weed risk assessment of three potential bioenergy fuel species *viz*., moringa (*M. oliefera),* physic nut *(J. curcas),* and castor bean (*R. communis)* for the Caribbean Islands.

MATERIALS AND METHODS

This study was conducted during the period of 2009 to 2012 at the Waterloo Research Centre, University of Trinidad and Tobago which is located in the southern Caribbean. Three observation plots were established with moringa, jatropha, and castor bean on the Waterloo Soil Series in June, 2009, at a density of 2,500 plants. ha^{-1} on cambered beds. The plants were rain-fed, zero chemical and all operations were done manually.

The plant morphological and phenological characteristics (plant height, leaf area, flowers and fruit production, flowering cycle, and yield) were recorded throughout the plant juvenile and reproductive stages. The mature pods were harvested and yield analysis conducted. Similar observations were conducted from three other locations which were characterized by poor and marginal soils in Mc Bean Village, Carli Bay, and Caroni Village, Trinidad.

The WRA (Pheloung et al., 1999) was selected to assess invasiveness with additive approach for each of the 49 questions with set scores. This survey instrument covered distribution, agro-climatic conditions, invasive characteristic, and morphological and physiological traits of the species. All the questions are required for completion of the WRA on any species or taxon. If the summed scores are >6, the taxon is predicted to become invasive and should be rejected for import/production; if the sum is <1, the taxon is not predicted to become invasive and should be accepted; scores of 1 to 6 indicate that further evaluation is necessary before a prediction is possible (Gordon et al., 2010). The assessment was conducted by four assessors using the observations compiled over the study period and the mean scores used in the final report.

RESULTS

Phenology and reproductive characteristics

The phenological characteristics of the species under study indicated that there was no dormancy in the fresh seeds and they are viable and germinated 4 to 9 days after sowing. After one year, all three species maintained good germination (>95%) and viability (80 to 90 %).The vegetative / growth phase varied between 3 to 6 months while jatropha and castor bean had 3 distinct flowering cycles in the year, moringa was constantly flowering/ fruiting with 10 new flushes per year over the three year period of study (Table 1).

Jatropha maintained a medium height and hardy shrub-like structure (1 to 1.5 m), whilst castor bean and moringa were lush green architecture (4 to 5 m). Jatropha grew well despite the unusual dry season period of January to May, 2010, but did not produce any new vegetative structures, shed most of it leaves, and reduced its flowering and seed production. All the plants continued to produce normal seed yield without any dormancy or loss of seed viability. The dispersal distance for natural field emergence for both castor bean and jatropha varied

Table 1. Agronomic and phenological characteristics[1] of moringa (*Moringa oliefera),* physic nut *(Jatropha curcas),* and castor bean (R*incinus communis)* .

Phenology and reproductive characteristics	Bioenergy crops		
	M. oliefera	***J. carcus***	***R. communis***
Days to germination (1 year old seeds)	100	100	100
Length of vegetative growth (days)	180	90	140
flowering cycle / year	10	3	3
flower yield/ cluster (nos)	21	19.0 (2.83)	19 (1.14)
flower cluster yield / tree (nos)	25 to 36	34 (1.27)	23.2 (7.89)
Pod yield / cluster	2 to 4	28 (2.02)	16.96 (4.89)
new pods/tree/month	24 to 27	30 (3.01)	29 (6.34)
flowering to harvest (DAS)	45	82	80
harvest cycles / year	9 to 10	3 to 4	2 to 3
harvestable fruit pods / tree/ flush	30 (4.78)	646 (12.25)	408
Pod Yield . $tree^{-1}$. yr^{-1}	750	2584	1020
Nos. seeds . pod^{-1}	20	4	4
Weight 1000 seed (g)	350	36.4	113.36
Seed yield $kg.tree^{-1}.yr^{-1}$	5.25	0.376	4.364
Seed yield ($t.ha^{-1}.yr^{-1}$)	13.12	0.96	13.90
Oil yield ($t.ha^{-1}.yr^{-1}$)	5.01	0.68	2.52

Values in parenthesis are SE.

between was 3 to 18 m^2. Moringa seeds remained in the pod, long after it shed and the dispersal range was less than 0.5 m from the edge of the canopy cover.

There was no germination of moringa seeds on the soil under the trees, and on examination, the fallen pods collected after 3 months revealed most (60%) of the seeds were damaged by insects and were not viable *in-situ*. Castor bean and jatropha seeds persisted in the soils were longer (3 to 6 months) than moringa, but all showed declined viability (10%). It was observed that there were no birds or animals feeding on the plants or seeds, and there were no assisted transfer of dissemination of seed by animal.

Biogeographical characteristics

The history and biogeographical characteristics which described the domestication/cultivation, climate and distribution, and weed elsewhere are presented in Table 2. Moringa has higher domestication scores (3) compared to jatrpha (0) and castor bean (0), and is a highly domesticated plant which is used as an ethnic vegetable by the East Indian descendants in the Caribbean. It has naturalized and adapted to wide ecological conditions and is not considered as a weed. However, jatropha and castor bean are not domesticated or naturalized, and are considered as unwanted in agricultural and wastelands.

Under ‘climate and distribution’ (Table 2), there were no differences in the scores among moringa (4) compared to jatropha (5) and castor bean (5). Jatropha can tolerate very dry growing conditions, while castor bean flourished on the banks of water courses under dry to waterlogged conditions. All the spp. adapted well to low or zero agricultural inputs, and survived under low soil moisture conditions in the dry season, and flowered and seeded profusely in the wet season.

Under ‘weeds elsewhere’ (Table 2), there were significant differences in the scores among moringa (1) compared to jatropha (-7) and castor bean (-7). Jatropha was introduced as an ornamental plant. However, because of its noxiousness, dispersal range, and tendency to form clumps that are difficult to manage, its cultivation is limited. Castor bean is a shrub weed and forms dense canopy and impenetrable clumps on the periphery of farmlands and moist abandoned fields. The overall scores for history and biogeographical characteristics (Table 2), showed that there were significant differences in the scores among moringa (3) compared to jatropha (-2) and castor bean (-2).

Biology and ecological characteristics

The biology and ecological characteristics of the undesirable traits (Table 3) revealed that there were significant differences in the scores among moringa (0) compared to jatropha (9) and castor bean (9), and that the latter two had more undesirable characteristics. The pods of jatropha and castor bean have burs which can attach themselves to animals passing through these trees. However, there were no grazing or wild animals observed in the areas understudy. Both are fire hazards in the natural ecosystem due to the formation of impenetrable thickets compared to moringa which is sparse and widely spaced. All the spps are tolerant to low

Table 2. History and biogeographical characteristics (domestication/cultivation, climate and distribution, and weed elsewhere) of moringa (*Moringa oliefera),* physic nut *(Jatropha curcas),* and castor bean (R*incinus communis)* response according to the WRA.

Biogeographical characteristics		Response		
		M. oliefera	***J. carcus***	***R. communis***
Domestication/ Cultivation	highly domesticated	-3	0	0
	naturalized	1	-1	-1
	weedy races	-1	1	1
Climate and Distribution	suited to Trinidad and Tobago climates	1	2	2
	Quality of climate match data	1	1	1
	environmentally versatile	1	1	1
	Native or naturalized (extended dry periods)	1	1	1
	history of repeated introductions outside its natural range	0	0	0
Weed elsewhere	Naturalized beyond native range	1	1	1
	Garden/amenity/disturbance weed	0	-2	-2
	Weed of agriculture/horticulture/forestry	0	-2	-2
	Environmental weed	0	-2	-2
	Congeneric weed	0	-2	-2
	subtotal	**3**	**-2**	**-2**

Table 3. Biology and ecological characteristics of the undesirable traits moringa (*Moringa oliefera),* physic nut *(Jatropha curcas),* and castor bean (R*incinus communis)* response according to the WRA.

Biology and ecological characteristics		Response		
		M. oliefera	***J. carcus***	***R. communis***
Undesirable traits	spines, thorns or burrs	0	1	1
	Allelopathic	0	1	1
	Parasitic	0	0	0
	Unpalatable to grazing animals	-1	1	1
	Toxic to animals	0	1	1
	Host for pests and pathogens	0	0	0
	allergies or toxic to humans	0	1	1
	fire hazard in natural ecosystems	0	1	1
	shade tolerant plant	0	0	0
	Grows on infertile soils	1	1	1
	Climbing or smothering growth habit	0	1	1
	dense thickets	0	1	1
	subtotal	**0**	**9**	**9**

soil moisture content, poor marginal soils, and can rejuvenate after fire.

Plant type and reproduction characteristics

The plant type and reproduction characteristics of the undesirable traits according to the WRA are presented in Table 4. All the species are hardy wood plants with no nitrogen fixing abilities. They did not show evidence of reproductive failure, and under drought conditions produced viable seeds, although the yields were slightly reduced. The species are self-fertilized and do not require any specialist pollinators. Only moringa can be propagated and produced by cuttings. The plant type and reproduction characteristics (Table 4) revealed that there were differences in the scores among moringa (3) compared to jatropha (1) and castor bean (1), none of the

Table 4. Plant type and Reproduction characteristics of the Undesirable traits moringa (*Moringa oliefera),* physic nut *(Jatropha curcas),* and castor bean (R*incinus communis)* response according to the WRA.

Plant type and Reproduction characteristics		Response		
		M.oliefera	***J.carcus***	***R.communis***
Plant type	Aquatic	0	0	0
	Grass	0	0	0
	Nitrogen fixing woody plant	0	0	0
	Geophyte	0	0	0
Reproduction	Evidence of substantial reproductive failure in native habitat	0	0	0
	Produces viable seed	1	1	1
	Hybridizes naturally	-1	-1	-1
	Self-fertilization	1	1	1
	Requires specialist pollinators	0	0	0
	vegetative propagation	1	-1	-1
	Minimum generative time (years)	1	1	1
	subtotal	**3**	**1**	**1**

plants exhibited the features outlined under plant type.

Dispersal mechanisms and Persistence attributes

The dispersal mechanism of propagules is seen as a major characteristic of aspecie which describes its invasiveness (Table 5). There were differences in the scores among moringa (-6) compared to jatropha (4) and castor bean (4). Moringa is mostly grown on cultivated or fallow fields, and usually involves human action and interference. The moringa pods shatter under very dry conditions while on the tree, but the seeds are not wind dispersed, although they are appear anatomically structured to be windblown.

Under dispersal mechanisms and persistence attributes characteristics there were differences in the scores among moringa (4) compared to jatropha (1) and castor bean (1), suggesting that moringa was more likely to be more dominant than the others. However, the seed are buoyant and can flow along water courses. It is unlikely that the seeds pass through animals undigested and remain viable, even though the seeds are fed to animals as a protein source. Jatropha and castor bean are not likely to be dispersed by human interference, even accidently, but the shattering force could spread the seeds to short distances (Table 1). This is evidenced by the presents of clumps in proximity to the parent plant. The fruits are not eaten by animals while on the tree, but shells on the soil suggest that rodents feed on all species.

The persistence attributes (Table 4) based on seed prolificacy, tolerance to cultivation or fire and natural enemies revealed that all the spps are similar in that regard. Jatropha and castor bean can be controlled by herbicides during the early vegetative phase. Under field conditions at the experimental site, moringa was observed to be very sensitive to herbicide drift of paraquat, but is able to rejuvenate and re-grow.

Weed risk assessment characteristics

The summary of the WRA scores (Table 6) demonstrated that moringa (-3) was consistently more domesticated as a crop than jatropha (0) and castor bean (0). Moringa (0) was less likely to be colonized as ‘unwanted plant ‘or weed compared to jatropha (-7) and castor bean (-7). Jatropha (9) and castor bean (9) have significantly more undesirable traits than moringa, but their plant type and architecture are similar. Moringa is higher yielding and can produce more seeds per tree, but it is the dispersal mechanism that characterizes jatropha (4) and castor bean (4) as invasive weeds. Moringa has more positive persistency attributes (3) than the other two spps (1). The assessment indicated that the total score for moringa was zero (0), compared to jatropha and castor which was thirteen (13) each.

DISCUSSION

The application of the WRA in the determination of the agronomic and invasiveness of three potential bioenergy fuel species *viz*., moringa physic nut and castor bean was justified. The tool is not simply a questionnaire but required specialist knowledge by the Assessors, and available published data to support its application. Further, it can determine invasiveness/noninvasiveness, but cannot be used as a regulatory instrument by plant quarantine or other agencies to declare weed invasive /non invasive unless the the spp is cultivated in the ecological zone to make that judgmental decision (Shay, 1993; Salisbury,

Table 5. Dispersal mechanisms and Persistence attributes characteristics of the Undesirable traits of moringa (*Moringa oliefera),* physic nut *(Jatropha curcas),* and castor bean (R*incinus communis)* response according to the WRA.

Dispersal mechanisms and Persistence attributes		**Response**		
		M.oliefera	***J.carcus***	***R.communis***
Dispersal mechanisms Of Propagules	unintentionally	-1	1	1
	intentionally by people	-1	1	1
	produce contaminant	-1	1	1
	wind	-1	1	1
	buoyant	1	1	1
	bird	-1	-1	-1
	other animals (externally)	-1	1	1
	other animals (internally)	-1	-1	-1
Persistence attributes	Prolific seed production	1	1	1
	persistent propagule bank (> 1 yr)	1	1	1
	controlled by herbicides	1	-1	-1
	Tolerates/ benefits from mutilation, cultivation or fire	1	1	1
	Effective natural enemies present in Trinidad and Tobago	-1	-1	-1
	Subtotal	**-3**	**5**	**5**

Table 6. Weed Risk assessment characteristics of morning (*Moringa oliefera),* physic nut *(Jatropha curcas),* and castor bean (R*incinus communis)* response according to the WRA.

Parameter	***M.oliefera***	***J.carcus***	***R.communis***
Domestication/ Cultivation	-3	0	0
Climate and Distribution	4	5	5
Weed elsewhere	1	-7	-7
Undesirable traits	0	9	9
Plant type	0	0	0
Reproduction	3	1	1
Dispersal mechanisms	-8	4	4
Persistence attributes	3	1	1
total	0	13	13
outcomes	evaluate	reject	reject

2008).

A short coming in this study was that the tool lacked an appropriate approach to assess the competiveness ability for soil moisture, nutrient, light and mutual antagonism. It is accepted that Taxa predicted to be invasive in their introduced range are likely to incur ecological and economic harm if cultivated, including increased carbon expenditures for their mechanical or chemical control outside of cultivation sites (Jefferson et al., 2004). If the contribution of those species to renewable energy generation is considered to be significant, then the effect-tive barriers to invasion and continuous monitoring and adequate resources management should be directed towards rapid detection and elimination of spp beyond the area cultivated.

Moringa which could be considered as a silviculture crop is naturalized but not considered invasive. However, the expanded cultivation of a species previously only grown at low density could significantly alter propagule pressure that can shift dispersal and colonization frequency. It is generally accepted that the cultivation of native species as bioenergy crops may pose greater risk of invasion than do others.

The weed risk assessment characteristics gave overall scores for moringa (0), jatropha *(13)* and castor oil (13), which suggests that moringa should be further evaluated, whilst the other two should be rejected as bioenergy crops for the Caribbean. In both instances, it can be directly related to their climatic adaptation and distribution; jatropha (5) and castor oil (5), and was further compounded by their dispersal mechanism (5) for both of them.

The study suggests that jatropha and castor bean should not be considered as bioenergy crops within the ecological limits in which this study was conducted, and that moringa should be further evaluated as bioenergy crop against invasiveness, given its agronomic potential as a high yielding oil crop.

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