INTRODUCTION

Recently, many kinds of exotic weeds have been found to cause serious problems in Japan. The invasion pattern was different from that of weeds which had been accidentally introduced in the past. These had spread gradually from the primary naturalized point along roads or railroad tracks. In contrast, the new exotic weeds appeared at the same time in all areas affected. They included many tropical species that grow up to three meters in height. These cause yield losses even in fields of forage crops, where comparatively tall crops are grown.

To determine what was responsible for the invasion of these new foreign weeds and their invasion route, Japan’s Ministry of Agriculture, Forestry and Fisheries carried out a research project from 1993 to 1996 (Project Report 1998a). Some local government institutes also carried out a project to develop ways of controlling the exotic weeds and preventing their seeds from spreading (Project Report 1998b). This Bulletin gives the results of this study of the source of the weeds, and describes the weed species involved and their distribution. The Bulletin also discusses the problem in general terms, and the future outlook.

Keywords: dairy farming, exotic weeds, feed grain, imported grains, Japan, weeds
initially believed that fodder crop seeds or imported feed might be the source of the invasion.

Possibility of invasion via fodder crop seeds

Because crop seeds for forage production are usually produced in foreign countries and exported to Japan, they provide an opportunity for exotic weeds to invade. However, fodder crop seeds are subject to strict inspection. It would be impossible for fodder crop seeds which were contaminated with weed seeds to pass the inspection. In fact, no weed seeds were found in imported maize seeds during our investigation.

Possibility of invasion via imported feed

The amount of feed such as concentrates and hay imported into Japan has been increasing recently, and it was noted that this increase coincided with the occurrence of foreign weeds (Fig. 2).

Imported grain which was used as feed stock for concentrated feed was investigated to determine whether foreign weed seeds were present. All grain imported during one year at the port of Kashima was thoroughly tested for weed seeds. The results showed that many kinds of weed seeds were mixed in with the grain imports (Table 1). Some of these species were noxious weeds (i.e. they were particularly damaging and/or particularly difficult to control).

An increasing amount of hay has also been imported into Japan in recent years, because many dairy farmers are unable to supply all their own feed. We checked samples from residues of imported hay remaining in the backs of trucks arriving at a dairy farmers’ cooperative over six months. Although many seeds were included in each sample, they were not those of the recently observed exotic noxious weed species.

These results suggested that the source of exotic weeds is most likely to be imported feed grain, which is used as an ingredient in concentrated feed. Most of this imported feed grain is from the United States.

Route of exotic weed seeds from the port to the field

At ports

When pests are found in imported grain, the grain is treated with methyl bromide. However, this treatment does not affect weed seeds.

At the feed factory

Imported grains used as livestock feed are processed in several way. They may be subjected to:
- Mechanical crushing (>2 mm);
- Pelletized steaming at 70 - 80°C after crushing;
- Heated under pressure to 130°C, 3 atm.

Many feed grains receive only the first treatment, which does not affect seed viability.

In the digestive system of animals

The effect on weed seeds of passing through the rumen of cows was studied. Only one species, *Abutilon theophrasti*, showed a decreased germination rate. Passing through the digestive species of livestock did not seem to reduce the germination rate of other imported weed species. In
Fig. 2. Changes in the amount of grain imported into Japan (based on FAO statistical data)

Table 1. Exotic weeds which have invaded Japan, mixed with imported grain

<table>
<thead>
<tr>
<th>Grain</th>
<th>Exporter</th>
<th>No. of imports</th>
<th>Total number of species</th>
<th>Number of seeds of each species</th>
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<td></td>
<td></td>
<td></td>
<td>100 ≤</td>
<td>50 ≤ 10 ≤ 2 ≤ 1</td>
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<td>USA</td>
<td>42</td>
<td>545</td>
<td>21 14 63 199 248</td>
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<td>21</td>
<td>3 6 12</td>
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<tr>
<td></td>
<td>Argentina</td>
<td>1</td>
<td>4</td>
<td>2 1</td>
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<tr>
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<td>13</td>
<td>289</td>
<td>31 7 44 97 110</td>
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<tr>
<td></td>
<td>Sudan</td>
<td>4</td>
<td>27</td>
<td>3 7 17</td>
</tr>
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<td></td>
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<td>2</td>
<td>7</td>
<td>5 2</td>
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<tr>
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<td>17</td>
<td>2 6 7</td>
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<td>1</td>
<td>19</td>
<td>1 5 12</td>
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<td></td>
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<td>2</td>
<td>29</td>
<td>5 2 3 10 9</td>
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<td>Oat</td>
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<td>4</td>
<td>112</td>
<td>18 6 23 39 26</td>
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</table>

Grain: C = Corn, L = Lupine, R = Rapeseed, S = Sorghum, Soy = Soybean, W = Wheat etc.
Exporting country: A = Australia, Ar = Argentine, C = Canada, Ch = China, G = Germany, Sa = South Africa
fact for many weeds species, it promoted germination.

Composting

Sometimes animal manure is composted by farmers, but sometimes it is spread directly onto fields. If the compost is well fermented, many weed seeds have reduced viability (Nishida et al. 1998). However, if fermentation is not complete or the manure is applied directly onto fields, no weed seeds are killed.

In the field

Many exotic weeds have resistance or tolerance to herbicides currently used in Japan. In many cases, these species have escaped from control programs carried out in their countries of origin. Current weed control methods in Japan tend to leave many exotic weeds unharmed. Thus, the number of exotic weeds invading Japan in imported grains and spreading out over farmers’ fields is increasing.

KINDS OF WEEDS MIXED IN IMPORTED GRAIN

Table 2 shows the list of the weed names we determined (Enomoto et al. 1996). The seeds of one of the most common foreign weeds, *Abutilon theophrasti*, were found in soybeans produced in USA and in lupines produced in Australia. A large number of seeds from several *Amaranthus* species were found in a range of grains from several countries. Seeds of an unusual species belonging to this family, *Amaranthus spinosus*, were found in soybeans from USA. This may have contributed to the spread of this weed species into the northern part of Japan (Shimizu 1998). Surprisingly, it was found that a number of native species, such as *Setaria faberi* Herrm, had been “reimported”. In addition, some species such as *Digitaria sanguinalis* or *Echinochloa muricata*, which do not have Japanese names because they were previously unknown in Japan, were also found mixed with imported grain.

LOSES CAUSED BY MAJOR EXOTIC WEEDS

*Abutilon theophrasti* Medik. (Fig. 3)

This is an annual plant belonging to the Malvaceae family. It is tall, fecund, self-fertile and contains a great deal of fiber. This plant was grown as a fiber crop in Japan until the 1920s. However, the weedy ecotype is genetically different from the crop type (Fig. 4) (Kurokawa et al. 1998a). Because the weed grows to about three meters in height and competes with crops, it causes serious yield losses. Moreover, the plant has a strong odor that may be transferred into milk if dairy cows take feed which includes *Abutilon theophrasti*.

*Solanum carolinense* L. (Fig. 5)

This plant is a perennial species belonging to the Solanaceae family, which propagates by both seeds and roots. This weed is very difficult to control, because most herbicides are ineffective and because it can propagate by its roots. It causes serious crop losses, while its sharp spines cause injuries to both livestock and people. It also contains alkaloids which are toxic to animals.

*Cyperus esculentus* L. (Fig. 6)

This sedge is a Cyperaceae species. It can be spread by vegetative propagation as well as seeds. Most herbicides are ineffective against this plant.

*Sicyos angulatus* L. (Fig. 7)

This vine belongs to the Cucurbitaceae family. It winds around the stems of crops such as corn and covers the plants. Even if it occurs infrequently, it can cause serious damage to crops.

*Datura stramonium* L. (Fig. 8)

This is a poisonous weed, which is highly toxic to both livestock and human beings. It can be troublesome even when the frequency of occurrence is low.

ATTEMPT TO CONTROL FOREIGN WEEDS

Local governments in Japan have developed two approaches to the control of exotic weeds. One is based on chemical herbicides, and the other is based on non-chemical control methods (Project Report 1998b).

Chemical control

Table 3 shows the list of herbicides tested, and their effect in controlling important introduced weeds. It was found that *Datura stramonium* could
Important exotic weeds in Japan

Fig. 3. *Abutilon theophrasti* suppressing the growth of corn

Fig. 5. *Solanum carolinense*

Fig. 6. *Cyperus esculentus*

Fig. 7. *Sicyos angulatus*

Fig. 8. *Datura stramonium*

Fig. 4. Genealogical tree of the weed *Abutilon theophrasti* accessions, based on DNA analysis (Kurokawa 1998a)

Asterisks show accessions mixed in with imported grain
<table>
<thead>
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<th>Herbicides registered for corn production</th>
<th>Abutilon theophrasti</th>
<th>Datura stramonium</th>
<th>Sicyos angulatus</th>
<th>Ipomoea coccinea</th>
<th>Cyperus esculentus</th>
<th>Ipomoea spp.</th>
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<td>Bentazon</td>
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<td></td>
<td>FS</td>
<td>F</td>
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</tr>
</tbody>
</table>

S: soil application  
F: foliar application  
Blanks show applications not tested  
Bold characters show that applications were effective. Normal characters show that applications were not effective in controlling this weed.
Fig. 9. Effect of paddy-upland rotation on the viability of *Abutilon theophrasti* seeds.

a: Change in the percentage of *Abutilon* seedlings in paddy rice.
b: Percentage of viable *Abutilon* seeds after paddy rice.


Table 4. List of noxious weed species distributed widely in the world

<table>
<thead>
<tr>
<th>Grain</th>
<th>Exporter</th>
<th>No. of imports</th>
<th>Total number of species</th>
<th>Number of seeds of each species</th>
<th>100 ≤</th>
<th>50 ≤</th>
<th>10 ≤</th>
<th>2 ≤</th>
<th>1</th>
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<td>21</td>
<td>3</td>
<td>6</td>
<td>12</td>
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<td></td>
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<tr>
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<td>1</td>
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<tr>
<td></td>
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<td>31</td>
<td>7</td>
<td>44</td>
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<td>3</td>
<td>7</td>
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<td>7</td>
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<td>2245</td>
<td>228</td>
<td>80</td>
<td>345</td>
<td>796</td>
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Micania cordata B.L. Robinson
Mikania micrantha H.B.K.
Micania scandens Wild
Picris hieracioides L.
Scolymus maculatus L.
Senecio aquatic Hill
Senecio vernalis Waldst. et Kit.
Senecio viscosus L.
Sphaeranthus indicus L.
Sphaeranthus sueveolens DC.
Tetragonia major Jacq.
Vernonia baldwinii Torr.
Xanthium pungens Wallr.
Cephalea perrotetii A.DC.
Corchorus tridens L.
Corchorus trilocularis L.
Triumfetta pilosa Roth
Triumfetta semiloba Jacq.
Acalypha alopecuroidea Jacq.
Acalypha ciliata Forssk.
Caperonia palustris St. Hill
Croton capitatus Michx.
Croton glandulosus L.
Croton hirtus L'Herit.
Croton lobatus L.
Euphorbia exigua L.
Euphorbia falcata L.
Mercurialis annua L.
Micrococcus mercurialis Benth.
Phyllanthus mederspachianus L.
Sclerochrysis maxima Wight et Arn.
Oxalis latifolia H.B.H.
Erodium malacoides L'Herit.
Geranium molle L.
Geranium tuberosum L.
Aeschynomene aspera L.
Aeschynomene sensittiva Sw.
Alysicarpus rugosus DC.
Celosopogon mucunoides Desv.
Cessia obtus Roxb.
Crotalaria retusa DC.
Crotalaria spectabilis Roth
Crotalaria verrucosa L.
Daubentonia punicea DC.
Desmodium adscendens DC.
Desmodium cuminum Schinz et Thell.
Indigofera linnei Ali
Indigofera viscosa Lam.
Lathyrus sativus L.
Medicago ciliaris Willd.
Medicago falcata L.
Mimosa invisa Mart.
Mimosa pigra L.
Mucuna pruriens DC.
Phaseolus trifolius Ait.
Pueraria phaseoloides Benth.
Rhynchosia mammonia DC.
Sebania aculeata Poir.
Sebania sesban Merr.
Physalis micrantha Link
Physalis viscosa L.
Schwenkia americana L.
Solanum dulcamara L.
Solanum incanus L.
Solanum sodomaeum L.
Galeopsis speciosa Mill.
Glychoma hederacea L.
Hypis pectinata Poit.
Hypis verticillata Jacq.
Leonotis nepetaphylla R. Br.
Leonturus cardiaca L.
Oximum gratissimum L.
Prunella vulgaris L.
Vicia peregrina L.
Potentilla reptans L.
Brassica campestris L.
Cardamine hisruta L.
Diplotaxis erucoides DC.
Diplotaxis muralis DC.
Hirschfeldia incana Lagreze-Fossat
Styliobroms loselli L.
Cleome chelidoni L.
Cleome monophylla L.
Cleome rutidosperma DC.
Fumaria capreolata L.
Fumaria densiflora DC.
Fumaria parviflora Lam.
Fumaria vaillantii Lois.
Papaver aggregatum L.
Ranunculus acris L.
Ranunculus aquatilis L.
Ranunculus ficaria L.
Drymaria cordata Willd.
Silene rubella L.
Mollugo nudicaulis Lam.
Trianthema pentandra L.
Boerhavia erecta L.
Alternanthera philoxeroides Gleseb.
Amaranthus dubius Mart.
Amaranthus quitensis H.B.K.
Amaranthus thunbergii Moq.
Celosia trigyna L.
Papulio lappacea A.Juss.
Atriplex semibaccata R.Br.
Chenopodium opulifolium Schrad.
Chenopodium polyspernum L.
Chenopodium rubrum L.
Emex australis Steinh.
Polygonum hydropiperoides Michx.
Polygonum punctatum Eill.
Urtica dioica L.
Juncus acutus L.
Juncus articulatus L.
Juncus maritimus Lam.
Heteranthera dubia Macm.
Heteranthera reniformis Ruiz et Pav.
Monochoria hastata Solms
Cyanotis exillaris D. Don
Ludwigia erecta Har.
Trapa natans L.
Ammannia auriculata Willd.
Rotala leptophylla Koehne
Viola arvensis Murr.
Viola tricolor L.
Bergia capensis L.
Melochia pyramidata L.
Walteria americana L.
Anoda cristata Schlecht.
Malva nicaensis All.
Side cordifolia L.
Side linifolia Cav.
Side urens L.
Cyperus articulatus L.
Cyperus bulbosus Vahl
Cyperus corymbosus Rottb.
Cyperus diffusus Vahl
Cyperus longus L.
Cyperus luzuloides Retz.
Cyperus procerus Rottb.
Cyperus pulcherimus Willd. et Kunth
Cyperus pygmaeus Rottb.
Cyperus strigosus L.
Eleocharis equisetina Presl
Eleocharis obtusa Schult.
Fimbristylis acuminata Vahl
Fimbristylis quinquangularis Kunth
Fimbristylis schoenoides Vahl
Scirpus acutus Muхи.
Scirpus articulatus L.
Scirpus holoschoenus L.
Scirpus supinus L.
Agropyron intermedium
Agrostis semiarticulata C. Christ.
Alopecurus myosuroides Huds.
Andropogon bicornis L.
Andropogon pertusus Willd.
Andropogon saccharoides Swartz
Anthoxanthum aristatum Boiss.
Aristida adscensionis L.
Avena sterilis L.
Aegopopus affinis Chase
Brachiaria flexe J.C.E.Hubб.
Brachiaria distachya Stapf
Brachiaria plantaginea Hithc.
Bromus arvensis L.
Bromus diandrus Roth
Bromus erectus Huds.
Bromus madritensis L.
Bromus racemosus L.
Cenchrus ciliaris L.
Centotheca lappacea Desv.
Desmostachya bipinnata Stapf
Dichanthium caricosum A. Camus
Digitaria filiformis Koel.
Digitaria horizontalis Willd.
Digitaria longiflora Pers.

(Continued over page)
Vicia narbonensis L.
Digitaria sanguinalis Scop.
Digitaria scalarum Chiov.
Distichlis spicata Greene
Echinochloa crus-pavonis Schult.
Echinochloa pyramidalis Hitchc.
et Chase
Echinochloa stagnina Beauv.
Eragrostis pectinacea Nees
Eragrostis tremula Hochst.
Eragrostis unioloides Nees
Festuca bromoides L.
Glyceria fluittans R. Br.
Glyceria maxima Holmb.
Holcus mollis L.

Courtoisia cyperoides Nees
Hyparrhenia rufa Stapf.
Ischaemum timorense Kunth
Lolium rigidum Gaud.
Melinis minutiflora Beauv.
Muhlenbergia frondosa Fern.
Olismenus burmannii Beauv.
Oottchoa nodosa Dandy
Pnicum antidotale Retz.
Pnicum brevifolium L.
Pnicum fasciculatum Sw.
Pnicum texanum Buckl.
Paspalum plicatum Michx.
Paspalum virgatum L.
Pennisetum pedicellatum Trin.
Pennisetum polystachyon Schult.
Phalaris brachystachys Link
Poa bulbosa L.
Sporobolus poiretii Hitchc.
Themeda arguens Hack.
Urochloa panicoides Beauv.
Alisma gramineum Lej. et Gmel.
Echinodorus cordifolius Griseb.
Sagittaria guayanensis H.B.K.
Sagittaria latifolia Wild.
Najas flexilis Rostk. et Schm.
Najas quadrulupensis Magnus
Potamogeton lucens L.
Potamogeton nodosus Poir.

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Fig. 10. The fruit of the weed *Emex australis*, which has recently invaded Japan from Australia in imported hay

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![Graph showing percentage of weed species with germinating seeds against maximum temperature in compost (°C).](chart.png)

**Fig. 11.** Percentage of weed species which retained their ability to germinate after being composted at varying temperatures

**Source:** Nishida et al. 1998
Fig. 12. Interspecific differences in susceptibility to electron irradiation
Source: Kurokawa et al. 1999

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Decline in price of milk

↓

Need for farmers to raise milk productivity

Increase in the number of animals reared by each farmer

More concentrates given, to raise the amount of milk produced by each cow

Animal waste in amounts too large to compost adequately

Increase in the amount of imported feed grain

Increased invasion by foreign weeds

Fig. 13. Context of the foreign weed problem
easily be controlled with existing herbicides. However, it is important that control programs eradicate all plants, because they are so poisonous. Many weeds such as Abutilon theophrasti or Sicyos angulatus are very difficult to control with existing herbicides. Herbicides have no control effect at all over Solanum carolinense.

Non-chemical control

Sometimes chemical control is difficult to apply. There may be no existing effective herbicide, while new herbicides take a long time to develop. In addition, it may be difficult to rely on herbicides alone from the viewpoint of sustainable agriculture. Ways of controlling major foreign weeds without herbicides were examined during the project by local governments. An example of these attempts is shown in Fig. 9.

PREVENTING INVASION BY NEW FOREIGN WEEDS

A list containing 316 weed species which may possibly invade Japan in the future was drawn up by Konnai et al. (Project Report 1998a) and is shown in Table 4. After this list was made, it was found that Emex australis (included in the list) had already invaded Japan. This weed, which is one of the worst in Australia, produces a number of spiny fruits (Fig. 10). It is clear that we can expect many additional weeds to invade in future, unless precautions are taken.

The only way to prevent the germination of weed seeds is to compost animal wastes adequately. The relationship between the temperature of fermenting compost and seed viability has been studied (Nishida et al. 1998, Nishida et al. 1999). It was found that seeds cannot survive in compost which reaches a maximum temperature during fermentation of more than 60°C (Fig. 11). Ensuring that the temperature of wastes reaches a sufficiently high level during composting is very important in preventing the invasion of new weeds.

Some new techniques have been tested lately to prevent weed invasions at ports. One of these is electron irradiation (Kurokawa et al. 1998b, Kurokawa et al. 1999). The susceptibility of different species to electron irradiation was found to vary widely (Fig. 12).

CIRCUMSTANCES SURROUNDING THE FOREIGN WEEDS PROBLEM

The circumstances surrounding the problem of foreign weeds are shown in Fig. 13. In Japan, a recent fall in milk prices has brought a financial crisis to dairy farmers. In this difficult situation, farmers have had to raise milk productivity in order to survive.

There were two ways of raising productivity. One was to increase the number of animals reared, and the other was to increase the average milk yield per cow. The first method produced animal wastes in too large a quantity for adequate composting. Consequently the seeds remained viable. The second method encouraged farmers to use more feed concentrates, which increased the chances that foreign weeds would invade, mixed in with imported grain. The combination of these factors resulted in the sudden appearance of a serious foreign weed problem.

WHAT WILL HAPPEN IN THE NEAR FUTURE?

We can see that the causes of the foreign weed problem are complex. If the situation does not improve, what will happen in the near future? This will depend mainly on the exporting countries. It is their actions, rather than those of Japan, which will determine the types and numbers of foreign weeds that will invade.

For example, a tolerance gene for non-selective herbicides has been introduced into some crops grown in the United States. In the future, weeds tolerant to non-selective herbicides may appear. Consequently, such herbicide-tolerant weeds may invade Japan. It is important to prevent this, and to find a way of changing the social and economic situation of agriculture.

REFERENCES


