Integrated Pest Management (IPM) & Insect Resistance Management (IRM) for Fall Armyworm in South African Maize

Compiled by IRAC South Africa, May 2018 (revised June 2021)

1 Introduction

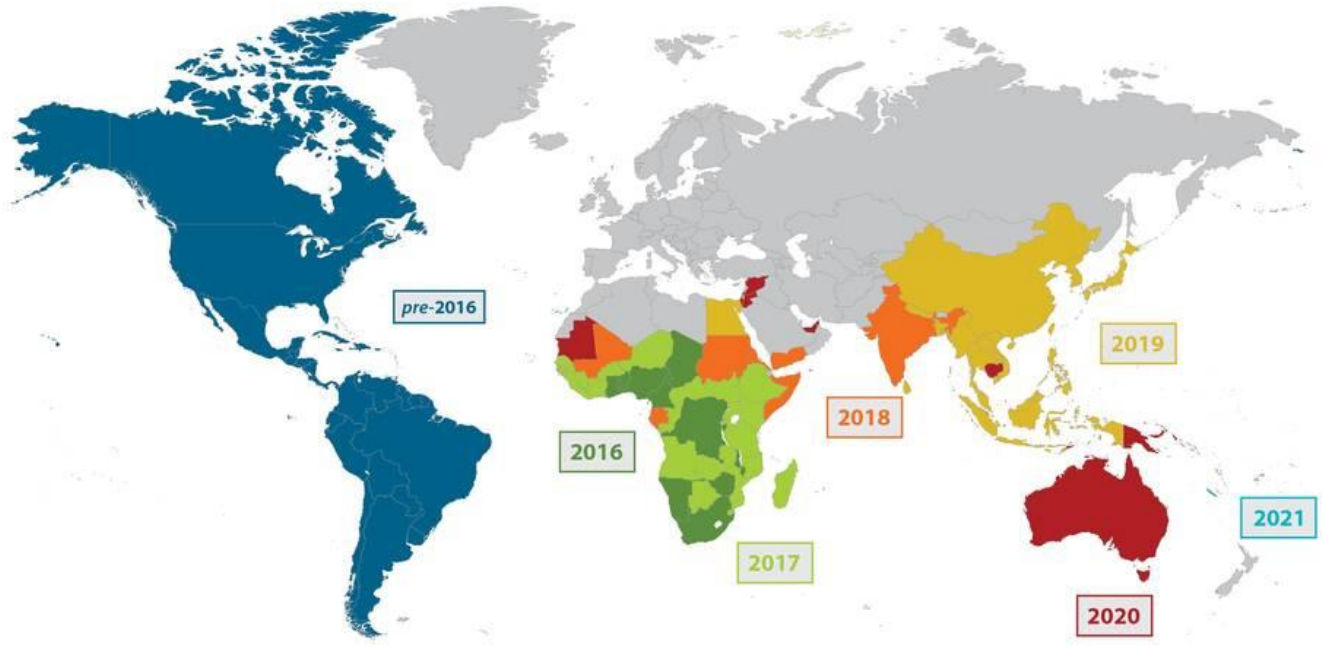
Fall Armyworm (*Spodoptera frugiperda*), FAW, is endemic to tropical and subtropical regions of North & South America. Larvae feed on more than 80 plant species, including maize, rice, sorghum, millet, sugarcane, vegetable crops and cotton. FAW can cause significant yield losses if not well managed. Multiple generations per year occur and under favourable conditions, adults can fly up to 100 km per night.

FAW was first detected in Central and Western Africa in early 2016 (Benin, Nigeria, Sao Tome and Principe, and Togo) and further reported and confirmed in the whole of mainland Africa (except Lesotho and the Island States), in Burkina Faso, Cabo Verde, Cameroon, Gambia, Ghana, Guinea Bissau, Niger, Senegal, and Ethiopia, Burundi, Kenya, Rwanda, South Sudan, Uganda (FAO Briefing Note on FAW, Oct 2017). In South Africa it was first detected in the summer of 2016, and identification confirmed in February 2017 (IPPC Feb 2017 report). Since its detection in South Africa, it has further spread to northern parts of Africa, to Asia and Australia (http://www.fao.org/fall-armyworm/monitoring-tools/faw-map/en/).

Although Bt GM maize has been proven to be an efficient and reliable technology against FAW in South Africa (Botha *et al.* 2019) and other parts of the world, a singular reliance on Bt-technology will not be sufficient to manage this pest. Some reports of FAW resistance to Bt-technology have been recorded (Fatoretto *et al*, 2017; Botha *et al.* 2019). In addition, Bt GM maize is not currently registered for the control of fall armyworm in South Africa. Integrated Pest Management programmes will be required to ensure continued high maize productivity, as well as manage the risk for resistance development against Bt-technologies in South Africa. Bt-technologies are widely used in commercial maize production in South Africa and an efficient system of structured refugia has been adopted with an approx. 90% compliance by growers to reduce the risk of resistance development in *Busseola fusca*, the African Maize Stalk Borer. Current IRM plans for *Busseola fusca* and *Chilo partellus* require growers to plant either a minimum 5% unsprayed or minimum 20% sprayed refuge.

In South Africa, it will be critically important to have a harmonised approach to IRM for FAW across the industry and across technologies. This approach should combine a clear and simple structured refuge policy which does not confuse growers between the requirements for FAW and maize stalk borers in South Africa, and which enables a high grower compliance. There are several commercialised Bt-products in South Africa which are very similar. This approach is in the best interests of the seed industry, growers and South African consumers.

Map of areas affected by Fall Armyworm since 2016 (June 2021)



Source: FAO http://www.fao.org/fall-armyworm/monitoring-tools/faw-map/en/

2 The Need for Integrated Pest Management to deliver effective FAW control

Although Bt-technologies in maize offer a very good control option for FAW, it is clear that this on its own will not deliver durable and sustainable options into the future. It is important that transgenic technologies be coupled with effective insecticide programmes to ensure a workable and lasting solution for FAW, which is likely to remain a significant pest of not only maize, but many other row and vegetable crops in South Africa.

The proposed FAW IPM working group, residing under IRAC and Crop Life SA, offers one of the best avenues to develop a sustainable set of IPM recommendations to align the industry and ensure high adoption of the same, while also ensuring durability of control systems.

3 Control of FAW with Bt

Several Bt-technologies have been approved for commercial cultivation in maize in South Africa. These are the following events:

1.	MON810	YieldGard	Bayer
2.	MON89034	YieldGard II	Bayer
3.	Bt11	AgriSure	Syngenta

These events express combinations of Cry1 and Cry2 proteins, which have varying levels of efficacy against FAW (Botha *et al.* 2019).

Bt-technologies are widely used in maize production in South Africa and a sophisticated system of structured refugia has been adopted by growers to reduce the risk of resistance development in *Busseola fusca*, the African Maize Stalk Borer. Current IRM requires growers to plant either a minimum 5% unsprayed or minimum 20% sprayed refuge. Compliance is very high, in the order of 90%.

The SANSOR Innovation committee has recently aligned IRM recommendations for FAW and other maize stalk borers for Bt-maize production in South Africa. The purpose of this document was to expand these recommendations to include an insecticide component in the control programmes for maize stalk borers and FAW. A harmonised approach to IRM is expected to prolong the efficacy of all Bt–technologies and registered insecticides in maize in South Africa.

4 IRM Recommendations for Bt-Maize (from SANSOR)

- **Planting either a minimum of 5% unsprayed or 20% sprayed non-Bt maize refuge within 400m of the transgenic maize is considered mandatory for managing resistance to plant incorporated Bt-toxins**
- The application of insecticides to the non-transgenic refuge can either neutralise or reduce the resistance management benefits of planting the structured refuge. Therefore, under low pest pressure conditions it is recommended not to apply insecticides to the refuge.

- The initial period (first 30 days) after seeding is considered the most critical period for plant protection from insects. Seed treatment or early use of foliar insecticides can provide early pest control and help crop establishment in both the transgenic crop and the refuge.
- Under high pest pressure the application of insecticides may be necessary in both the transgenic crop and the refuge in order to maintain the crop.
- The following action thresholds are recommended to minimise the number of insects in the traited crop, whilst maximising the productivity of the refuge (both yield & susceptible insect production).
- For *Busseola fusca* and *Chilo partellus*
    - Transgenic maize: Insecticide application when 5-10% of the plants exhibit *Busseola/Chilo* damage (5% preventative, 10% action threshold)
    - Refuge maize / non-Bt maize: 5% Refuge – no spraying, 20% refuge insecticide application when 10% of the plants exhibit *Busseola/Chilo* damage.
- For *Spodoptera frugiperda* (FAW)
    - Transgenic maize: Insecticide application when 5-10% of the plants exhibit plant damage at Davis scale 3 & above (5% preventative, 10% action threshold)
    - Refuge maize / non-Bt maize: 5% Refuge – no spraying, 20% Refuge - Insecticide application when 20% of the plants exhibit damage at Davis scale 3 or more.
- **For *Spodoptera frugiperda* only: Under conditions of extreme infestation (> 20% of the plants infested at a Davis rating of 3 or more) in the 5% unsprayed refuge, it may be necessary to control FAW by applying insecticides. Should the refuge be sprayed in these circumstances, the Bt field should be sprayed as well.**
- The use of *Bacillus thuringiensis* based foliar insecticide sprays is not allowed in the refuge.
- All the associated refuge requirements for maize borers should be adhered to (Industry proposal August 2017).
- Only insecticides that have been registered under Act 36 of 1947 should be used when controlling FAW in South Africa.
- Furthermore, it is recommended that an Integrated Pest Management approach be developed to combat FAW and to prolong the efficacy of Bt-technologies in maize in South Africa.

5 Davis Visual Rating Scale

Types of lesions caused by FAW (Davis 1992)

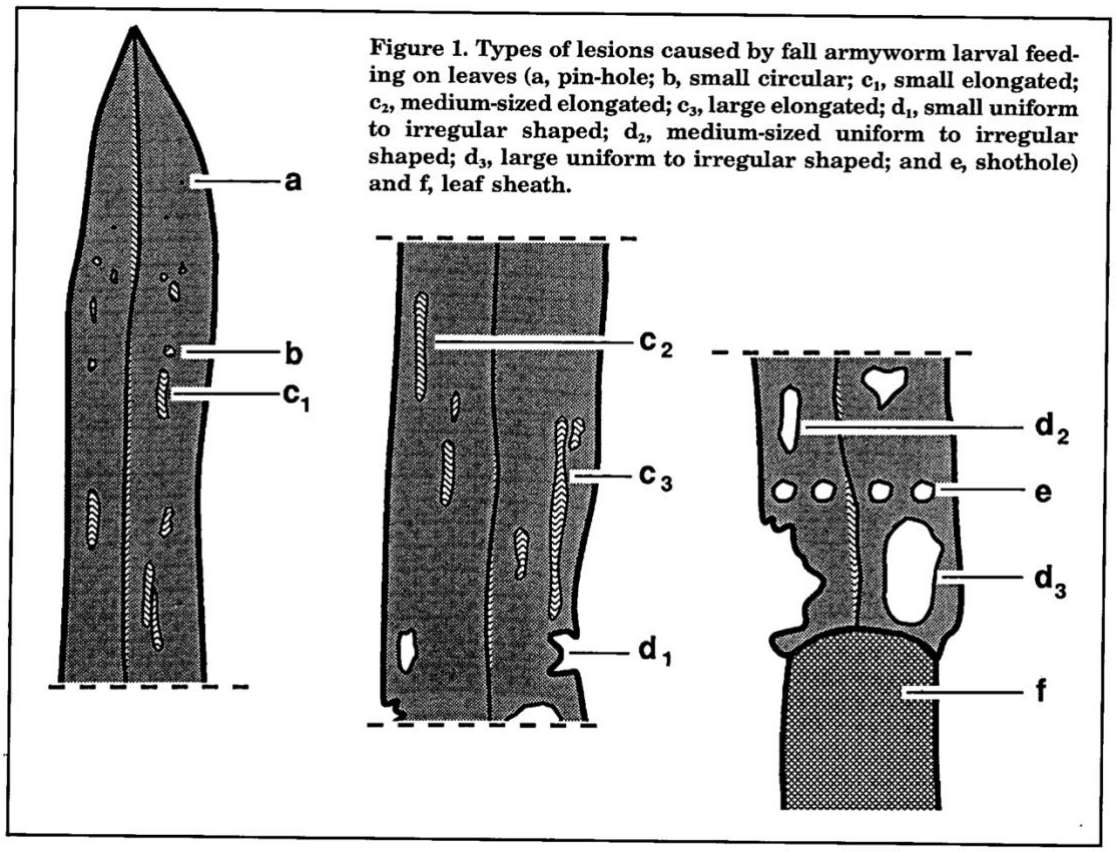
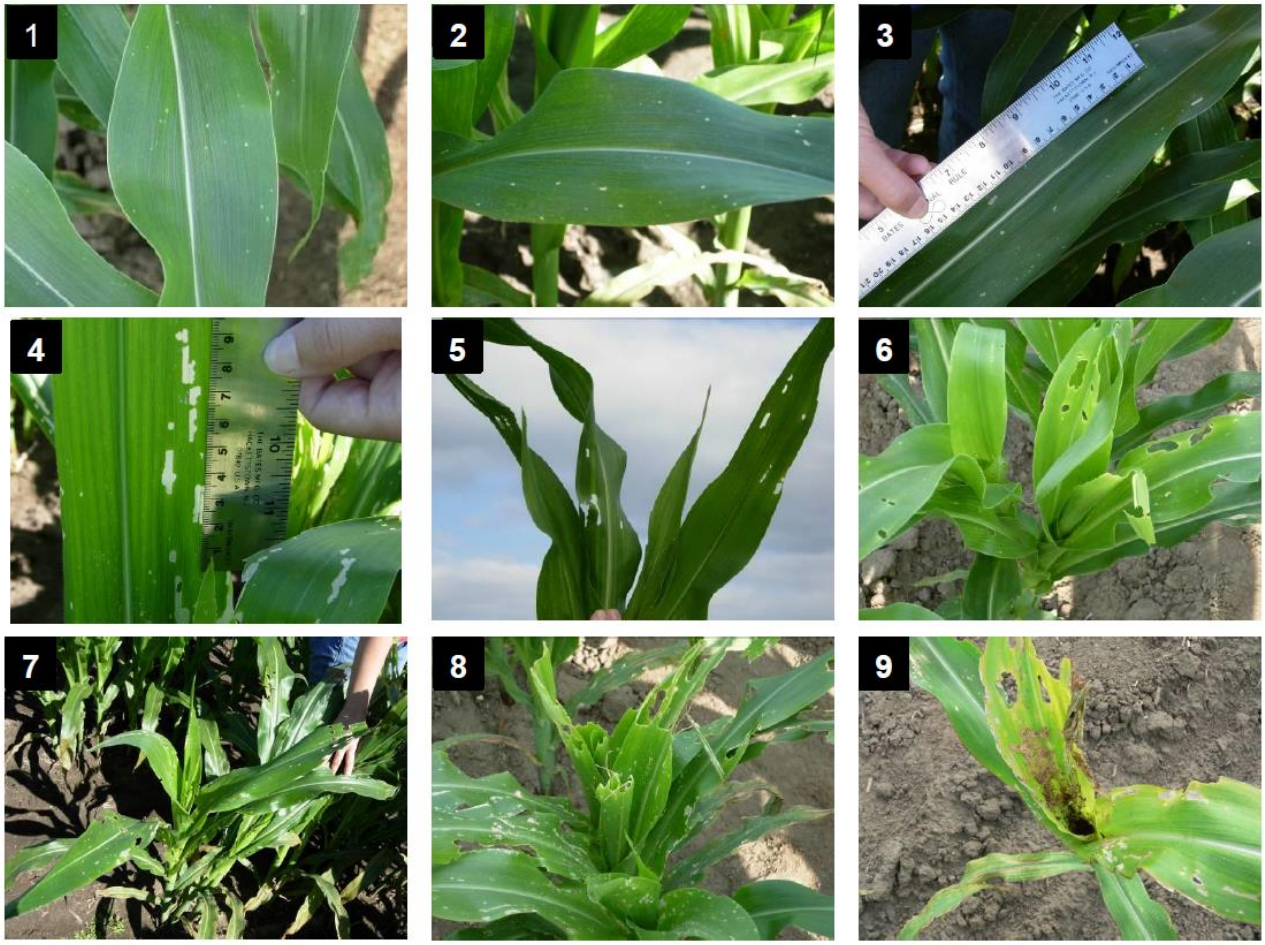


Figure 1. Types of lesions caused by fall armyworm larval feeding on leaves (a, pin-hole; b, small circular; c_1, small elongated; c_2, medium-sized elongated; c_3, large elongated; d_1, small uniform to irregular shaped; d_2, medium-sized uniform to irregular shaped; d_3, large uniform to irregular shaped; and e, shothole) and f, leaf sheath.

Visual guide of Davis Scale (Source: DuPont Pioneer, Brazil)



6 Insecticides & Insecticide programs for FAW control

General

1. Application windows are recommended where multiple insecticide applications are required.
2. FAW has an approximately 30-day generation period – establish application windows that are approximately 30 days apart to ensure that sequential generations of FAW are not exposed to the same insecticide Mode Of Action (MOA) in sequential insecticide applications.
3. Multiple applications of the same MOA in a single window period should be avoided.
4. Seeds treated with an insecticide may not provide effective control for the duration of the first window. If additional foliar applications are required in the first window, they should be of a different MOA, and should be applied no later than 25 days after planting.
5. The use of selective insecticides with reduced impact on non-target and beneficial insects should be used where possible.
6. Management of crop residues / volunteer plants before planting and after harvest is critical – burn down to remove host plants/weeds before planting and apply insecticides post-harvest if FAW is observed.
7. Sequential maize plantings will increase the local populations of FAW.
8. Learn which insecticides have the same MOA / belong to the same groups, and make sure different MOA are used in each window period. See Tables 1-11, and also the Diagrams on pages 18-20 for examples of Window applications.

Known insecticide resistance in FAW

Resistance has been reported in the following groups: Carbamates (1A), Organophosphates (1B), Pyrethroids (3), Bt's (11A) (IRAC. Strategies for Sustainable Control of Fall Armyworm, *Spodoptera frugiperda* www.irac-online.org).

Insecticides and MOA groups registered for FAW in South Africa (refer to http://www.irac-online.org/modes-of-action/)

Nerve & Muscle Targets

1. Group 1: Acetylcholine esterase (AChE) inhibitors: 1A: Carbamates, 1B: Organophosphates
2. Group 3: Sodium channel modulators: 3A: Pyrethrins & Pyrethroids
3. Group 5: Nicotinic acetylcholibe receptor (nAChR) allosteric modulators: Spinosyns
4. Group 6: Chloride channel activators: Avermectins
5. Group 14: Nicotinic acetylcholine receptor (nAChR) blockers: Cartap hydrochloride
6. Group 22: Voltage dependant sodium channel blockers: 22A: Indoxacarb, 22B: Metaflumizone
7. Group 28: Ryanodina receptor modulators: Diamides

Midgut Targets

1. Group 11: Microbial disruptors of insect midgut membranes: 11A: *Bacillus thuringiensis*, 11B: *Bacillus sphaericus*

Growth & Development Targets

1. Group 15: Inhibitors of chitin biosynthesis: Benzolureas: e.g. Flufenoxuron, Lufenuron, Novaluron
2. Group 18: Ecdysone receptor antagonists: Diacylhydrazines e.g. Methoxyfenozide

Unknown Mode of Action

1. UND: Compounds with unknown MOA: Pyridalyl

FAW Resistance management (http://www.irac-online.org/)

To prevent the development of insecticide resistance, use a combination of all available pest management and resistance management tools to decrease FAW exposure to insecticides.

- Always follow the label directions of each product.
- Consult product label or IRAC's website (www.irac-online.org) to determine the MOA of each product.
- Do not treat successive generations with products of the same MOA.
- Follow the "treatment windows" approach:

  A "treatment window" is the period of residual activity provided by single or sequential applications of products with the same mode of action. This "treatment window" should not exceed approximately 30 days (generally used as the length of an insect pest generation) but can be less and should not exceed more than 2 applications of products from the same MOA.

- Generally, the total exposure period of products representing a single MOA applied throughout the crop cycle (from seedling to harvest) should not exceed approximately 50% of the crop cycle or exceed 50% of the total number of insecticide applications targeted at the same pest species.
- Apply insecticides only when needed based on economic thresholds.
- Choose products from Tables 1-11, making sure not to apply products from the same Table (MOA) in the same window. Ensure 60 days between applications of the same MOA, according to IRAC guidelines.

Table 1: IRAC Group 1 agrochemicals registered to control FAW in South Africa

Brand Name	Registration Number	Active ingredients	Type	Resistance Group (IRAC)	Resistance sub Group (IRAC)	Registered for Use on the Following Crops:
Spitfire 900 SP	L8197	Methomyl	Contact insecticide	1	1A	Maize
Avi Klorpirifos	L4318	Chlorpyrifos	Contact insecticide	1	1B	Maize
FarmAg Methomyl 90 SP	L3436	Methomyl	Contact insecticide	1	1A	Maize
Masta 900 SP	L9449	Methomyl	Contact insecticide	1	1A	Maize and potatoes
Agropyrifos	L4888	Chlorpyrifos	Contact insecticide	1	1B	Maize, pastures and Potatoes
Pyrinex 480 EC	L4673	Chlorpyrifos	Contact insecticide	1	1B	Maize
Mylomex 900 SP	L4383	Methomyl	Contact insecticide	1	1A	Cruciferae (cabbage, broccoli, cauliflower and brussels sprouts), maize, tobacco, sorghum, wheat, lupins, lucerne, veld and grazing
Methomate 200 SL	L8123	Methomyl	Contact insecticide	1	1A	maize, cotton ,sorghum and veld grazing
Methomyl 200 SL	L7100	Methomyl	Contact insecticide	1	1A	maize, cotton ,sorghum and veld grazing
Avi-Merkaptothion DP	L4278	Mercaptothion / malathion	Stomach and contact insecticide	1	1B	Cruciferae (cabbage, broccoli, cauliflower and brussels sprouts), Sorghum, groundnuts, maize, cotton, sugarcane, tomatoes, flowers, ornamentals, peaches and plums, sugarcane, lucerne
Datathion 500 EC	L828	Mercaptothion / malathion	Stomach and contact insecticide	1	1B	Broccoli, Brussels sprouts, Cabbage, Cauliflower, Grazing, Maize, Sorghum, Wheat
FarmAg Profenofos 500	L5547	Profenofos	Stomach and contact insecticide	1	1B	Cotton, potatoes

Table 2: IRAC Group 3 agrochemicals registered to control FAW in South Africa

Brand Name	Registration Number	Active ingredients	Type	Resistance Group (IRAC)	Resistance sub Group (IRAC)	Registered for Use on the Following Crops:
Akito	L6709	Beta-cypermethrin	Stomach and contact insecticide	3	3A	maize, sorghum, sweetcorn, wheat, tomatoes, peas, lupins, lucerne, groundnuts and Cruciferae (cabbage, broccoli, cauliflower and brussels sprouts)

Table 4: IRAC Group 5 agrochemicals registered to control FAW in South Africa

Brand Name	Registration Number	Active ingredients	Type	Resistance Group (IRAC)	Resistance sub Group (IRAC)	Registered for Use on the Following Crops:
Delegate 250 WG	L8392	Spinetoram	contact and stomach insecticide	5	5A	Cruciferae (cabbage, broccoli, cauliflower and brussels sprouts), maize, sweetcorn and sorghum
Tracer 120 SC	L7234	Spinosad	Contact and stomach insecticide	5	5A	Baby marrows, Butternuts, Cucumbers, Gem squash, Gherkins, Hubbard squash, Lawns, Lettuce, Marrows, Melons, Musk melons, Patty pans, Pumpkins, Spinach, Squashes, Tomatoes, Watermelons

Table 5: IRAC Group 6 agrochemicals registered to control FAW in South Africa

Brand Name	Registration Number	Active ingredients	Type	Resistance Group (IRAC)	Resistance sub Group (IRAC)	Registered for Use on the Following Crops:
Emma	L9022	Emamectin benzoate	Stomach translaminnar insecticide	6	6	Maize, sweetcorn and potatoes
Proclaim	L7581	Emamectin benzoate	Stomach translaminnar insecticide	6	6	Barley, beans, groundnuts, peas, maize , sweetcorn , sorghum, sunflower, soy bean, dry bean, wheat
Promec 20 EW	L9729	Emamectin benzoate	Stomach translaminnar insecticide	6	6	Cruciferae (cabbage, broccoli, cauliflower and brussels sprouts), maize, sweetcorn,
Vitex 50	L9525	Emamectin benzoate	Stomach translaminnar insecticide	6	6	Cruciferae (cabbage, broccoli, cauliflower and brussels sprouts), maize, sweetcorn,
Warlock 19.2 EC	L9872	Emamectin benzoate	Stomach translaminnar insecticide	6	6	Maize and sweetcorn

Table 6: IRAC Group 11 agrochemicals registered to control FAW in South Africa

Brand Name	Registration Number	Active ingredients	Type	Resistance Group (IRAC)	Resistance sub Group (IRAC)	Registered for Use on the Following Crops:
Delfin	L9761	Bacillus thuringiensis var kurstaki Strain SA-11	Bioinsecticide	11	11	Cruciferae (cabbage, broccoli, cauliflower and brussels sprouts), barley, cotton, maize, sorghum, soybean and wheat.
Eco-Bb	L8469	Beauveria bassiana	Bioinsecticide	11	11	Cruciferae (cabbage, broccoli, cauliflower and brussels sprouts) Maize, sweetcorn, soybean, tomatoes and sorghum
Florbac WG	L5531	Bacillus thuringiensis var. aizawai	Bioinsecticide	11	11	Maize and sweetcorn

Table 7: IRAC Group 15 agrochemicals registered to control FAW in South Africa

Brand Name	Registration Number	Active ingredients	Type	Resistance Group (IRAC)	Resistance sub Group (IRAC)	Registered for Use on the Following Crops:
Sorba	L5343	Lufenuron	Insect growth inhibitor (IGI)	15	15	Barley, beans, dry bean, cruciferae(cabbage, broccoli, cauliflower and brussels sprouts),groundnuts, maize, peas, sweetcorn, sunflower, soy bean, sorghum, and wheat
Judge	L9927	Lufenuron	insect growth inhibitor (IGI)	15	15	Maize, sweetcorn and potatoes
LepideX	L7977	Lufenuron	Insect growth inhibitor (IGI)	15	15	Broccoli, Brussels sprouts, Cabbage, Cauliflower
Dimilin 25 WP	L5483	Diflubenzuron	Contact insecticide	15	15A	Maize, sweetcorn, and potatoes
Dimilin SC 48	L7140	Diflubenzuron	Contact insecticide	15	15A	Maize, sweetcorn and potatoes

Table 8: IRAC Group 22 agrochemicals registered to control FAW in South Africa

Brand Name	Registration Number	Active ingredients	Type	Resistance Group (IRAC)	Resistance sub Group (IRAC)	Registered for Use on the Following Crops:
Steward	L8435	Indoxacarb	Stomach and contact insecticide	22	22A	Cotton, lettuce, maize, peppers, sorghum, soy bean, sweetcorn, potatoes and sugarcane
Advance	L9147	Indoxacarb	Stomach and contact insecticide	22	22A	Cotton, maize and sorghum, veld and grazing, peppers, soya beans
Addition	L9146	Indoxacarb	Stomach and contact insecticide	22	22A	Cotton maize, sorghum, veld and grazing, peppers, soya beans
Doxstar Flo	L9884	Indoxacarb	Stomach and contact insecticide	22	22A	cruciferae(cabbage, broccoli, cauliflower and brussels sprouts), maize, peppers and sweetcorn
Steward	L6332	Indoxacarb	Stomach and contact insecticide	22	22A	Cotton, lettuce, maize, sweetcorn, soy beans, sorghum, and potatoes
Margin 300 WDG	L9009	Indoxacarb	Stomach and contact insecticide	22	22A	Cotton, Grazing, Maize, Pastures, Sorghum
InCide 300 WG	L10524	Indoxacarb	Stomach and contact insecticide	22	22A	Maize, potatoes, sweetcorn

Table 9: IRAC Group 28 agrochemicals registered to control FAW in South Africa

Brand Name	Registration Number	Active ingredients	Type	Resistance Group (IRAC)	Resistance sub Group (IRAC)	Registered for Use on the Following Crops:
Coragen	L8529	chlorantraniliprole	Stomach and contact insecticide	28	28	Cotton, maize, sorghum, sweetcorn, sugarcane and potatoes
Belt	L8860	Flubendiamide	Non systemic	28	28	Endive, lettuce, maize, spinach and maize
Prevathon	L9150	Chlorantraniliprole	Stomach and contact insecticide	28	28	Maize, sweetcorn, and sorghum

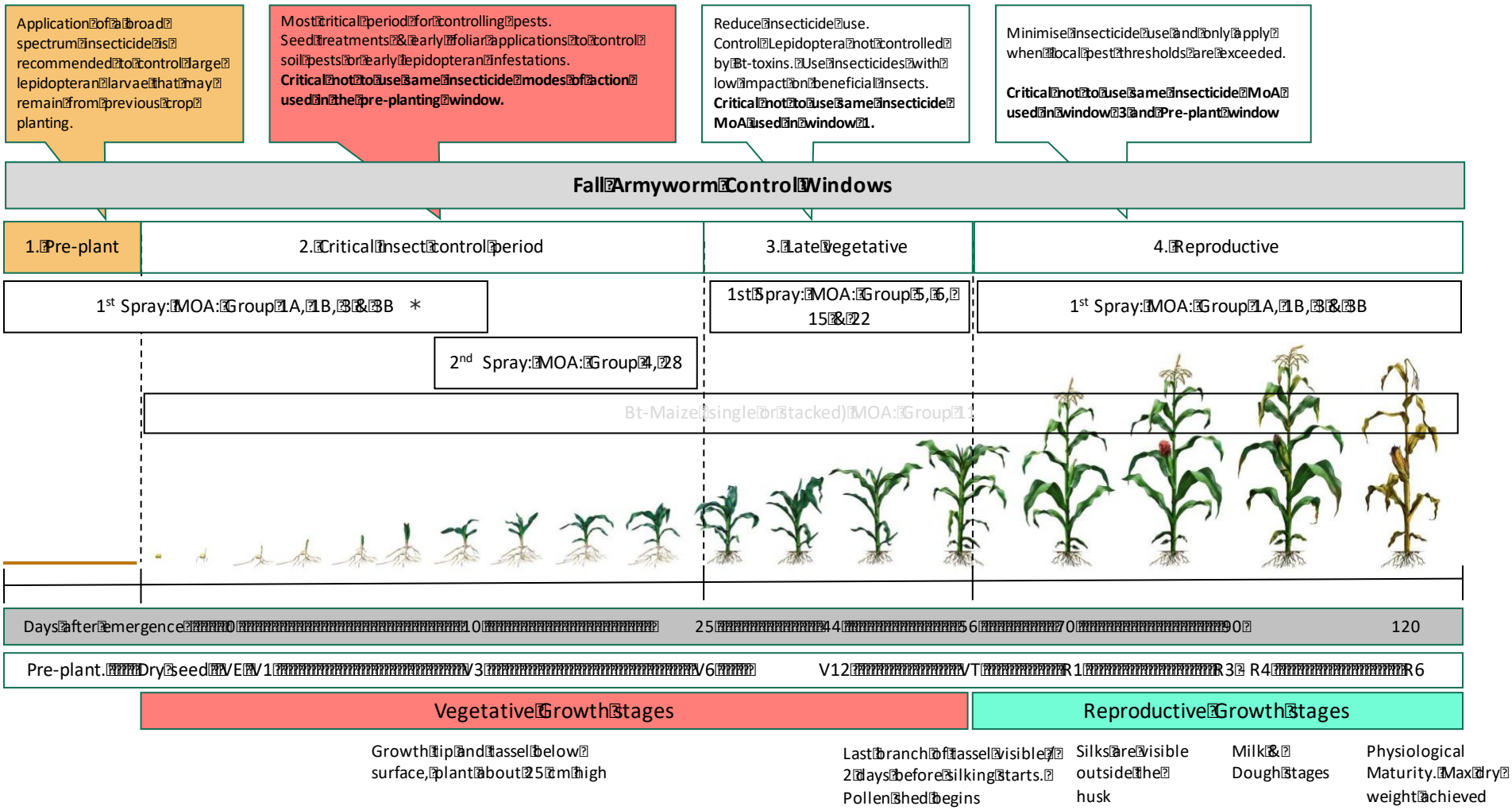
Table 10: Products with UNKNOWN MOA registered to control FAW in South Africa.

Brand Name	Registration Number	Active ingredients	Type	Resistance Group (IRAC)	Resistance sub Group (IRAC)	Registered for Use on the Following Crops:
Sumipleo SC	L8377	Pyridalyl	Stomach & contact insecticide	Unknown	Unknown	Maize and sweetcorn

Table 11: Products with multiple IRAC Group agrochemicals registered to control FAW in South Africa. Use of these products in one window disqualifies the use of the second MOA in the product in the same window.

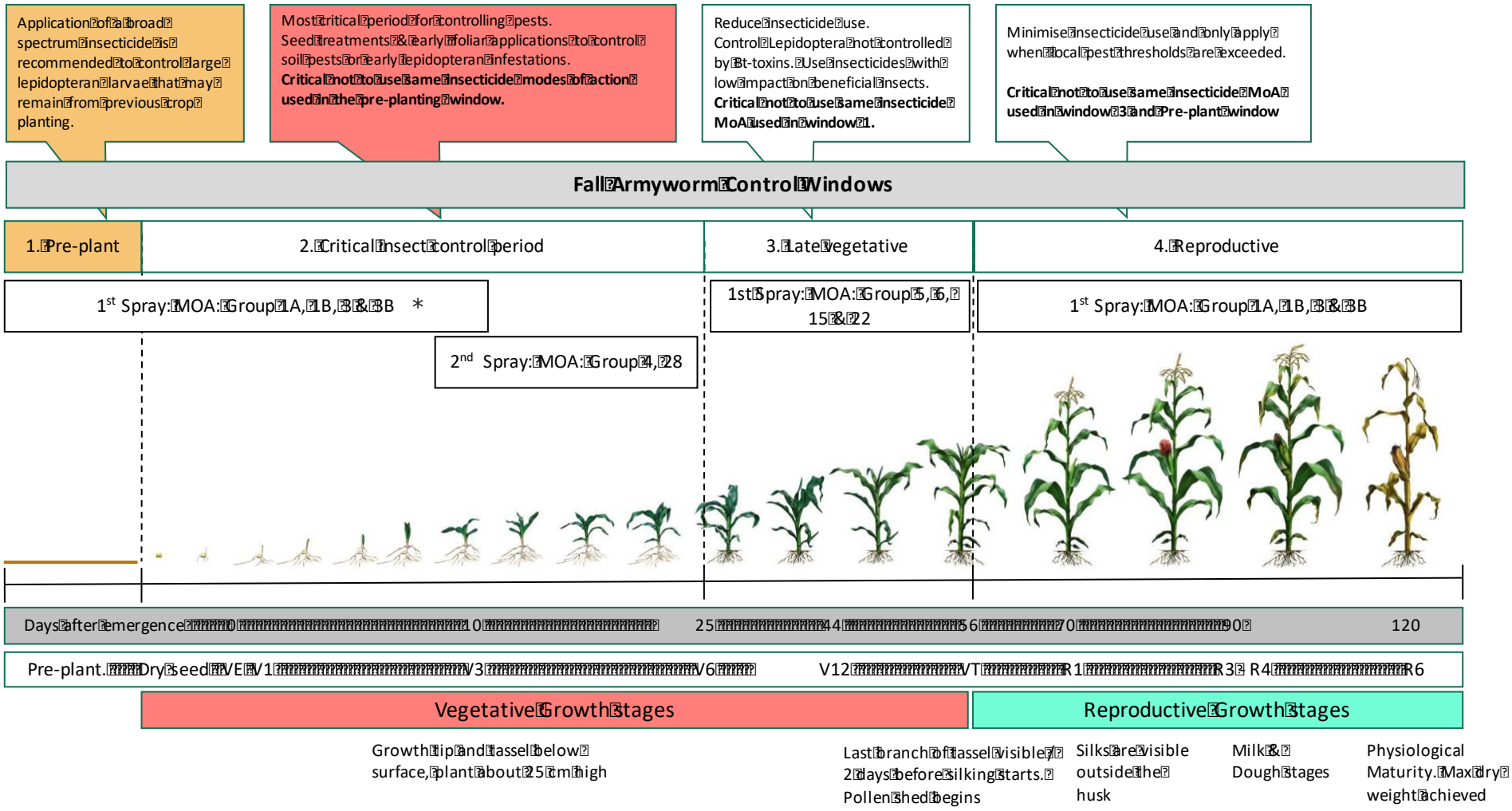
Brand Name	Registration Number	Active ingredients	Type	Resistance Group (IRAC)	Resistance sub Group (IRAC)	Registered for Use on the Following Crops:
Oncol Super 220 EC	L7649	Benfuracarb / fenvalerate	Systemic & contact insecticide	1 3	1A and 3	Maize, sweetcorn, and sorghum
Cyperfos 500 EC	L7606	Chlorpyrifos/ Cypermethrin	Stomach & contact insecticide	1 3	1B and 3B	Maize, wheat and sorghum
Plemax	L10246	Indoxacarb/ novaluron	Chitin inhibition, Stomach & contact insecticide	22 15	22A and 15	Maize and sweetcorn
Ampligo	L8685	Chlorantraniliprole/ lambda- cyhalothrin	Stomach & contact insecticide	3 28	3 and 28	Barley, canola, maize, sweetcorn, groundnuts, soy bean, sunflower, and wheat
Uphold 360 SC	L10164	Spinetoram/ methoxyfenozide	Contact & stomach insecticide	5 18	5A and 18	Maize, sweetcorn, and sorghum
Limit 350 EC	L8601	Chlorpyrifos / lambda-cyhalothrin	Contact and stomach insecticide	1 3	1A and 3A	Maize, soya beans
Linear 350 EC	L8602	Chlorpyrifos / lambda-cyhalothrin	Contact and stomach insecticide	1 3	1A and 3A	Maize, soya beans

Application Windows && Example MOA's for Bt-Maize main crop



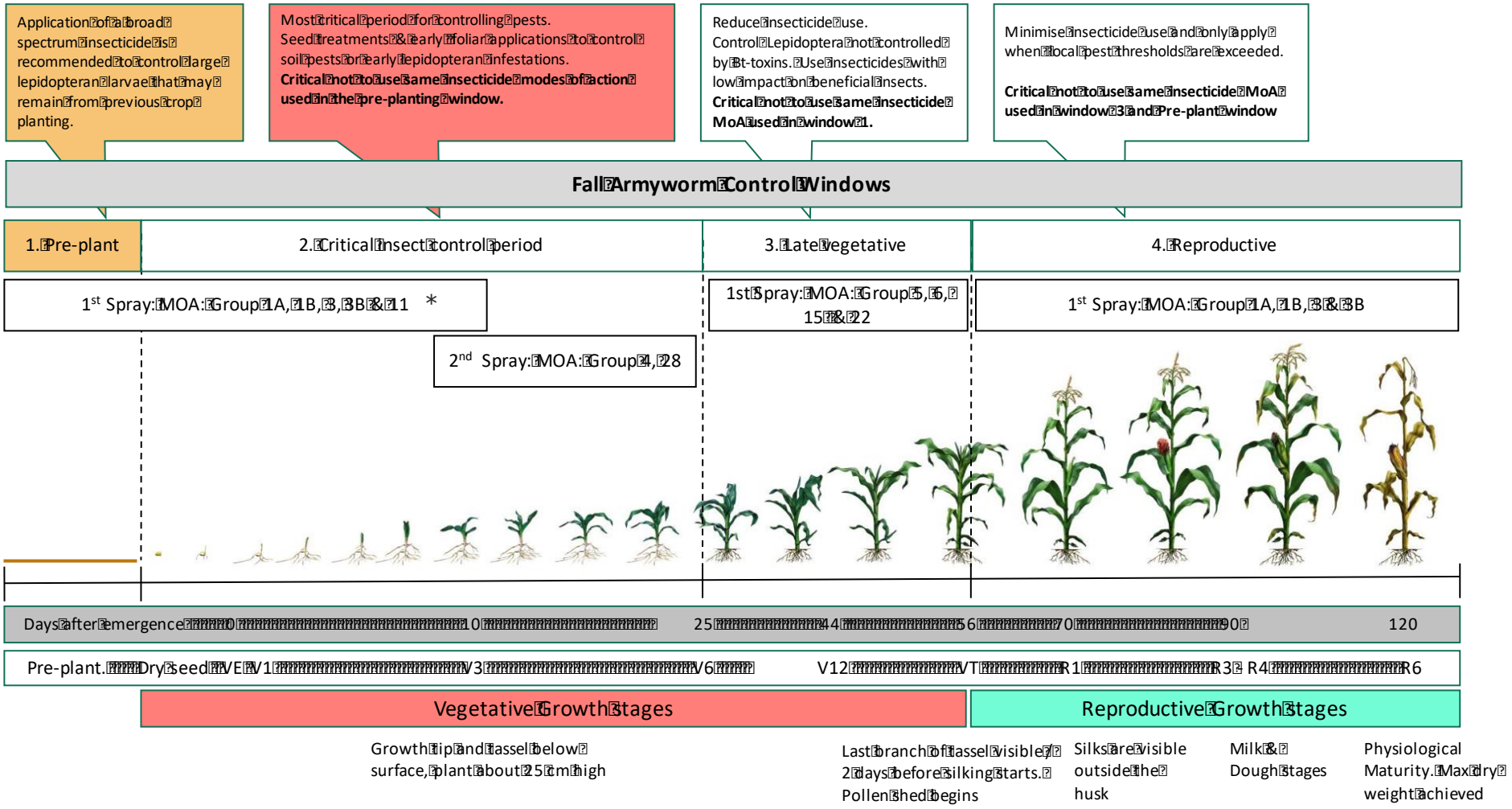
NB: Group 11 insecticides may also be applied on Bt-maize, * Choice of MOA groups for example purposes

Application Windows & Example MOA's for non-Bt-Maize refuge



NB: Group 11 insecticides may not be applied on non-Bt maize refugia, * Choice of MOA groups for example purposes

Application Windows && Example MOA's for Conventional Maize Crop



* Choice of MOA groups for example purposes

7 Additional Resources & References

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- A list of insecticides registered for use against FAW may be found at http://www.daff.gov.za/daffweb3/Branches/Agricultural- Production-Health-Food-Safety/Food-Import-Export-Standards/Fall-armyworm
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- FAO map: http://www.fao.org/fall-armyworm/monitoring-tools/faw-map/en/

For more information on fall armyworm, visit the Agri-Training website: https://agritraining.co.za/

