NEW DEVELOPMENTS OF DIMETHYL DISULFIDE (DMDS) IN EUROPE

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Several soil pests and weeds, in particular nematodes and yellow nutsedge, represent today a bottleneck for the productivity of the European farms. Pressure from nematodes has grown during the last decade in the Southern countries, because of the Methyl Bromide ban in 2000s and also due to the fact that 1.3D and chloropicrine registrations weren't renewed (now again under a new evaluation process by EU authority), and are used only in limited periods of 120 days under derogation regime. Meantime, MITC generators (metam sodium and potassium and dazomet) have been re-registered with the limitation of use once in three years or limited dose rate in open field for metam (153 Kg a.i./Ha). The other post-planting chemical and alternative solutions available, are not enough effective to solve the problems of high-nematodes populations in several crops, like protected vegetables, carrot, strawberry, tobacco, and many others.

Among weed species, a major concern in Europe is the yellow nutgrass (*Cyperus esculentus*), already listed in EPPO List of Invasive Alien Plants since 2004. This weed is now spread across most of the countries in Europe, causing severe problems for the cultivation of carrot, strawberry and tree nurseries, and many other vegetable crops. Some effective herbicide active ingredients against *Cyperus* spp., previously available, lost registration at EU level. Therefore, the problems from yellow nutsedge are increasing, as the weed has high reproduction potential and spatial dissemination, while no effective control is actually in place.

Certis Europe has entered in to an exclusive agreement with Arkema for the development, registration and distribution of Dimethyl Disulfide (DMDS) as soil fumigant in Europe. This product, now under EU registration process, will be a future pillar of Certis CleanStart program for the sustainable soil pest management in Europe.

DMDS developments in Europe. There are results from more than 300 European field efficacy studies for DMDS, carried out in the last years, showing consistent results, over time and in different geographies, against several soil pest. DMDS has shown a wide-spectrum of activity, such as nematicide, fungicide and herbicide effect. Very effective control of the main European plant-parasitic nematodes has been proved, including *Meloidogyne* spp., *Heterodera* spp., *Globodera* spp., *Pratylenchus* spp., *Ditylenchus* spp., *Xiphinema* spp., etc. The product has demonstrated also a good fungicide efficacy against important soil fungi, in particular: *Fusarium* spp., *Verticillium* spp., *Phytophtora* spp., *Pythium* spp. and *Rhizoctonia* spp. In addition, DMDS has shown good control of many weeds, in particular of the following species: *Cyperus* spp., *Portulaca* spp., *Amaranthus* spp., *Chenopodium* spp., *Stellaria* spp., and several others.

***Meloidogyne* spp.** The root-knot nematodes (*Meloidogyne* spp.) are the major threat for protected crops in Europe, the most frequent species in Southern

Europe are *M. incognita, M. javanica,* and *M. arenaria*. For this reason a total of 7 trials were carried out during 2012-2014 in Italy (3), Spain (2) and Greece (2), against root-knot nematodes, in conditions of medium-high level of nematode infestation. DMDS (Accolade/Paladin^{TM} EC, containing 94.1% a.i.) was applied in drip chemigation, at 300 and 400 kg a.i./Ha and compared with 1,3-dichloropropene (140-230 kg a.i./Ha) and a non-treated control. Applications were in sandy or sandy-loamy soils during the hot season (June-September) with soil temperatures in the range 24-43 °C. Before application, soil and chemigation lines were covered with virtually impermeable film (VIF).

Table 1**:** Average of 7 trials on *Meloidogyne* spp. in protected tomato in Southern Europe. Gall Severity Index (GSI) at harvest and cumulative yield

	GSI at harvest	Tomato yield[1]
Non- treated check	5.3	100.0
DMDS 400	1.0	162.7
DMDS 300	1.3	155.1
1.3D 120-200 L/Ha	1.4	161.5

Note: yield of untreated check: 46.8 MT/Ha; [1] % compared to the non-treated (100)

DMDS gave effective control of *Meloidogyne* spp. at both rates of application, looking at GSI value and yield, when compared with the untreated check These results confirm the excellent efficacy of DMDS against root-knot nematodes in protected fruiting vegetables.

Pratylenchus penetrans. DMDS, as shank formulation (Accolade/Paladin^{TM} 99.1%), was applied to control the root-lesion nematode *P. penetrans* in strawberry nurseries. Three trials were carried out during 2013-2014 in The Netherlands. The soil was sandy with organic matter content of 3.5-5.0%. The average level of *Pratylenchus* spp. natural infestation was very high (16-33 specimens/ml soil). DMDS was applied at 300, 400 and 500 kg a.i./Ha and compared with metam sodium (MS) at 153 kg a.i./Ha and a non-treated control. Applications were made in spring (April-May) and autumn (October) with soil temperatures in the range 10-20 °C. After application, soil was covered with virtually impermeable film (VIF) or totally impermeable film (TIF).

Table 2**:** Average of 3 trials on *P. penetrans*. Counting of nematodes before fumigation (Pi) and at harvest (Pf) and number of plants harvested from a minimum of 20 mother plants (3.75 m^2) and relative yield as % of harvested plants compared to non-treated plots (100%)

Treatment/ doses kg a.i./ha	Number of *P. penetrans* / 100 ml			Production of runners	
	Pi	Pf	Efficacy (%)	Nr. Plants	% yield
Non- treated	2424.0	991.0	-	14.1	100.0
DMDS 500	2087.0	4.2	100.0	78.9	642.3
DMDS 400	1964.3	20.1	98.6	70.3	568.6
DMDS 300	2261.0	37.8	94.6	52.8	421.6
MS 153	2143.6	45.3	93.6	65.2	489.0

As a result of fumigation efficacy (Table 2), greater numbers of nursery plants were harvested from the fumigated plots. Yield increases averaged 642.3% for DMDS 500, 568.6% for DMDS 400 and 421.6 for DMDS 300 kg/Ha.

***Globodera* spp**. DMDS was used as shank formulation (99.1%) in five trials to control the potato cyst nematodes (PCN) in The Netherlands and United Kingdom. Soils were sandy and nematode infestation was high. DMDS was applied at 300 and 400 kg a.i./Ha and compared with MS at 153 kg a.i./Ha and

a non-treated check. The fumigants were applied in spring (April-May) with soil temperatures in the range 10-20 °C. After application, soil was covered with virtually impermeable film (VIF) or totally impermeable film (TIF).

Table 3**:** Average results of 5 potato trials on *Globodera* spp on nematode countings before fumigation (Pi) and at harvest (Pf), reproduction rate (Pf/Pi), and yield compared to non-treated plots (100%)

Treatment/ doses kg a.i./ha	Nematode eggs and second stage juveniles/100 g soil			Yield (% of the untreated)
	Pi	Pf	Pf/Pi	
Non- treated	2715.8	14019.8	5.8	100.0
DMDS 400	2330.2	6323.4	2.8	156.8
DMDS 300	2393.8	7014.8	2.9	155.0
MS 153	2331.0	9051.8	3.7	148.3

DMDS suppressed the reproduction of the nematodes and as a result of the fumigation efficacy, compared to non-treated plots (considered 100%), average yields were 156.8% for DMDS 400 kg/Ha and 155% for 300 kg/Ha (Table 3).

***Fusarium* spp**. Six field trials were carried out in Italy with DMDS shank formulation (99.1%) in 2013. Soils were loamy and artificially infested with the pathogen. DMDS was applied at 400 and 600 kg a.i./Ha and compared with dazomet at 495 kg a.i./Ha. Applications were in late spring with soil temperatures in the range 17-22 °C. After application, soil was covered with VIF.

Table 4**:** Average of 6 trials on *F. oxysporum* f. sp. *lactucae* in Italy

Treatment/doses kg a.i./ha	Disease Index (%)	Fresh marketable lettuce (g/m^2)
Non- treated check	48.8	390.2
DMDS 600	5.5	5240.8
DMDS 400	11.6	3813.4
Dazomet 495	12.8	4270.1

Both, disease index and yield indicated a very good efficacy of DMDS. The best control was obtained with DMDS 600, but DMDS 400 and Dazomet 495 were also significantly superior to the non-treated control (Table 4).

Other 4 drip trials were carried out in Italy against *Fusarium* spp. in tomato (*F. oxysporum* f. sp. *lycopersici* and *F. oxysporum* f. sp. *radicis lycopersici*), with DMDS EC formulation (94.1%) for drip application. DMDS was applied at 400 and 600 kg a.i./Ha and compared with a combined application of 1.3D+Chlorpicrine at 188+188 kg a.i./Ha and a non-treated check. After the fumigant applications, soil was covered with VIF

Table 5**:** Average of 4 trials against *F. oxysporum* f. sp. *lycopersici* and *F. oxysporum* f. sp. *radicis lycopersici*. Evaluation at the end of tomato crop cycle

Treatment/doses kg a.i./ha	Infected and dead tomato plants (%)
Non- treated check	35.0
DMDS 400	23.9
DMDS 600	12.2
1.3D+Chlorpicrine 188+188	18.6

Again, DMDS at 600 kg/Ha was the most effective treatment, but also DMDS at 400 kg/ha was effective compared to the non-treated check (Table 5). For the long-cycle fruiting vegetable crops, in particular tomato and pepper, combined application of DMDS 400 + metam 600 are actually under investigation in

Europe, in order to allow farmers to have a full control coverage of both nematodes and soilborne diseases.

Cyperus esculentus. Two trials were conducted in 2016 (Italy and The Netherlands) with a DMDS 99.1% applied by shank formulation. Soils were sandy and yellow nutsedge infestation was medium-high. DMDS was applied at 400 kg a.i./Ha and compared with MS at 153 kg a.i./Ha, a combined application of DMDS 400 + MS 153 and a non-treated check. Applications were made in summer (June) with average soil temperatures around 20 °C in The Netherlands and 30 °C in Italy. After application, soil was covered with TIF.

Table 6**:** Average of 2 trials against yellow nutsedge carried out in 2016

Treatment/ doses kg a.i./ha	Evaluation done 102-113 Days After Application	
	Soil coverage (%)	Efficacy (%)
Non- treated check	58.9	-
DMDS 400	1.6	97.5
DMDS 400 + MS 153	1.0	98.3
MS 153	10.0	78.3

The trials showed a very good control of yellow nutsedge by DMDS (Table 6). In addition, several trials on *Cyperus* spp., especially in soils with very high infestation levels, are ongoing in 2017 to complete the biological dossier for the European registration. DMDS alone or in combination with MS, represents a good technical solution for controlling the nutsedge. The combined use of both fumigants, particularly in soil with very high nutsedge infestations (about 1000 plants/m^2) and co-presence of many other weeds (preliminary data available but not shown), will represent an effective herbicide solution for the our farmers.

Stewardship, registration and commercial feedback. As part of the Certis CleanStart Soil care program, a pan-European stewardship program has been developed for DMDS to support a sustainable soil fumigation practice that provides appropriate measures and ensure safety to humans (users, bystanders and residents) and the environment. Odor management of DMDS has been very successful in more than 500 applications (experimental and commercial) done so far in Europe, as no claim was received. DMDS stewardship program follows the principles of the Directive 2009/128/EEC on the sustainable use of pesticides. Key components of DMDS stewardship program includes: (i) Best Management Practices to minimize human and environmental impact; (ii) communication on product profile, storage and application requirements; (iii) training program and validation of professional applicators/operators; (iv) inspection and adjustment of application machinery; and (v) investigation and communication on different types of gas-tight films (VIF and TIF).

Meanwhile DMDS is under EU evaluation process in EU for its inclusion in Annex 1, three exceptional use permits have already been granted in Italy for the use of Accolade EC to control root-knot nematodes in several protected crops (2015-2017) In addition, two authorizations of commercial large-scale experimental permit were granted in Spain (Murcia region) for the same use in tomatoes. The feedback from the farmers, who used the product at large scale against nematodes, has been very positive, bringing a stronger support from stakeholders in those countries. Therefore, it can be inferred that DMDS, once registered, will be a new effective solution to control nematodes, soil fungi and weeds in Europe.