Regional variation in pathogenicity of *Meloidogyne incognita* populations on sweetpotato in Kyushu Okinawa, Japan.

Zen-ichi Sano¹ and Hideaki Iwahori²

To use resistant cultivars of sweetpotato effectively occurrence and distribution of pathogenic races of *M. incognita* were examined. Five sweetpotato differential cultivars, 'Norin-1', 'Norin-2', 'Tanegashimamurasaki-7', 'Elegant Summer' and 'J-red', which were selected from major Japanese sweetpotato cultivars based on resistance response to four *M. incognita* populations with different virulence were used as differential hosts. A total of 129 *M. incognita* populations were collected from mainly sweetpotato fields in Kyushu and Okinawa, Japan. Reproduction of the populations was assessed on the differentials based on production of egg-masses and pathogenic races were designated. Nine races, SP1 to SP9, were identified from these populations and 37.2%, 43.4% and 7.0% of the populations were, respectively, race SP1 that reproduces only on 'Norin-1', SP2 that reproduces on both 'Norin-1' and 'Norin-2', and SP4 that reproduces on four of the differential hosts but not on 'J-Red'. Region specific distribution was observed in these races. SP1 was widely distributed in Kumamoto and northern prefectures. SP2 was predominant in southern Kyushu, in both Miyazaki and Kagoshima Prefectures. SP4 was the major race in Okinawa Prefecture. Other races were detected from limited areas. Jpn. J. Nematol. 35(1), 1-12 (2005).

Key words: biotype, differential host, *Ipomoea batatas*, regional distribution, resistant cultivar.

INTRODUCTION

Sweetpotato is a quite important crop in central and southern parts of Japan. This crop has been grown for table use as well as for starch or liquor production. In addition, the fleshy roots of some sweetpotato cultivars were recently evaluated as functional food and its production has been encouraged (Yoshimoto, 2001). Plant-parasitic nematodes can be a problem in the cultivation of sweetpotato. In particular, *M. incognita* causes serious damage (Clark and

Mayer, 1988). *M. incognita* is widely distributed in sweetpotato cultivation areas in Kyushu, Japan (Iwahori et al., 2000; Iwahori et al., 2001). Many resistant cultivars have been developed to prevent damage caused by this nematode and are now used especially for starch production in Japan (Kumagai, 2002; Tarumoto, 1992).

Cultivation of resistant crops is one of the most effective, economical and environmentally safe strategies for reducing losses caused by nematodes. Moreover such resistant crops suppress nematode multiplication and reduce residual population densities of nematodes (Inagaki and Momota, 1983; Roberts, 1995; Tabuchi and Sakamoto, 1983).

However, virulent biotypes or races have been reported in the root-knot nematode species,

¹ Agro-environment Division, Japan International Research Center for Agricultural Sciences, Ohwashi 1-1, Tsukuba, Ibaraki 305-8686, Japan.

² Laboratory of Plant Nematology, National Agricultural Research Center for Kyushu Okinawa Region, Nishigoshi, Kumamoto 861-1192, Japan.

M. arenaria, *M. chitwoodi*, *M. hapla*, *M. incognita*, *M. javanica* and *M. naasi* (Goplen et al., 1959; Hartman and Sasser, 1985; Michell et al., 1973; Mojtahedi et al., 1988). Populations of *M. incognita* which had different pathogenicity to cultivars of sweetpotato have been detected as well (Cervantes-Flores et al., 2002; Giamalva et al., 1963; Kirby et al. 1975; Martin and Birchfield, 1973; Nishizawa, 1974; Sano et al., 2002). The intraspecific variation in the pathogenicity of *Meloidogyne* species makes it difficult to utilize resistant crops, because resistant cultivars are not effective in areas where virulent populations are prevalent. Therefore it is quite important to elucidate the pathogenic variation of nematodes for breeding crop cultivars with nematode resistance as well as for growing resistant cultivars effectively in crop rotation for nematode control.

In the present study, i) variations in the pathogenicity of *Meloidogyne incognita* populations were assessed using sweetpotato differential cultivars, ii) races were designated using these cultivars, and iii) distribution of the races was investigated in the Kyushu Okinawa region in Japan.

MATERIALS AND METHODS

Collection of soil samples infested with *M. incognita*:

Soil samples were collected in the prefectures of Saga, Nagasaki, Kumamoto, Miyazaki, Kagoshima and Okinawa in summer to autumn from 1999 to 2002. These samples were collected mainly in sweetpotato fields and additionally in a few other crop fields such as taro. The soils were collected from about 10 points in each field with a shovel, then mixed together to produce one composite sample of approximately 2,000 g. The sweetpotato cultivar or crop growing in each field was identified at the time of soil sampling.

Establishment of single egg-mass cultures of *M.*

incognita:

A seedling of susceptible tomato, 'Pritz', was transplanted to a corresponding 15-cm clay pot filled with soil from each sample. After 2 to 3 months of growth in a greenhouse, tomato root systems were harvested and washed. Individual roots with a few isolated galls each containing a single female with a single egg-mass were removed from the root systems. An egg-mass was taken from one of the galls with forceps and placed in a glass vial with water. The female in the gall where the egg-mass was taken was identified by observation of the perineal pattern. If the female was identified as *M. incognita* the egg-mass was inoculated to tomato, 'Pritz', planted in a 15-cm pot filled with a seedling culture soil ('Kenbyo':Yaenogei Co. Ltd.). Tomato plants were grown in a greenhouse at average temperature of 27°C to raise single egg-mass populations.

Preparation of second stage juveniles:

Tomato roots systems were harvested and washed after 2 to 3 months of growth in a greenhouse. Two hundred or more egg-masses of each *M. incognita* population were taken from the root systems with a forceps, placed on a filter made by a thin layer of absorbent cotton put on a sheet of cotton gauze. The filters with egg-masses were partially immersed in water in a 50 ml beaker for 2 days at 25°C. Second-stage juveniles (J2) that emerged and migrated through the filter were used to determine race status.

Sweetpotato differential cultivars:

Five sweet potato cultivars, 'Norin-1', 'Norin-2', 'Tanegashimamurasaki-7', 'Elegant Summer' and 'J-red' were used as differentials. These cultivars were selected from 24 major sweetpotato cultivars based on their compatibility to four populations of *M. incognita* collected from different places in Japan (Sano et al., 2002). All of these cultivars were obtained from the

Laboratory of Sweetpotato Breeding, Department of Upland Crop Research, National Agricultural Research Center for Kyushu Okinawa Region.

Identification of races by the differential host test:

Four to five node cuttings of the differential cultivars were put into 200 ml beakers with tap water for about a week at room temperature. After taking root the cuttings were cut off in the vicinity of the nodes and a single node cutting with roots shortened to a length of a few centimeters was transplanted in a corresponding 9 cm pot with 200 g of soil prepared by mixing equal volumes of autoclaved andosol and 'Kenbyo'. Four days after transplanting when seedlings had rooted, approximately 500 J2 of each population in 1 ml of water were evenly injected into the soil of each pot. The pots were placed in a greenhouse at an average temperature of 27°C (24°C - 30°C). Root systems of the cultivars were removed and washed 35 days after inoculation of J2. The root systems were immersed in 0.5% Phloxine B water solution for several seconds to stain egg-masses. The solution remaining on the root systems was washed off in running water and then numbers of egg-masses produced were counted. Nematode populations producing more than two egg-masses were considered reproductive (+). All other populations were considered non-reproductive (−). Races were designated based on patterns of egg-mass production on the five differential cultivars. Each differential cultivar-nematode population combination was replicated five times and these tests were repeated once.

RESULTS

A total of 129 *M. incognita* populations in Kyushu Okinawa were examined. Localities of these populations, original cultivars of sweetpotato or crops grown, numbers of egg-masses

produced on the differential cultivars and designated races are summarized in Table 1.

'Kokei-14' which is a well-known cultivar for table use and highly susceptible to *M. incognita* was growing in about 30% of fields where soil samples were collected. Another susceptible cultivar, 'Koganengan' was growing in 13 fields. Cultivars in about 30% of the fields were not identified. Some of these might have been cultivars for starch production and others might have been 'Kokei-14'.

Quite a large variation was observed in numbers of egg-masses produced by *M. incognita* populations on the differential cultivars (Table 1, Fig. 1). All the populations produced egg-masses on the differential, 'Norin-1' which was regarded as a typical susceptible cultivar to *M. incognita* (Tarumoto, 1992). However, numbers of egg-masses produced varied continuously on this cultivar from a few to 310.6 and the average for all populations was 75.0 per 500 inoculated J2. Some populations most of which were collected from the islands of Goto, Nagashima, Tanegashima, and Amami, produced only a few egg-masses. Sweetpotato was grown in all the fields where soil samples of these populations were collected.

In another differential, 'Norin-2' which has been regarded as a highly resistant cultivar to *M. incognita* (Tarumoto, 1992), about 60% of populations examined did produce egg-masses and the average number of those egg-masses was 60.5. There was a relatively continuous range of values observed in the numbers of egg-masses in this cultivar. The populations that produced egg-masses on 'Norin-2' were found sporadically from the prefectures of Saga, Nagasaki and Kumamoto. On the other hand they were frequently detected in Miyazaki and especially in Kagoshima, southern prefectures of Kyushu.

Only a few populations produced egg-mass-

Table 1. Numbers of egg-masses produced by 129 *Meloidogyne incognita* populations in Kyushu Okinawa on sweetpotato differential cultivars.

Places nematode populations collected ^b	crops or sweet- potato cultivars grown	Differential sweetpotato cultivars ^a					Races designated
		Norin-1	Norin-2	Tanegashima murasaki-7	Elegant summer	J-red	
(Saga Pref.)							
Karatsu Region							
Sakibe, Chinzei	Tosabeni	104.3±23.5	0.0	0.0	0.0	0.0	SP1
Sakibe, Chinzei	Tosabeni	113.0±21.0	41.7±4.7	0.2±0.4	0.6±0.8	0.0	SP2
Sugamuta, Karatsu	—	150.6±29.2	0.0	0.0	0.0	0.0	SP1
Takekiba, Karatsu	Potato	15.6±7.7	0.0	0.0	0.0	0.0	SP1
(Nagasaki Pref.)							
North Region							
Funagoshi, Sasebo	Pumpkin	116.0±18.9	0.0	83.8±51.6	148.3±50.3	0.0	SP6
Goto							
Aokata, Kamigoto	Kokei-14	83.2±46.3	0.0	0.0	0.0	0.0	SP1
Hiyamizu, Kamigoto	Sweetpotato ^c	171.3±17.8	0.0	0.0	0.7±1.0	0.0	SP1
Tatsugushi, Shinoome	Sweetpotato	95.9±52.4	0.0	0.2±0.4	0.4±0.8	0.0	SP1
Wakamatsu, Wakamatsu	Sweetpotato	179.6±55.7	0.2±0.4	0.2±0.4	0.0	0.0	SP1
Mabushi, Wakamatsu	Okra	16.3±5.6	88.8±29.2	0.0	0.0	0.0	SP2
Fukumi, Narao	Sweetpotato	147.7±26.1	0.0	0.2±0.5	0.0	0.0	SP1
Takaitabi Narao	Sweetpotato	75.9±32.9	0.0	0.0	0.0	0.0	SP1
Kamiozu, Fukue	Sweetpotato	0.2±0.4	64.5±23.4	0.0	0.0	0.0	SP7
Kamisakiyama, Fukue	Kokei-14	7.9±10.4	49.6±25.3	0.0	0.0	0.0	SP2
Kusuhara, Kisiku	Tobacco	130.5±19.8	0.0	0.0	0.4±0.6	0.0	SP1
(Kumamoto Pref.)							
Kumamoto Region							
Iwamoto, Kyokushi	Fig	79.4±19.7	0.0	0.0	0.0	0.0	SP1
Suya, Nishigoshi	Norin-1	215.3±51.3	0.0	0.0	1.2±1.9	0.0	SP1
Hirakawa, Odu	Kokei-14	39.6±22.5	0.0	0.0	0.0	0.0	SP1
Hirakawa, Odu	Kokei-14	53.1±28.3	0.0	0.3±0.5	0.0	0.0	SP1
Hirakawa, Odu	Kokei-14	77.2±24.0	0.0	0.2±0.4	0.7±1.0	0.0	SP1
Hirakawa, Odu	Kokei-14	50.8±47.4	20.4±6.1	0.7±0.8	0.0	0.0	SP2
Hirakawa, Odu	Kokei-14	90.2±41.9	0.3±0.8	0.0	0.3±0.8	0.0	SP1
Hirakawa, Odu	Kokei-14	79.0±19.4	0.0	0.2±0.4	0.2±0.4	0.0	SP1
Hirakawa, Odu	Taro	40.3±10.9	0.0	0.0	0.2±0.4	0.0	SP1
Hirata, Mashiki	Kokei-14	72.5±15.8	39.9±24.8	0.0	0.0	0.0	SP2
Hirata, Mashiki	Kokei-14	208.3±30.2	0.0	0.2±0.5	0.7±0.9	0.0	SP1
Hirata, Mashiki	Kokei-14	85.7±35.5	0.0	0.0	0.0	0.2±0.4	SP1
Tabaru, Mashiki	Kokei-14	62.4±8.5	0.0	106.8±28.6	1.3±0.6	0.0	SP3
Kotani, Mashiki	Kokei-14	64.9±47.8	0.0	0.0	0.0	0.2±0.4	SP1
Kotani, Mashiki	Kokei-14	46.5±29.6	0.0	0.0	0.0	0.0	SP1
Sugido, Mashiki	Kokei-14	39.9±24.8	0.0	0.0	0.4±0.9	0.0	SP1
Nunota, Nishihara	Kokei-14	113.1±27.7	0.0	0.4±0.4	0.0	0.0	SP1
Nunota, Nishihara	Taro	132.0±33.3	0.0	76.2±18.9	25.3±54.4	0.0	SP6
Komori, Nishihara	Kokei-14	81.0±19.4	0.0	0.0	0.0	0.0	SP1
Komori, Nishihara	Kokei-14	55.6±28.9	20.2±12.9	0.0	0.0	0.0	SP2
Komori, Nishihara	Kokei-14	96.2±24.4	0.0	0.4±0.5	0.0	0.0	SP1
Komori, Nishihara	Kokei-14	119.0±35.1	0.0	0.1±0.4	1.5±1.8	0.0	(SP1)
Toriko, Nishihara	Kokei-14	110.4±35.0	0.0	0.0	0.0	0.8±1.8	SP1

Table 1. continued

Places nematode populations collected ^b	crops or sweet- potato cultivars grown	Differential sweetpotato cultivars ^a					Races designated
		Norin-1	Norin-2	Tanegashima murasaki-7	Elegant summer	J-red	
Amakusa Region							
Tsuji island, Itsuwa	Kokei-14	106.8±27.7	0.0	0.0	0.6±1.4	0.0	SP1
Tsuroro, Reihoku	Sweetpotato	58.4±21.1	0.0	0.0	0.0	0.0	SP1
Tsuroro, Reihoku	Sweetpotato	60.5±25.4	0.0	0.0	0.0	0.0	SP1
Shimodakita, Amakusa	Kokei-14	43.2±16.2	0.0	0.4±0.5	0.0	0.0	SP1
Takahama, Amakusa	Sweetpotato	81.7±22.0	0.0	0.0	0.0	0.0	SP1
Ohe, Amakusa	Shichifuku	66.6±22.2	0.2±0.3	0.0	0.4±0.9	0.0	SP1
Kojima, Kawaura	Sweetpotato	33.8±54.7	0.0	0.0	0.0	0.0	SP1
(Miyazaki Pref.)							
North Moutain Region							
Kawasuiryu, Kitakata	Beniazma	310.6±68.0	32.3±27.5	0.0	4.9±5.9	2.1±1.8	(SP2)
Kawasuiryu, Kitakata	Beniazma	72.1±25.5	61.7±13.1	0.0	0.0	0.0	SP2
North Plain Region							
Angawa, Kadokawa	Sweetpotato	7.1±4.3	0.0	0.0	0.0	0.0	SP1
Angawa, Kadokawa	Sweetpotato	56.1±34.6	0.0	84.1±8.5	7.3±16.4	0.0	SP6
Tamemizu, Kijou	Kokei-14	203.0±49.5	31.7±13.3	0.0	4.2±5.1	2.4±1.7	(SP2)
Tamemizu, Kijou	Koganesengan	100.4±23.3	0.0	0.0	0.0	0.0	SP1
Yudomari, Kawaminami	Koganesengan	42.8±12.3	119.9±27.9	0.0	0.0	1.0±2.2	SP2
Hikari, Saito	Kokei-14	41.4±29.7	42.3±12.4	0.0	0.0	0.5±0.5	SP2
Kasuga, Shintomi	Kokei-14	101.9±31.4	72.3±11.4	0.0	0.7±1.0	0.5±0.5	SP2
Azehara, Shintomi	Koganesengan	159.5±35.6	137.7±48.1	1.2±1.0	1.9±1.8	3.7±2.6	(SP2)
Saka, Shintomi	Koganesengan	123.9±59.5	13.4±11.6	0.0	1.8±2.6	0.0	(SP2)
South Moutain Region							
Mochio, Miyakonojoushi		14.0±11.5	51.7±30.9	0.0	0.0	0.0	SP2
South Plain Region							
Kajihara, Sadowara	Kokei-14	34.4±17.4	77.5±27.2	0.0	1.4±3.2	0.7±0.8	SP2
Kunitomi	Tobacco	20.0±10.2	0.0	1.4±1.1	0.0	0.0	SP1
Fumoto, Aya	Sweetpotato	137.3±65.5	0.0	0.0	0.0	0.0	SP1
Fumoto, Aya	Sweetpotato	26.9±7.6	0.0	0.0	0.0	0.0	SP1
Uryuno, Miyazaki	Kokei-14	23.2±21.2	0.0	95.1±31.1	19.2±28.0	0.0	SP6
Nakanamise, Tano	Kokei-14	57.1±22.3	5.5±2.1	0.0	0.0	0.4±0.5	SP2
Honjo, Kushima	Kokei-14	29.2±9.2	26.8±8.7	0.2±0.4	0.0	0.0	SP2
Honjo, Kushima	Kokei-14	12.0±10.4	0.2±0.5	0.2±0.5	0.0	0.0	SP1
Minamikata, Kushima	Kokei-14	41.0±51.9	28.5±30.6	0.0	0.0	0.0	SP2
Kushima, Kushima	Kokei-14	18.1±9.7	36.7±17.7	0.0	0.3±0.8	1.2±1.0	SP2
Ichinose, Kushima	Kokei-14	18.6±9.8	0.0	0.0	0.0	0.0	SP1
Kazuuji, Kushima	Kokei-14	137.4±27.7	7.6±10.1	0.0	0.0	0.0	SP2
Sangahira, Kushima	Kokei-14	115.2±38.3	48.0±37.9	0.0	0.7±1.6	0.2±0.4	SP2
Sangahira, Kushima	Kokei-14	26.4±9.9	94.5±37.8	0.0	0.0	1.1±2.5	SP2
Sangahira, Kushima	Kokei-14	10.9±7.7	27.2±19.2	0.0	0.2±0.4	0.0	SP2
Magaya, Kushima	Kokei-14	48.0±7.8	14.8±7.8	0.0	0.0	0.0	SP2
(Kagoshima Pref.)							
Izumi · Isa							
Siomi, Nagashima	Sweetpotato	0.8±0.9	70.0±33.5	0.0	0.0	0.0	SP7
Siomi, Nagashima	Sweetpotato	1.9±1.3	27.4±9.8	0.0	0.0	0.2±0.4	(SP7)
Obamakami, Nagashima	Kokei-14	86.6±38.7	28.4±14.6	0.0	0.0	0.0	SP2
Obamazaki, Nagashima	Potato	44.1±17.0	83.2±21.4	0.0	0.0	0.4±0.8	SP2

Table 1. continued

Places nematode populations collected ^b	crops or sweet- potato cultivars grown	Differential sweetpotato cultivars ^a					Races designated
		Norin-1	Norin-2	Tanegashima murasaki-7	Elegant summer	J-red	
Nagasaki-bana, Nagashima	Potato	191.3±18.7	0.0	0.2±0.4	0.0	0.0	SP1
Yadou, Azuma	Sweetpotato	13.9±11.7	147.6±19.2	0.0	0.0	2.1±2.2	SP2
Kuronohama, Akune	Sweetpotato	0.6±1.2	81.4±16.0	0.0	0.0	0.0	SP7
Oosumi							
Shinkawacho, Kanoya	Sweetpotato	107.2±25.7	138.6±22.3	0.0	0.0	0.0	SP2
Tasakimachi, Kanoya	Kokei-14	51.9±39.3	139.7±30.1	0.0	0.0	0.0	SP2
Hosoyamada, Kushira	Kokei-14	131.5±65.7	124.6±33.7	0.0	0.0	1.9±3.7	SP2
Shoei, Kushira	Koganesengan	17.4±12.5	23.5±7.2	0.0	0.6±0.9	0.0	SP2
Ikenohara, Higashikushira	Sweetpotato	155.4±79.2	217.9±48.8	0.0	0.0	1.4±1.4	SP2
Ushiroda, Takayama	Koganesengan	44.8±27.9	126.5±49.3	1.3±1.3	0.0	0.0	SP2
Ushiroda, Takayama	Koganesengan	42.9±37.4	77.5±16.2	1.0±1.4	0.0	0.0	SP2
Nagayoshi, Osaki	Koganesengan	172.8±45.3	60.6±34.7	0.0	0.0	0.8±0.9	SP2
Nagayoshi, Osaki	Shiroyutaka	151.5±39.0	54.0±24.6	0.0	1.2±2.7	4.1±3.9	SP2
Nagayoshi, Osaki	Sweetpotato	47.2±14.0	61.7±46.4	0.0	0.0	3.5±5.5	SP2
Jinryo, Osaki	Taro	126.0±41.0	118.7±38.9	0.0	0.0	1.1±1.8	SP2
Jinryo, Osaki	Sweetpotato	29.4±35.7	56.1±20.3	0.0	0.0	0.0	SP2
Kamimyo, Aira	Koganesengan	53.6±35.8	17.8(1rep.)	0.0	0.0	3.0	SP2
Kurumada, Aira	Koganesengan	100.0±27.8	18.2±10.0	0.0	0.0	0.0	SP2
Tobaru, Aira	Koganesengan	108.1±36.7	80.5±17.2	0.0	0.0	0.2±0.4	SP2
Yasunaga, Onejime	Kokei-14	206.5±52.5	171.3±30.2	0.0	0.7±0.6	2.0±1.3	SP2
Ibusuki · Kawabe							
Beppu, Makurazaki	Sweetpotato	90.7±21.5	6.9±2.7	0.0	0.0	0.0	(SP2)
Beppu, Makurazaki	Sweetpotato	25.1±15.1	41.4±27.2	0.0	0.0	1.2±2.0	SP2
Beppu, Makurazaki	Sweetpotato	157.6±35.7	98.7±48.1	0.0	0.7±0.8	0.0	SP2
Kamibeppu, Ei	Sweetpotato	58.2±38.7	64.1±17.8	0.0	0.7±1.8	0.0	SP2
Omagari, Ei	Sweetpotato	40.1±21.3	64.4±17.8	0.0	0.0	0.0	SP2
Matunaga, Ei	Sweetpotato	41.4±34.2	73.1±35.7	0.0	0.0	0.0	SP2
Tanegashima Region							
Ohsaki, Nishinoomote	Sweetpotato	8.8±9.4	0.0	0.0	0.0	0.0	(SP1)
Kunigami, Nishinoomote	Sweetpotato	60.8±18.7	70.0±11.7	0.0	0.0	0.2±0.4	SP2
Kubota, Nishinoomote	Sweetpotato	67.2±13.7	33.4±20.7	0.0	0.0	0.0	SP2
Hamawaki, Nishinoomote	Sweetpotato	2.0±1.8	75.1±37.7	0.0	0.0	0.2±0.5	(SP2)
Guniwa, Nishinoomote	Tanegashimamurasaki-7	116.8±25.9	84.3±69.0	47.0±18.0	75.8±59.6	1.2±1.7	SP4
Higashime, Nakatane	Sweetpotato	13.1±12.6	69.1±32.6	0.0	0.0	0.0	SP2
Higashime, Nakatane	Sweetpotato	49.2±7.2	47.1±17.0	0.0	0.2±0.5	0.0	SP2
Koromonotaira, Nakatane	Tanegashimamurasaki-7	77.4±25.1	25.8±14.1	46.3±25.4	68.7±26.1	0.0	SP4
Uehou, Nakatane	Sweetpotato	26.0±13.4	69.9±13.5	0.0	0.0	0.0	SP2
Noohno, Minamitane	Sweetpotato	154.5±5.6	90.9±23.5	0.0	0.0	29.6±23.5	SP8
Shinhase, Minamitane	Sweetpotato	1.5±1.4	1.3±0.8	0.0	32.1±26.7	0.0	SP9
Amami							
Maeno, Amagi	Ginger	15.1±16.3	0.0	0.0	0.0	0.0	SP1
Setuko, Setouchi	Sweetpotato	4.6±2.3	77.1±23.7	78.0±21.4	1.1±1.5	0.0	(SP5)
Hanatoku, Tokunoshima	Taro	53.5±24.1	0.0	0.0	0.0	0.0	SP1
(Okinawa Pref.)							
Main Island north							
Ie	<i>Monstera</i> sp.	29.6±23.3	0.0	0.0	0.0	0.0	SP1

Table 1. continued

Places nematode populations collected ^b	crops or sweet- potato cultivars grown	Differential sweetpotato cultivars ^a					Races designated
		Norin-1	Norin-2	Tanegashima murasaki-7	Elegant summer	J-red	
Main Island South							
Uehara, Yonashiro	Bise	36.4±15.5	31.6±5.3	108.0±28.9	37.7±70.4	0.0	SP4
Uehara, Yonashiro	Bise	17.3±7.9	9.2±5.3	39.6±30.4	42.5±28.5	0.0	SP4
Uehara, Yonashiro	Bise	3.1±3.0	64.5±11.6	181.3±24.0	0.6±1.4	0.0	(SP5)
Ikei, Yonashiro	Bise	28.4±15.8	86.9±63.0	129.8±48.4	34.6±48.8	0.2±0.4	SP4
Gushikawa, Gushikawa	Miyano-36	179.5±39.0	74.1±13.9	157.7±62.6	2.0±1.2	0.4±0.6	SP4
Gushikawa, Gushikawa	Sweetpotato	125.0±37.9	6.5±4.5	77.6±33.1	52.0±56.4	1.0±1.2	SP4
Ishigaki Region							
Nakasuji, Taketomi	Miyano-36	55.9±41.9	0.0	0.0	0.5±0.8	0.0	SP1
Isobe, Ishigaki	Bise	57.3±55.1	0.0	164.9±164.9	91.2±102.1	1.4±1.7	SP6
Isobe, Ishigaki	Bise	56.3±30.3	0.0	109.7±27.0	18.7±30.2	0.0	SP6
Kabira, Ishigaki	Sweetpotato	118.9±61.2	59.9±25.0	111.8±16.9	69.2±70.0	0.2±0.5	SP4
Akaishi, Ishigaki	Sweetpotato	120.7±70.4	91.5±34.7	133.2±58.3	72.2±47.8	0.0	SP4
Hirakubo, Ishigaki	Sweetpotato	115.4±35.5	0.0	132.7±45.5	194.5±18.6	0.0	SP6

a) Figures are average numbers of egg-masses with SD per 500 J2 inocula per root system.

See Table 2 for the race differentiation. Some values slightly deviated from the standard in races within parenthesis.

b) Populations of *M. incognita* were collected mainly from sweetpotato growing area in Kyushu Okinawa Region.

c) Cultivars were not identified.

Fig. 1. Variation in numbers of egg-masses produced on differential sweetpotato cultivars, Norin-1' and 'Norin-2' by *Meloidogyne incognita* populations examined. Populations are arranged in ascending order according to their numbers of egg-masses.

Table 2. Responses of *Meloidogyne incognita* races detected in Kyushu Okinawa region on sweetpotato differential hosts.

Sweetpotato differential cultivar	Races detected ^a								
	SP1	SP2	SP3	SP4	SP5	SP6	SP7	SP8	SP9
Norin-1	+	+	+	+	—	+	—	+	—
Norin-2	—	+	—	+	+	—	+	+	—
Tanegashimamurasaki-7	—	—	+	+	+	+	—	—	—
Elegant summer	—	—	—	+	—	+	—	—	+
J-red	—	—	—	—	—	—	—	+	—

a) The races were differentiated based on egg-mass numbers per root-system of each differential cultivar inoculated with second stage juveniles(J2). —: less than one egg-masses/500 J2, +: more than two egg-masses/500 J2.

Table 3. Distribution of *Meloidogyne incognita* races in Kyushu Okinawa Region.

Areas of weather forecast	No. of popula- tions examined	% occurrence of races								
		SP1	SP2	SP3	SP4	SP5	SP6	SP7	SP8	SP9
(Saga Pref.)	4	75.0	25.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Karatu Region	4	75.0	25.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(Nagasaki Pref.)	11	63.6	18.2	0.0	0.0	0.0	9.1	9.1	0.0	0.0
North Region	1	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0
Goto	10	70.0	20.0	0.0	0.0	0.0	0.0	10.0	0.0	0.0
(Kumamoto Pref.)	30	83.3	10.0	3.3	0.0	0.0	3.3	0.0	0.0	0.0
Kumamoto Region	23	78.3	13.0	4.3	0.0	0.0	4.3	0.0	0.0	0.0
Amakusa region	7	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(Miyazaki Pref.)	28	25.0	67.9	0.0	0.0	0.0	7.1	0.0	0.0	0.0
North Mountain Region	2	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
North Plain Region	9	22.2	66.7	0.0	0.0	0.0	11.1	0.0	0.0	0.0
South Mountain Region	1	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
South Plain Region	16	31.3	62.5	0.0	0.0	0.0	6.3	0.0	0.0	0.0
(Kagoshima Pref.)	43	9.3	74.4	0.0	4.7	2.3	0.0	7.0	2.3	2.3
Izumi · Isa	7	14.3	42.9	0.0	0.0	0.0	0.0	42.9	0.0	0.0
Oosumi	16	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ibusuki · Kawabe	6	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tanegashima Region	11	9.1	54.5	0.0	18.2	0.0	0.0	0.0	9.1	9.1
Amami	3	66.7	0.0	0.0	0.0	33.3	0.0	0.0	0.0	0.0
(Okinawa Pref.)	13	15.4	0.0	0.0	53.8	7.7	23.1	0.0	0.0	0.0
Main Island North	1	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Main Island South	6	0.0	0.0	0.0	83.3	16.7	0.0	0.0	0.0	0.0
Ishigaki Region	6	16.7	0.0	0.0	33.3	0.0	50.0	0.0	0.0	0.0
Sum of Kyshu Okinawa	129	37.2	43.4	0.8	7.0	1.6	5.4	3.1	0.8	0.8

es on differentials, 'Tanegashimamurasaki 7' and 'Elegant Summer' in Kyushu. However particularly in Okinawa these populations were common. Some populations produced egg-masses on a differential, 'J-red', though the numbers of egg-masses were few except for one population (Minamitane, Tanegashima Region) that

produced 29.6.

Based on the results of Table 1 the patterns of egg-mass production on the five differential cultivars are presented in Table 2. Nine patterns were differentiated from 129 populations assayed. Based on these patterns nine sweetpotato races, SP1 to SP9, were designated, where

the letters SP stand for sweetpotato. The race SP1, for instance, produces egg-masses and reproduces only on 'Norin-1' and SP2 reproduces on both 'Norin-1' and on 'Norin-2'.

According to the rates of occurrence of *M. incognita* sweetpotato races in the Kyushu Okinawa region presented in Table 3, SP1 and SP2 were two major races that represented 37.2% and 43.4%, respectively, of assayed populations in this region. Other individual races occupied less than 10%. However, in individual regions distinct differences were observed in rates of race occurrence. SP1 is widely distributed in central and northern areas. The rate of occurrence was more than 80% in Kumamoto Prefecture. SP2, on the other hand, tended to be distributed predominantly in the southern part of Kyushu. Particularly in the Osumi and Ibusuki-Kawabe Regions, Kagoshima Prefecture, all the populations were SP2. In Okinawa Prefecture the situation differed greatly from the other regions. SP4 that reproduces on four of the differential hosts but not on 'J-red' represented 54% of the populations. In the Tanegashima Region, Kagoshima Prefecture, the rate of SP4 was relatively high also (18%).

DISCUSSION

The present study demonstrated a large pathogenic variation in populations of *M. incognita* to sweetpotato. Nine races were detected in this nematode in Kyushu Okinawa region by identification using five sweetpotato differential cultivars. In this investigation, nematode populations identified were raised from single females to evaluate the extent of pathogenic variation in this nematode. It was also confirmed that some populations were identified to be the same race by repeated tests (Data unpublished).

Netscher and Taylor (1979) stated that variation in pathogenicity to hosts among populations of the same root-knot nematode species

might be very common. Our results support their assumption. Hartman and Sasser (1985) have proposed a differential host test and identified 4 races of *M. incognita* by the response to tobacco, 'NC 95' and cotton, 'Delta Pine'. However some populations that they differentiated as the same race were found to be different in the response to the same cultivars of sweetpotato (Cervantes-Flores et al., 2002). The utility of their scheme may be restricted to cotton and tobacco production areas (Roberts, 1995). It is considered that nematode races should be identified by differentials of a particular plant for breeding the particular plant cultivars with nematode resistance and for cropping such cultivars to control nematodes. Sweetpotato is hexaploidy and self-incompatible, and genes for nematode resistance have not yet been identified. In this study, therefore, the differentials for race identification were selected to represent the groups of sweetpotato cultivars which had similar compatibility to four *M. incognita* populations collected from sweetpotato fields in different geographical regions (Sano et al., 2002).

The results of this study indicate that the distribution of the races was region specific in the Kyushu Okinawa region. The cultivars of sweetpotato grown in a field may probably influence the distribution of nematode races, because reproduction of *M. incognita* populations depends on the cultivars of sweetpotato (Sano et al., 2002). The race SP4 was exceptionally common in Okinawa Prefecture and Tanegashima Island. This race was able to reproduce on 'Miyano-36' which was primarily grown in Okinawa Prefecture. This race also reproduces on 'Tanegashimamurasaki-1' and 'Tanegashimamurasaki-7' which are common in Tanegashima Island. Other major races, SP1 and SP2, on the other hand, were not able to reproduce on these cultivars (Sano et al., 2002). SP4 might have reproduced selectively on these

cultivars and this may contribute to the race distribution in these areas.

Distinct differences were also observed between areas of SP1 and SP2 distribution. SP1 was predominant in Kumamoto Prefecture and SP2 was prevalent in both Miyazaki and Kagoshima Prefectures. 'Kokei-14' which is a highly susceptible cultivar to both races is grown widely in Kumamoto Prefecture and is also grown in many fields of the South Plain region of Miyazaki Prefecture where SP2 was predominant. Therefore, the distribution of the two races cannot be directly attributed to the cultivars growing in these areas. Lately it was found that SP2 was widely distributed in forests and wilderness areas of Miyazaki and Kagoshima Prefectures (Sano and Iwahori, 2004). This finding indicates that SP2 is widely distributed in the two prefectures and is common in sweetpotato fields. So far SP2 has not been detected from wilderness areas in Kumamoto Prefecture.

Variation in numbers of egg-masses produced by *M. incognita* was large and there was a continuous range of values on both 'Norin-1' and 'Norin-2' (Fig. 1). Since this nematode is an obligatory mitotically parthenogenetic species (Triantaphyllo, 1985), recombination of chromosomes should not occur. It is not known why such large pathogenic variation occurs in *M. incognita*. SP1, SP2 and SP4 were identified to be the three major races in the Kyushu Okinawa region. Therefore in breeding programs of sweetpotato, resistant cultivars or breeding lines should be evaluated with these three races. The information on the distribution of these races reported in this study should help to choose appropriate resistant cultivars for cropping in a particular area.

ACKNOWLEDGEMENT

Authors thank Dr. Jerome. T. Gaspard for

his critical reviewing the manuscript. Authors also thank Mr. Shojiro Zen, Saga Upland Farming Experiment Station, Mr. Kiyotoshi Yokomizo, Nagasaki Prefectural Agricultural and Forestry Experiment Station, Mr. Hiraku Orita, Nagasaki Prefectural Shimabara Agricultural Extension Center, Mr. Hiroaki Trigoe, Kagoshima Prefectural Sensatsu Agricultural Improvement and Advisory Center and Mr. Satoshi Taba, Ryukyu University, for their assistance in collection of populations of *Meloidogyne incognita*.

REFERENCES

- Cervantes-Flores, J. C., Yencho, G. C. and Davis, E. L. (2002) Host reactions of sweetpotato genotypes to root-knot nematodes and variation in virulence of *Meloidogyne incognita* populations. HortScience 37, 1112-1116.
- Clark, C. A. and Mayer, J. W. (1988) Compendium of sweet potato disease. APS Press, St. Paul, 74 pp.
- Giamalva, M. J., Martin, W. K. and Hernandez, T. P. (1963) Sweet potato varietal reaction to species and races of root-knot nematodes. Phytopathology 53, 1187-1189.
- Goplen, B. P., Stanford, E. H. and Allen, M. W. (1959) Demonstration of physiological races within three root-knot nematode species attacking alfalfa. Phytopathology 49, 653-656.
- Hartman, K. M. and Sasser, J. N. (1985) Identification of *Meloidogyne* species on the basis of differential host test and perineal-pattern morphology. In: *An advanced treatise on Meloidogyne. Vol. II: Methodology* (Barker, K. R., Carter, C. C. and Sasser, J. N. eds.), Cooperative Publication of the Department of Plant Pathology, North Carolina State University and U. S. Agency for International Development, Raleigh, N. C., 70-77.

- Inagaki, H. and Momota, Y. (1983) Population decrease of the root-knot nematode, *Meloidogyne incognita*, by the nematode-resistant sweet potato varieties and its durability in the next year. Proceedings of the Kanto-Tosan Plant Protection Society 30, 183-184. (in Japanese)
- Iwahori, H., Sano, Z. and Ogawa, T. (2000) Distribution of main plant-parasitic nematodes in sweet potato and taro fields in Kyushu and Okinawa, Japan. 1. Survey in the central and southern parts in Kyushu Island (Kumamoto, Miyazaki and Kagoshima Prefs.) and development of an effective DNA analysis method for species identification. Kyushu Plant Protection Research 46, 112-117. (in Japanese)
- Iwahori, H., Sano, Z. and Torigoe, H. (2001) Distribution of main plant-parasitic nematodes in sweet potato and taro fields in Kyushu and Okinawa, Japan. 2. Survey in several islands around Kyushu and Nansei Islands. Kyushu Plant Protection Research 47, 112-117. (in Japanese)
- Kirby, M. F., Dickson, D. W. and Smart, G. C. Jr. (1975) Physiological variation within species of *Meloidogyne* occurring in Florida. Plant Disease Reporter. 49, 353-356.
- Kumagai, T. (2000) Recent advance on sweet-potato breeding in Kyushu National Agricultural Experiment Station. Breeding Research 2, 97-104. (in Japanese)
- Martin, W. J. and Birchfield, W. (1973) Further observations of variability in *Meloidogyne incognita* on sweetpotato. Plant Disease Reporter 57, 199.
- Michell, R. E. Malek, R. B. Taylor, D. P. and Edwards, D. I. J. (1973) Races of the barley root-knot nematode, *Meloidogyne naasi*. 1. Characterization by host-preference. Journal of Nematology 5, 41-44.
- Mojtahedi, H., Santo, G. S. and Wilson, J. H. (1988) Host tests to differentiate *Meloidogyne chitwoodi* race 1 and 2 and *M. hapla*. Journal of Nematology, 20, 468-473.
- Netscher, C. and Taylor, D. P. (1979) Physiological variation with genus *Meloidogyne* and its implications on integrated control. In: Root-knot nematodes (*Meloidogyne* species) (Lamberti F. and Taylor, C. E. eds.) Academic Press, New York, 269-294.
- Nishizawa, T. (1974) A new pathotype of *Meloidogyne incognita* breaking resistance of sweetpotato and some trials to differentiate pathotypes. Japanese Journal of Nematology 4, 37-42.
- Roberts, P. A. (1995) Conceptual and practical aspects of variability in root-knot nematodes related to host plant resistance. Annual Review of Phytopathology 33, 199-221.
- Sano, Z., Iwahori, H. Tateishi, Y. and Kai, Y. (2002) Differences in the resistance of sweet potato cultivars and lines to *Meloidogyne incognita* populations. Japanese Journal of Nematology 32, 77-86. (in Japanese)
- Sano, Z. and Iwahori, H. (2004) Differences in pathogenicity of *Meloidogyne incognita* populations on sweet potato inhabiting in forests and wilderness in central and southern Kyushu, Japan. Kyushu Agricultural Research 66, 93. (in Japanese)
- Tabuchi, S. and Sakamoto, S. (1983) Relationship between reproduction of *Meloidogyne incognita* (Kofoid et White) Chitwood and resistance of sweet potato. Proceedings of Association of Plant Protection in Kyushu 29, 126-129. (in Japanese)
- Tarumoto, I. (1992) Breeding of resistant varieties to root-knot nematodes, *Meloidogyne incognita* in sweet potato. In: -Senchu Kenkyu no Ayumi- (Progress in

Nematology). A commemoration of the Twentieth Anniversary of the Japanese Nematological Society (Nakasono, K. ed.), 282-285. (in Japanese)

Triantaphyllou, A. C. (1985) Cytogenetics, cytology and phylogeny of root-knot nematodes. In: An advanced treatise on *Meloidogyne*. Vol. 1: Biology and Control (Sasser, J. N. and Carter, C. C. eds.),

Cooperative Publication of the Department of Plant Pathology, North Carolina State University and U. S. Agency for International Development., Raleigh, N. C., 113-126.

Yoshimoto, M. (2001) New trends of processing and use of sweetpotato in Japan. *Farming Japan* 35, 22-28.

Received April 15, 2004.