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Species Dominance of *Tetranychus urticae* and *Panonychus ulmi* (Acari: Tetranychidae) in Apple Orchards in the Southern part of Korea

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남부지역 사과원내 점박이응애와 사과응애의 우점변화

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ABSTRACT: This study investigated population fluctuations in two mite species in apple orchards over 20-year period. The occurrence of two major mite pests infesting apple trees, two-spotted spider mite *Tetranychus urticae* and European red mite *Panonychus ulmi* (Acari: Tetranychidae), was investigated from 1992 to 2011 in major apple-producing districts, including four to eight cities, in the southern part of the Republic of Korea. The 20-year trend revealed that more orchards were infested by *T. urticae* from 1992 to 1999, but thereafter *P. ulmi* became dominant. The observed mean density of *P. ulmi* was consistent, whereas that of *T. urticae* fluctuated during this period. The analysis of occurrence in four time periods reveals that the density of *T. urticae* decreased after 2002. The monthly sampling, revealed that the density of *P. ulmi* was higher in April, whereas the density of *T. urticae* was higher from May to August. This change may be due to a change in the frequency of pesticide spraying, ground vegetation management, a decrease in nitrogen fertilization, and the overall orchard management practices. However, this projection should be examined in more detail. On the basis of the findings of this study, it can be concluded that cultural practices, including fertilization, and environmental changes, such as pesticide spray frequency and integrated pest management practices, affect species dominance and population densities of the two mite species in apple orchards.

Key words: Dominance change, Mite, Population density

초 록: 이 연구는 사과원에서 20년동안 두 종 응애의 밀도변화를 조사하기 위하여 수행하였다. 사과나무를 가해하는 두 종의 응애 해충, 점박이응애(*Tetranychus urticae*)와 사과응애(*Panonychus ulmi*)의 발생을 1992년부터 2011년까지 8개 도시 포함, 한국의 남부지역에 위치한 사과주산지역에서 조사하였다. 20년간의 추세는 많은 과원이 1992년부터 1999년까지는 점박이응애가 주로 가해를 하였지만 2000년도부터는 사과응애가 우점하기 시작했다. 사과응애의 평균관찰밀도는 일정했고 점박이응애의 밀도는 이 기간동안 일정하지 않았다. 5년주기별 발생추세 분석은 점박이응애의 밀도가 2002년 이후에 감소하는 것을 보여주었다. 4월부터 9월까지 월별피해과원율과 두종 응애의 평균발생밀도는 사과응애의 밀도가 4월에 높지만 점박이응애의 밀도가 5월부터 9월까지 높았다. 이런 변화는 살충제 살포횟수, 초경재배관리, 질소비료 사용의 감소와 전체적인 과원관리의 변화 등으로 기인한다. 그러나 이러한 예측은 이를 증명하기 위해 보다 자세한 연구가 필요하다. 본 연구를 통해 비료살표와 같은 재배법과 살충제 살포횟수와 종합적해충관리 등의 환경적 변화가 사과원에서 두종 응애의 우점종과 발생밀도에 영향을 준 것으로 보인다.

검색어: 우점종변화, 응애, 발생밀도

Tetranychus urticae is an economically important pest in apples (Kim et al., 2008; Kim and Lee, 2005; Yiem, 1993). Because of its short developmental period, *T. urticae* occurs many generations in a year and keeps its high population density. Also, *T. urticae* easily develops resistance to acaricides. In apples, they infest the leaf vein mainly on the abaxial side. Orange-colored female adults overwinter in gaps under rough

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bark, ground weeds, and fallen leaves. They move and infest the weeds or apple trees growing after March, and change their appearance with two black spots on their body and lay eggs (Apple Research Station, 2012). *Panonychus ulmi* also infests apples and cause damage. Infestation of *P. ulmi* is somewhat sporadic in apple orchards; as soon as leaves spread, the mite feeds on the chlorophyll in intercellular sap on adaxial leaves. The damage on the leaf surface is seen as white spots. *P. ulmi* mainly overwinters as red eggs in branch points of small branches or around winter sprouts. The eggs of *P. ulmi* hatch in late April and pass through developmental stage of larva with three legs and nymph with four legs (Apple Research Station, 2012).

In the Republic of Korea, of mites infesting apple orchards, *P. ulmi* was the dominant species until 1970s. In the early 1960s, the proportion of orchards infested by *P. ulmi* peaked to over 90%. However, the dominant species changed from *P. ulmi* to *T. urticae* in the late 1970s. These mites continuously have been causing major problems in some apple orchards (Kim and Lee, 2005). Therefore, these mite populations and their damages in apple orchards is always need the integrated pest management.

Although there are many reports on these mite species, few researches were conducted about the change in the dominance between *P. ulmi* and *T. urticae* in apple orchards. Kim and Lee (2005) described the historical changes of population abundance of *P. ulmi* and *T. urticae,* based on research reports of the National Horticulture Research Institute from 1958 to 1998 at Suwon, with explanation of various factors. Over use of acaricides, outbreak and resurgence of resistant mites, competition between mite species, and the changes of cultivation environment to control mites in most apple orchards were known to be major factors to maintain the dominance of *T. urticae* (Foott, 1962, 1963; Lee, 1990; Kim and Lee, 2005).

In the study of dominance change of mite species in apple orchards in Gyeongbuk province, data analysis from infested orchard ratio and population densities revealed that species dominance changed from *T. urticae* to *P. ulmi* around year 2000, while their densities did not show obvious difference. To know the reason why this species dominance change was caused, we try to analyze some factors focus on at one typical orchard. We put forward three reasons why these densities changed: (i) the decrease of spraying frequencies of pesticides, (ii) recently changed cultivation environments, and (iii) the decrease in nitrogen fertilization.

This ecological study was conducted to compare the occurrence and development of *T. urticae* to *P. ulmi* in apple orchards in South Korea. Population fluctuation of mite species in apple orchards may involve many factors. To explain this dominance change, factors such as spraying times of agrochemicals, cultivation method, and decrease of nitrogen fertilization, were considered.

Materials and Methods

Overall trends of two mite species occurrence in apple orchards

Investigation on the population and infested orchard ratios of two-spotted spider mite *T. urticae* and European red mite *P.*

Table 1. The number of apple orchards surveyed from 1992 to 2011

Province	Area	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Gyeong Buk	Gunwi	5	5	5	5	5	4	4	4	4	2	3	3	3	2	3	3	3	3	3	3
	Andong	5	5	5	5	5	4	3	3	3	4	4	4	4	3	3	3	3	3	3	3
	Yeongju	5	5	5	5	5	4	3	3	3	1	1	2	3	2	3	3	3	3	3	3
	Yeongcheon	5	5	5	5	5	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	Cheongsong			5	5	5	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	Uiseong					5	4	3	4	4	3	3	3	3	3	3	3	3	3	3	3
	Mungyoung							1													
	Yecheon							1													
Gyeong Nam							4	1	3	3		2	2	3		1	1	1		2	2
Jeon Nam								2	2	2	1	3	3	4		1	1	1		2	2
No. Total orchards		20	20	25	25	30	28	24	25	25	17	22	23	26	16	20	20	20	18	22	22

ulmi (Acari: Tetranychidae) were conducted from 1992 to 2011 in the major apple producing districts in the southern part of Republic of Korea, Gunwi, Andong, Yeongju, Yeongcheon, Cheongsong, Uiseong, Mungyeong, Yecheon (north of Gyeongbuk province), Geochang (Gyeongnam) and Jangsu (Jeonnam) (Table 1). The investigation was done twice in a month from April to September. The population densities of *T. urticae* and *P. ulmi* were observed by counting the number of adults at mobile stage by naked eyes in total 100 leaves of specified five trees (20 leaves per tree) in each orchard. Yearly population size was calculated the total number of mites observed from April to September. If an orchard observed the mites on the leaf, we regarded this orchard as infested by the mites. The mite infested orchard ratio with *T. urticae* and *P. ulmi* (%) was expressed as the percentage of infested orchards over the total number of orchards. Also, the population density of *T. urticae* on weeds was observed by counting the number of adults observed on the broad leaf weeds for five minutes. The infested orchard ratio with *T. urticae* on weeds was expressed as the percentage of infested orchards over the total number of orchards.

To understand the 20-year trend of the change, mean population and infested orchard ratio was compared by year and month as the same method described. Because mite population has fluctuated during long period, so we divided the period into four groups by five years (A period: 1992-1996; B period: 1997-2001; C period: 2002-2006; and D period: 2007-2011), and data was temporally compared from April to September.

Trend of two mite populations in a selected orchard

From a selected apple orchard in Yeongju, population density of *T. urticae* and *P. ulmi* by year and month was observed as above described methods. This orchard is located on Bongam-ri, Anjeong-myeon at Yeongju-si and major variety is 'Fuji' with the area of approxmiately 10,000 m^2. Planting system was covered by ground cover crop. Mite population abundance of *T. urticae* and *P. ulmi* from 2000 to 2011 was examined. The relative abundance was calculated by dividing *P. ulmi* (or *T. urticae*) abundances by the sum of *P. ulmi* and *T. urticae* abundances from April to September. Data for population density of *T. urticae* and *P. ulmi* by month were analyzed by Duncan's multiple range test at 5% level using MYSTAT 12 (Systat, Chicago).

Analysis of factors affecting mite populations

Spraying frequency per year of agrochemicals including their brand names and population densities of the two mite species were also investigated from a selected apple orchard in Yeongju from 1997 to 2011. Population density of two mite species in this orchard was investigated using the same methods as described.

Planting system was investigated on the change of double grafting, presence or absence of ground cover, and tree height and dense planting in the same orchard from 2000 to 2011.

Application of inorganic fertilizers including nitrogen, phosphoric acid, potassium sulfate (K_2SO_4), burned lime and magnesium sulfate were investigated regarding the application amount per year from 2000 to 2011 for tree vigor. Data for total amount of five fertilizers were analyzed by Duncan's multiple range test at 5% level using MYSTAT 12 (Systat, Chicago).

Results

Population density and mite-infested orchard ratio

Mean infested orchard rate of *P. ulmi* was 12.4 - 69.1% per year and that of *T. urticae* was 5.1 - 70.0% (Fig. 1A). The highest rate of two mite species were observed in 1992. During 1990s, more orchards were infested by *T. urtica* than *P. ulmi*. But these rates were reversed after 2000 when *P. ulmi* became dominant. However, mite-infested orchard rates decreased consistently (*P. ulmi*: $y = -0.7299x + 37.937$; *T. urticae*: $y = -2.5067x + 62.312$) from 2001.

The yearly mean population density of *T. urticae* was also higher than that of *P. ulmi* during 1992 to 2000, but *P. ulmi* dominated after 2001. They became similar and lower in the 2000s (Fig. 2A). But this dominance fluctuation did not make a big difference; rather, it showed similar decreasing patterns. In 2001, the population of *T. urticae* decreased by more than 80%. Overall, population trend of two mite species decreased consistently with fluctuant (*P. ulmi*: $y = -0.9762x + 35.935$; *T. urticae*: $y = -2.5377x + 60.753$).

Trend of yearly infested orchard rates on weeds by *T. urticae*

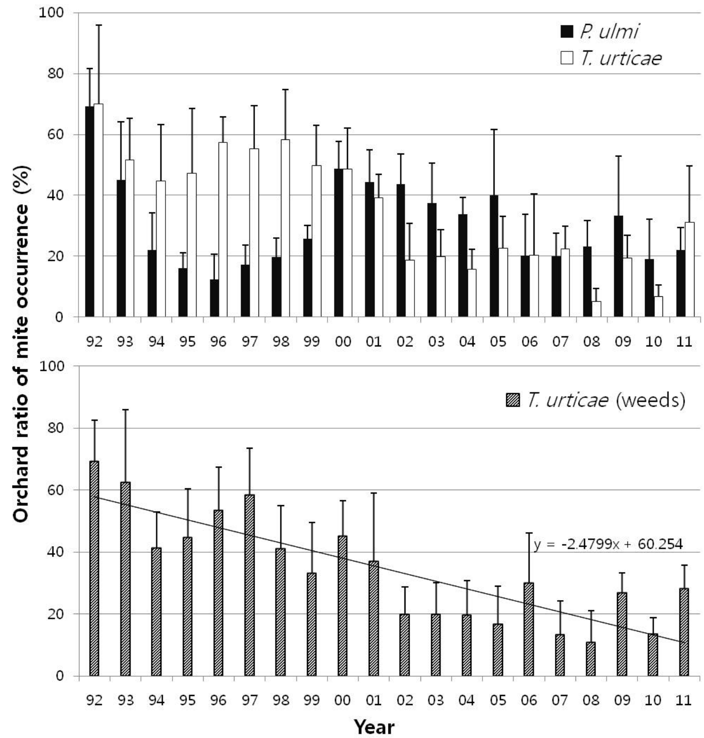

Fig. 1. The ratio of apple orchards infestation with *Tetranychus urticae* and *Panonychus ulmi* during the 1992–2011 period. Infestation ratios of (A) *T. urticae* and *P. ulmi* on apple trees, and (B) *T. urticae* in weeds.

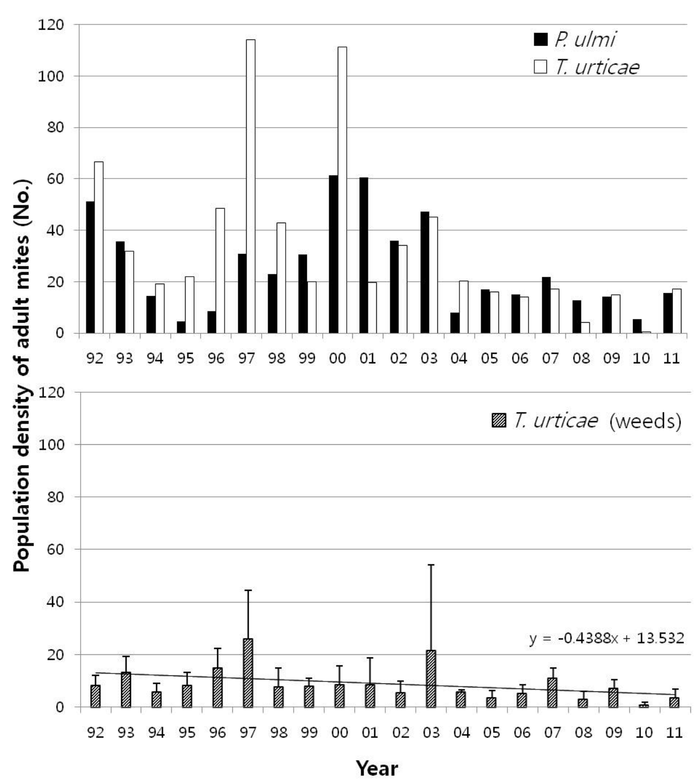

Fig. 2. Mean population densities of *Tetranychus urticae* and *Panonychus ulmi* in apple orchards during the 1992–2011 period. Mean population densities of (A) *T. urticae* and *P. ulmi* on apple trees, and (B) *T. urticae* on weeds.

(Fig. 1B) was similar to that on apple tree (10.8 - 69.1%), but mean population density of *T. urticae* (Fig. 2B) maintained low population during investigation period.

Monthly pattern of population size and infested orchard rates

Figs. 3 and 4 show the trend of infested orchard ratio and mean population from April to September per A period (1992-1996), B period (1997-2001), C period (2002-2006), and D period (2007-2011). Seasonal population of *P. ulmi* decreased gradually over five-year period, and infested orchard ratio in the D period was lowest compared with other periods (Fig. 3A). *P. ulmi*-infested orchard ratio was highest in early April during all periods but consistently decreased over periods. Seasonal infested orchard ratio of *T. urticae* also significantly decreased, especially in the C and D periods, compared with other periods (Fig. 3B). On weeds, seasonal infested orchard ratio of *T. urticae* showed a similar pattern to the ratio on apple tree (Fig. 3C). During 1992 to 2011, monthly population of *P. ulmi* was higher in April, but constantly decreased and maintained the population until September. Population fluctuation of *T. urticae* by month

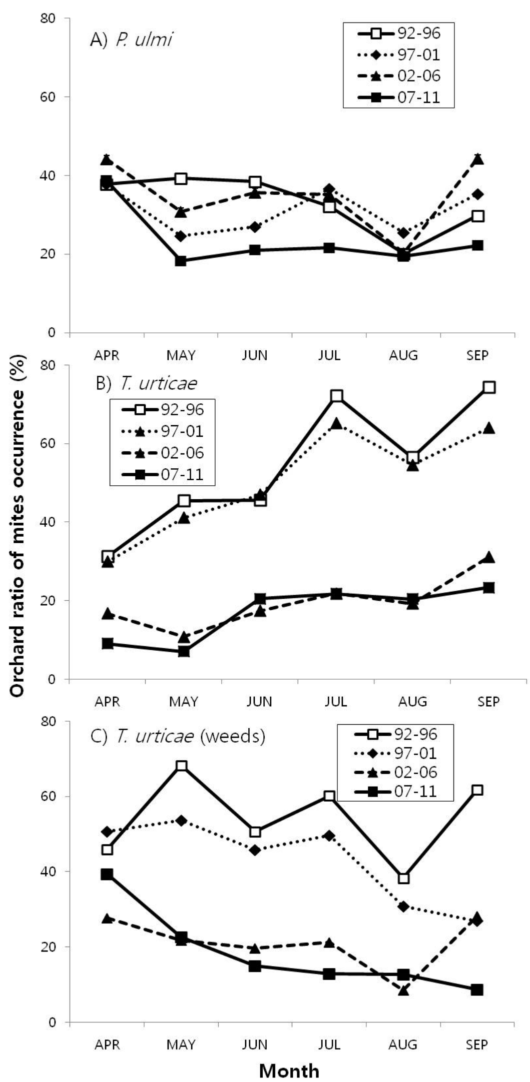

Fig. 3. The rates of apple orchards infestation with (A) *Panonychus ulmi* and (B) *Tetranychus urticae* on apple trees and C) *T. urticae* on weeds over four time periods (period A: '92–'96; period B: '97–'01; period C: '02–'06; and period D: '07–'11) during the 1992–2011 period.

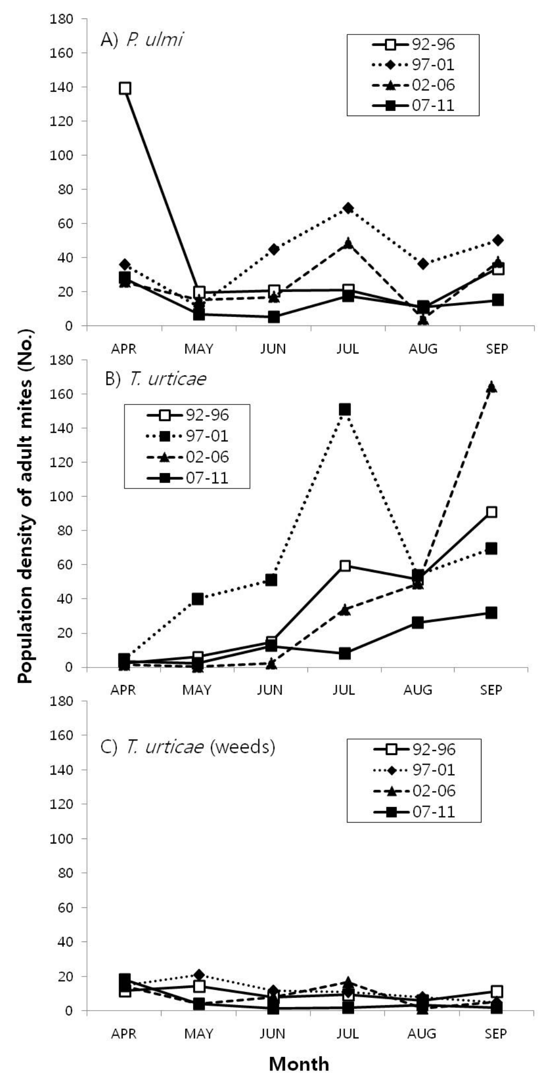

Fig. 4. Monthly average densities of (A) *Panonychus ulmi* and (B) *Tetranychus urticae* on apple treees and (C) *T. urticae* on weeds among investigated apple orchards over four time periods (period A: '92–'96; period B: '97–'01; period C: '02–'06; and period D: '07–'11) during the 1992–2011 period.

had a totally different trend - it is lowest in April and increased thereafter in trees. Conversely, population of *T. urticae* on weeds was high in April and May but decreased from June to September.

Population of *P. ulmi* in the D period was lowest (Fig. 4A). Monthly population of *T. urticae* was highest in the B period; the others have similar trends, with the lowest population shown during the D period (Fig. 4B). However, *T. urticae* on weeds had a lower population during all periods and months (Fig. 4C). During all investigated years, total population of *P. ulmi* maintained a low density, but population density of *T. urticae* increased monthly (Fig. 4).

Trend of two mite populations in a selected orchard

In a selected apple orchard at Yeongju, population density of two mites was investigated by year and by month from 2000 to 2011 (Fig. 5). Mean population density of *P. ulmi* by year was peaked at 2001, 2007 and 2011. However, mean population of *T. urticae* in trees and on weeds maintained low density (Fig. 5A). Populations of *P. ulmi* showed large fluctuations, and obviously more abundant than *T. urticae*. Besides, *T. urticae* on weeds had very low densities with scarce observations. Therefore, *T. urticae* has lower total population. Population density of *P. ulmi* by month was higher population density in April, probably from overwintering. But this density decreased from May to July and increased again from August to September. On the contrary, population of *T. urticae* during this period had lower densities in trees and on weeds during April to September (Fig. 5B). With different trend of all orchard investigated, population abundances of *P. ulmi* and *T. urticae* from 2000 to 2011was showed clearly the *P. ulmi* dominance since 2000 (Fig. 5C).

Factors affecting to change the dominance of two mite species in a typical orchard

Populations and infested orchard ratio of *T. urticae* and *P. ulmi* varied significantly among investigated orchards. However, change in the dominance between two mite species and decreases in their populations were common. Although the data of population density and infested orchard ratio did not have clear-cut from orchards investigated because of too big sample sizes, population abundance of one typical orchard obviously showed the dominance of *P. ulmi*. Survey was done only from 2000 to 2011 and it may convince somewhat different trends with a partial data for analysis. On the contrary, it could be possible to explain indirectly and reversely. For elucidating these factors in selected orchard, some factors performed on selected apple orchard may affect to decrease the growth of two mite species. So we try to clear and analyze this why the dominance was changed to *P. ulmi* in this orchard. To analyze what factors might affect this dominance change, we examined three factors left behind the other factors could be affect. And three factors

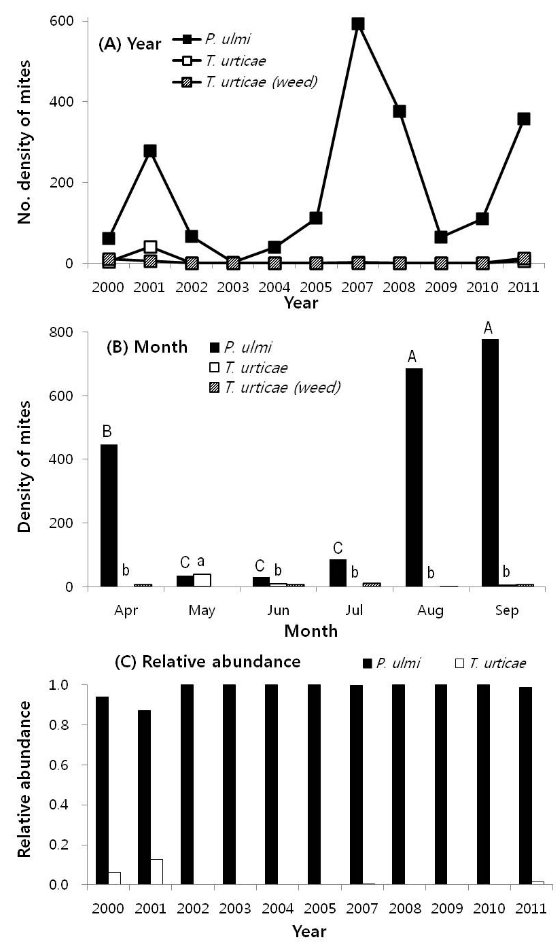

Fig. 5. Population density of *Panonychus ulmi* and *Tetranychus urticae* by year (A) and month (B) and their population abundance in a typical apple orchard. Changes in the population abundance of *P. ulmi* and *T. urticae* from 2000 to 2011. The relative abundances were calculated by dividing *P. ulmi* (or *T. urticae*) abundances by the sum of *P. ulmi* and *T. urticae* abundances from April to September. The same letter over the bar indicates no significant difference (DMRT, $P < 0.05$).

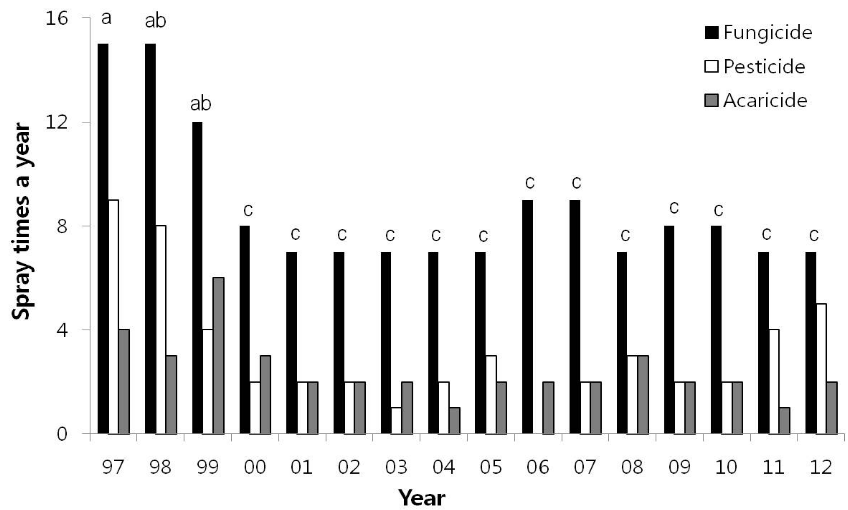

Fig. 6. Changes in the frequency of spraying per year in a typical apple orchard in Yeongju. The same letter over the bar indicates no significant difference (DMRT, $P < 0.05$).

considered with relation to dominance change of two mite species, chosen in one typical orchard at Yeongju.

Reduction of spraying frequencies of agrochemicals

In a selected orchard, agrochemicals sprayed based on the spray calendar. The results of the survey on use of agrochemicals (Fig. 6) revealed that spraying frequencies in 1997 were 15 times/year for fungicides, 9 times/year for pesticides, and 4 times/year for acaricides, but frequencies were reduced in 2011 to 7, 4, and 1 times/year, respectively. In particular, spraying frequency for acaricides reduced from four times in 1997 to once in 2011 a year.

Comparing of spraying times of agrochemicals by year showed the significant difference. Frequency of agrochemicals were sprayed many times at the begining of cultivation (1997-1999), but frequency was decreased under 15 times a year thereafter. This is indirect evidence that the farmers tend to spray more chemicals when the pest observed in high populations.

Changes of cultural practices

Planting system in a typical orchard has gradually changed. It was first planted the general rootstock (double grafting) with M26 until 2003, and some are changed to M26 rootstock and the others are grafted with M9 rootstock during 2004 to 2007. And it was completely changed to M9 rootstock after 2008.

As the change of planting system, apple tree in M26 rootstock was managed as the size of 4 × 2 m (tree height and cultivation distance), with 150 plants per 10 acre, apple tree in M9 rootstock was managed under 3.5 × 1.5 m, with 190 plants per 10 acre. These changes might affect the usage of the inorganic fertilizer as well as spraying of agrochemicals. It needed more fertilization in M26 double grafting than M9 double grafting for tree vigor.

Ground cover crops have many benefits to improve soil health, to reduce the use of fertilizer and to enhance populations of resident beneficial insects like predators and parasitoids such as *Phaseolius womersleyi*. During an investigation periods, all of 22 investigated orchards kept the ground covered with weeds.

Decrease of five kinds of fertilizer

From a typical apple orchard, the usage trends of five kinds of fertilizer was analyzed by year. Five inorganic fertilizers were usually used for fertilization. Especially, nitrogen fertilizer is recognized very important to the plant growth and vigor, and vulnerability to the disease and pests. Total usage amount of five kinds of fertilizer by year was analyzed significantly different at 2000, and little bit higher in 2001-2002 without significant, and the others year was used to low amount. So, we thought the dominance change of two mites is might affected by the

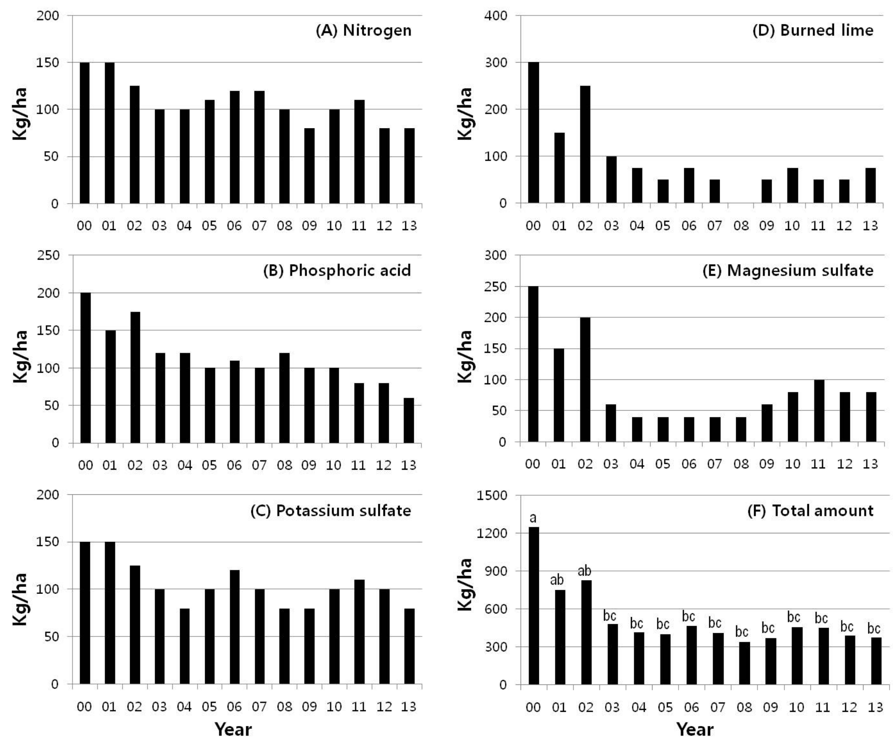

Fig. 7. Fertilization with five types of fertilizers in a typical orchard. (A) Nitrogen, (B) phosphoric acid, (C) potassium sulfate, (D) burned lime, (E) magnesium sulfate, and (F) total amount of used fertilizers. The same letter over the bar indicates no significant difference (DMRT, $P < 0.05$).

fertilizer's usage. All five inorganic fertilizers were less used over time (Fig. 7A-F).

It insisted on the continuous reduction in the amount of nitrogen fertilization used in apple orchards was also reported (Ministry of Agriculture and Forestry, 2007). The adequate amount of nitrogen fertilization will produce a small number of shoots and invigorate the vital power of fruit trees.

There are many factors could be affect to change the population of two mite species. This research only showed indirect evidence relating on *P. ulmi* population change to spraying times of agrochemicals and fertilizer's usage. However, it just only proved the farmers sprayed more chemicals when the pest observed in high populations. Unfortunately, mite populations and dominance change seemed affected by too many factors, not by few. Although many factors are considered to effect on this population change, we could not clarify the correlation between population and several factors.

Discussion

In the present study, *T. urticae* and *P. ulmi*, as major pests of apple orchards, were surveyed for population density and infested orchard ratio from 1992 to 2011. This study also confirmed the change of species dominance from *T. urticae* to *P. ulmi* in year 2000 (Fig. 1) from previous studies cited earlier. Another characteristic trend revealed was the decrease of total populations and infested orchard ratios of two mite species (Figs. 1 to 4). In a broad view point, long term fluctuation of orchard pests in apple orchards in South Korea has changed from peach fruit moth to mites and aphids (Lee et al., 1996; Hyun et al., 1991).

There are various aspects to consider in the dominance change of two mite species. First of all, spraying frequency of agrochemicals was reduced. In investigated apple orchards, synthetic pesticides were sprayed intensively before year 2000. Most of these showed high toxicity to *A. womersleyi*, a natural enemy of *T. urticae* and *P. ulmi*. The use of pesticides in orchards reduced the population of natural enemies such as predatory mites, Asian ladybirds, Braconids, and Eulophids resulting to the proliferation of mites as major pests in apple orchards (Croft and Hoyt, 1983; Metcalf and Luckmann, 1994). Before spraying acaricides, orchards did not have any mite problems, but the population of mites has increased after spraying (Kim and Lee, 2005). Orchards that adapted organic farming had less or no problems with mites are another example. It is well known that the resistance developed faster in *T. urticae* than in *P. ulmi*. If farms constantly sprayed pesticides frequently, it will result in faster development of resistance for *T. urticae* than *P. ulmi*. At higher spraying frequencies of pesticides, the possibility of *T. urticae* infestation will also increase. Therefore, it is hypothesized that this factor primarily caused the outbreak and dominance of *T. urticae*. Recent trends have changed pesticides formulations from highly toxicity to moderate/low toxicity with selective toxicity. Therefore, it is now possible to use pesticides with lower acaricide activity against the natural enemy of *T. urticae*, *A. womersleyi* (Park et al., 1996; Cheon et al., 2008).

Moreover, spraying frequencies of pesticides were reduced. Assessment of spraying times of pesticides in apple orchards in the past reveal that frequencies continuously increased until 1980, but constantly decreased after 1990 until 2008. Spraying frequencies increased again in 2010 and 2011 because heavy rains and high temperatures in summer induced the population of pests. Spraying frequencies of pesticides in conventional apple orchards were surveyed as follows: pesticides 9-12 times and acaricides 4-5 times for a total 13-16 times in 1994; pesticides 7.6 times and acaricides 2.8 times for a total 10.5 times in 2004; and, pesticides 8.7 times and acaricides 2.5 times for a total 10.7 times in 2011. Comparing 1994 to 2004, pesticide use decreased 5-6 times within the period, after which the frequency was maintained until 2011 (Lee et al., 1996; 2007). Spraying frequencies of pesticides also differed depending on the location. Fungicide-spraying ranged 8.0 to 14.4 times; pesticides from 8.2 to 13.2 times, and acaricides from 2.2 to 4.8 times (Lee S.W., unpublished observation). Therefore, status of occurrence pests in apple orchard will vary from the farm and spraying frequencies. In general, less frequency of spraying is better to manage the orchard, otherwise more spraying frequencies will increase the population of *T. urticae*. Depending on the timing of pesticide use, the dominance of two mite species will change. *P. ulmi* overwintered as eggs and this is the reason for its high population in April (Figs. 3 and 4). If orchards did not spray the pesticides, population of *P. ulmi* can occur higher in June and July. But if an orchard sprayed pesticides even once, it will lessen the possibility of occurrence of *P. ulmi,* because of its susceptibility but not *T. urticae.*

Agrochemical formulations sprayed in apple orchards were as follows: Mixture > Pyrethroids > Organophosphates > Nicotinoids > IGR. This trend was similar with the spraying frequencies at conventional orchards (Fig. 6). In the past, many farmers thought that diseases and pests can be controlled by spraying pesticides as many times as possible, but they are now using the spray calendar to control minimally, especially in case of Yeongju orchard. The laborious public relation through policy and education by the government seems to have a positive effect.

Previous studies explained that dominance change from *P. ulmi* to *T. urticae* for same period was caused by increasing spraying frequencies of pesticides in 1970s. This study, on the other hand, illustrated the dominance change from *T. urticae* to *P. ulmi* by decreasing spraying frequency of pesticides in the 2000s (Fig. 6).

Second, apple cultivation method has changed. Nationwide cultivation areas of apple decreased from 50,000 ha to 26,000 ha in the early of 1990s, and steadily increased after, through planting of M9 stocks in some cultivation areas (Ministry of Agriculture and Forestry, 2007). Apple cultivation areas in Gyeongbuk province represent 63% of the total in the republic of Korea. To reduce the labor resources and to increase work efficiency, the M9 stock was propagated in major apple orchards and later became the main stock by mass planting. In investigated orchards, the propagation of M9 began in 1998 and increased to 5% in 2000 and 28% at 2007. The M9 stock is short in height and the top of the canopy can be easily sprayed, reducing unnecessary spraying. This method of spraying not only manages diseases and pests, but also avoids excess pesticide spills on the ground cover inhabited by natural enemies. We tried to connect the change between plantation of M9 stock and population density, but failed at current status, we guess that other negative factor might be affected or more involved other factors on this. As a result, the farmers can easily manage the orchard and control the pests. The plantation of M9 stock coincides with the dominance change in mite species. The total population density of two mite species is thus reduced.

Ground cover may also be another key factor. In orchards without green cover, *T. urticae* will generally migrate to the fruit tree from the early April to May, but in orchards with green cover, *T. urticae* stays in the weed by preference or delayed the migration by providing the shelter. Moreover, it is easier to control the two-spotted spider mites by chemicals in the ground than the tree. In June, *T. urticae* will migrate to the fruit trees and thereafter the population is increased. It could be another evidence that population density of *T. urticae* on weeds was decreased from the early April to May, but those in trees was increased from this season, as shown in Fig. 3B and 3C. *T. urticae* is known for its prolific reproduction in high temperatures (Rural Development Administration, 2000), and this was proven by their continuously growing density from July to September. This implies that *T. urticae* stay in weeds during seasons of food scarcity (spring), but move to the apple tree when food become abundant in summer.

This is the reason why the population pattern of two mite species was shown by month. To control the overwintered *P. ulmi* eggs, conventional apple orchards generally apply mechanical oils in early spring or sprayed acaricides 1 to 2 times in early season to control occurrence of *T. urticae*. After these applications, *P. ulmi* is almost controlled and the population of *T. urticae* sharply decreases. Then continuous management is needed to prevent problems caused by *P. ulmi* or mostly by *T. urticae*. Undermanagement of conventional apple orchard will change the population of the two mite species.

According to explanation of Kim and Lee (2005), density of *P. ulmi* increases in early season population in the system of the ground cover sprayed with (non-selective) highly toxic pesticides ‒this is because the migration of *T. urticae* to the fruit tree becomes limited and the natural enemies are destroyed. Density of *P. ulmi* increases (but to a lesser extent) in the system of the ground cover sprayed with low toxicity. All orchard investigated by us managed by ground cover, so it is difficult to direct comparison how ground cover effect on population density of two mites. Nevertheless, it can be concluded that the ground cover and spraying of low toxicity affect the species dominance and population densities of the two mite species at apple orchards, as coincided with the explanation of Kim and Lee (2005).

Third, nitrogen fertilization is reduced. As nitrogen treatment increases, the population of *T. urticae* also increases (Najafabadi et al., 2011). Vice versa, the population of pests in our investigation is guessing to relate on the reduction of five kinds of fertilizer. Therefore, nitrogen fertilization is one of the important factors to control the population of pests (Bentz et al., 1995; Jansson and Ekbom, 2002). Recently, the continuous reduction in the amount of nitrogen fertilization used in apple orchards was reported. The adequate amount of nitrogen fertilization will produce a small number of shoots and invigorate the vital power of fruit trees.

Conclusion

The dominance change of two mite species in apple orchards is a very important factor in managing the pests. If the dominance and the population density of these pests can be controlled, it will easier to manage the orchards and become more profitable. This author looks forward to provide this research data to establish a system of integrated pest management in apple orchards.

This study revealed a pattern of dominance that coexists between *T. urticae* and *P. ulmi*; in all orchard investigated, but absolutely dominated by *P. ulmi* at independent orchard. Population density of *P. ulmi* is high in spring, versus that of *T. urticae* which maintains a lower population until June after which, a reversal in dominance occurs with *T. urticae* due to the favorable summer weather.

The ground cover of weeds provides a habitat for *T. urticae* and delays or restricts its migration to the fruit trees. Investigated orchards with ground cover had comparatively higher density of *P. ulmi* than *T. urticae*, but total population densities of two mite species were smaller.

Toxicity of agrochemicals affects the population of mites. As shown in Fig. 6, when agrochemicals with lower toxicity were sprayed after 2000, the spraying frequencies per year declined. Perhaps, the improved environment and cultivation methods in apple orchards have decreased the population density and orchard ratio of pest occurrence.

This study tried to find evidence of the relationship between the decrease in spraying frequency and the activity of natural enemy such as *A. womersleyi.* According to Kim et al. (1995), ground cover weeds in orchards protect the natural enemies against water-soluble agrochemicals. They explained that the competition between *T. urticae* and *A. womersleyi* occurs in the ground cover weeds. However, since this objective is not included in the scope of this study, We only assumed that this relationship will have an effect to some extent. A further study is needed to verify this.

We can suppose several factors in addition to abovementioned – inadequate removal of host plants and overwintering sites and problems caused by incorrect chemicals – that affect the population density of two mites. However, there is a need to clarify these factors, considering the biological, ecological, physical parameters through further research.

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