International Journal of PharmTech Research
CODEN (USA): IJPRIF, ISSN: 0974-4304, ISSN(Online): 2455-9563
Vol.9, No.10, pp 593-598, 2016

Use of Taylor's Power Law parameters in Nematode Sampling

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Abstract : Two insights on the use of Taylor's Power Law(TPL) are discussed. Improving optimum size of nematode samples via iteration is presented. Rearranging the TPL formulae to solve for the ratio of the half-width of the confidence interval to the mean of the nematode numbers rather than sample size is suggested especially in case of limited fund.
Key words: nematode sampling, reliability, sample size, spatial dispersion, Taylor's Power Law.

Introduction

Considerable losses in various crop production systems are caused byplant-parasitic nematodes (PPN) worldwide. A recent estimate of an averageof such crop losses by Abd-Elgawad and Askary[1] was found to be 12.6% of the top 20 life-sustaining crops.Various research directions are underway to study the components and aspects of PPN problems and find the best solutions in Egypt[2,3,4] and elsewhere[5,6,7]. An important direction is determining sample size optimization of PPN which should be useful in making economic and accurate pest management decisions. These latter may involve chemical, cultural, or biological applications, alone or in combination, as and where they are needed. Sampling the nematode populations in a field makes it possible to determine thePPN species present, theirinfestation levels, and detect the distribution pattern of a nematodespecies.Therefore, a management decision process of PPN isonly as good as the reliabilityof the sampleupon which nematode population measurements are based[8].

Asausefulandwidelyverifiedquantitativepatternforthousandsofbiologicalspecies covering various studies, e.g. in agriculture, medicine, and pharm, Taylor'sPowerLaw(TPL) could offer such sampling optimization of PPN [9,10,11,12,13,14]. This law is flexible, useful in determining transformations[15,16] and developing nematode sampling plans[17].Moreover, it is still under scrutiny by numerous researchers to understand its scientific roots and established concepts, explain its mechanisms, and provide an outlook of its future applications[18,19,20,21]. In this paper, two new insights are provided for TPL application to sample statistics in nematology.

1. Improving estimate of sample size. TPL states that the variance(S^2) of a population is proportional to a fractional power*(b)* ofits arithmeticmean ($\bar{x}$):

$$S^2 = a\,\bar{x}^{(b)} \text{ or } \log S^2 = \log a + b \log \bar{x} \quad , \quad a > 0 \qquad \text{(i)}$$

Where *a* and *b* are population parameters, *a* is a coefficient affected primarily by sample-size and habitat and *b* is a species-specific aggregation index that could be used to determine sample size optimization and derivation of appropriate normalizing transformations[15,16,22]. When parameters *a* and *b* of TPL are known, the sample size (n or n*) can be derived from:

$n = (1/E)^2 a\ \bar{x}^{b-2}$ or $n^* = (t_{\alpha[n-1]}/D)^2\ a\ \bar{x}^{b-2}$(ii)

Where n is the number of samples, $t_{\alpha[n-1]}$is the appropriate Student's *t* value for confidence limits of 1- α an dn-1degrees of freedom, and sampling reliability is defined in terms of the standard error to mean ratio (*E*) or the ratio of the half-width of the confidence interval to the mean (*D*)of the samples. Accordingly, TPL could be applied in sampling programs of nematodes to determine sample size optimization[13,17,23,24,25]. In order to solve for the unknown quantity (=n^*), researchers suggested using Student's *t* value equaled to 2.0 for the most common 95% confidence interval to simplify it since the estimates are not very precise. I suggest iteration for more appropriate Student's *t* value after applying TPL equations in order to improve the estimate of optimum sample size. Many classes teach to iterate for the t-value when solving for any of the terms in some formulae for confidence intervals but to the author's knowledge, sample size determined by TPL (e.g., McSorley *et al.*,[13]; Abd-Elgawad,[14]; Abd-Elgawad and Hasabo,[25]; Duncan and Phillips,[26]; Salama and Abd-Elgawad,[27]; Abd-Elgawad and Hammam,[28]) is not incorporated into the iteration process. Therefore, I introduced this process into actual TPL data selected from old (McSorley *et al.*, 1985; Abd-Elgawad and Hasabo, 1995)[13,25] and recently (Abd-Elgawad and Hammam, 2014)[28] published papers (Tables 1 and 2). Sample size function is iterated via applying the function repeatedly; using the output from the first simple equation as the input to the next iteration is easier when Microsoft Excel Worksheet is used (Table 1). So, iteration is followed herein to find a more suitable value of *t* instead of, 2, its supposed value. That is because the exact value of *t* depends entirely on the degrees of freedom; expressed as the number of samples – 1 (Sokal and Rohlf,[29]). Hence, iteration is continued until two consecutive sample sizes are the same (Table 1) to find the*t*value that rightly corresponds to the degrees of freedom. The Microsoft Excel Worksheet indicated that sample size is usually rounded up to the nearest integer (Table 1). Consequently, suggested iteration in solving for sample size, to reach *t*-value that precisely match the corresponding degrees of freedom might reveal an improved estimate of optimum sample size needed to achieve a 20% level of (*D*) reliability for heterorhabditid nematode-infected *Galleria mellonella* larvae, was 118 instead of 120 samples (Table 1).

Likewise, four examples are given in Table 2 using published data for sampling of the root-knot nematode *Meloidogyne incognita* (McSorley et al., 1985) and the ring nematode *Criconemella* spp. (Abd-Elgawad and Hasabo,[27]) ; e.g. the minimum numbers of samples needed to achieve a 25% level of (*D*) reliability for *Criconemella* spp. and *Meloidogyne incognita* were 8 and 389 instead of 5 and 402 samples, respectively (Table 2). Without iteration, the greater the distance between the number of samples and number 60 (where tabulated *t*-value = 2 for 95% confidence interval), the less accurate the result of the equation (ii), becomes.

Table 1.Exact figures from Microsoft Excel Worksheet used to calculate the sample size before (Student's *t* = 2) and after iteration for phytonematode and nematode-infected insect pests*.

Case	*E*	a		B		*t*	$_t2$	n^+
1	0.25	4.77	10	2.12	100.6094	2	4	402.4374
	0.25	4.77	10	2.12	100.6094	1.966	3.865156	388.8708
	0.25	4.77	10	2.12	100.6094	1.966	3.865156	388.8708
2	0.25	4.77	5	2.12	92.57949	2	4	370.3179
	0.25	4.77	5	2.12	92.57949	1.966	3.865156	357.8342
	0.25	4.77	5	2.12	92.57949	1.967	3.869089	358.1983
3	0.20	1.2	1	0.9044	30	2	4	120
	0.20	1.2	1	0.9044	30	1.98	3.9204	117.612
	0.20	1.2	1	0.9044	30	1.981	3.924361	117.7308

*Estimates are calculated using the equations: $n = (1/E)^2\ a\ \bar{x}^{b-2}$ or $n^+ = (t_{\alpha[n-1]}/D)^2\ a\ \bar{x}^{b-2}$ where n or n^+ is sample size, *E* = the standard error to mean ratio, *D* = the ratio of the half-width of the confidence interval to the mean of the samples, *a* and *b* are the parameters of Taylor's Power Law, $\bar{x}$ = the arithmetic mean of the nematode population, *t*α[n-1] is the appropriate Student's *t* value for confidence limits of 1- α and n - 1 degrees of freedom (http://www.danielsoper.com/statcalc3/calc.aspx?id=10) for populations of *Meloidogyne incognita* in cases 1 and 2 (McSorley *et al.*,[13]) and heterorhabditid nematode-infected *Galleria mellonella* larvae in case 3 (Abd-Elgawad and Hammam, 2014)[25].

Table 2.Minimum number of nematode samples needed to achieve a 25% level of reliability as defined in terms of standard error to mean ratio (*E*) or confidence intervalhalf-width to mean ratio (*D*) with iteration*.

Mean count per sample	Number of samples via *E*	Student's t-value	Number of samples via *D*	Reference
***Criconemella* spp.: The power law parameter s*a* =3.076, *b* =1.218**				
10	8	2 (assumed)	33	Abd-Elgawad and Hasabo, 1995[27]
		2.037 (n=33)	34	
		2.035 (n=34)	34	
100	1	2 (assumed)	5	
		2.776 (n=5)	10	
		2.262 (n=10)	7	
		2.447 (n=7)	8	
		2.365 (n=8)	8	
***Meliodogyne incognita*: The power law parameter s*a* =4.77, *b* =2.12**				
10	101	2 (assumed)	402	McSorley*et al*., 1985[13]
		1.966 (n=402)	389	
		1.966 (n=389)	389	
5	93	2 (assumed)	370	
		1.966 (n=370)	358	
		1.967 (n=358)	358	

*The *t*-valueiseitherassumedas2for95%confidenceintervaloriteratedusingits tabulated value from: http://www.danielsoper.com/statcalc3/calc.aspx?id=10.

2. Budget conscious choice of different reliability levels associated with fixed, cost-determined, sample sizes.

I hypothesize that pre-defined sample costs usually provide a basis of estimating the accuracy or reliability of nematode sampling especially in case of limited fund. Therefore, instead of the conventional approaches that are used to estimate numbers of samples needed to predict crop loss due to nematodes with a given error bound, I propose rearranging the TPL formulae to estimate the accuracy/precision of predictions given a predetermined sampling intensity. In other words, the spatial parameters might be used differently. Rather than determining the sample size for a given level of precision of the estimate indicated in the above-mentioned cited papers, they should determine the reliability for a fixed sample size. So, number of samples and probability level (1- α) are known but the reliability term (E or D) is determined from:

$$E = (a\bar{x}^{b-2}/ n)^{0.5}; \quad D = t_{\alpha[n-1]}E \quad \text{(iii)}$$

Statistically, solving first degree equation for these unknown reliability terms may be more delicate than solving for the unknown number of samples (*n*). This is because actual Student's *t*-value is also unknown variable in equation (ii) and therefore researchers usually have to assume $t \approx 2$ with 95% confidence (e.g., Elliott, 1971; Ferris, 1984)[9,30] for unknown *n*. Given such a case, the available fund to collect and process samples is divided by cost per sample unit to decide the number of samples that could be covered by limited fund (Table 3). The cost covers contributions of various activities to sampling the nematodes (e.g., Goodell and Ferris, 1981)[12]. Specialist advice on sampling reliability and how principles are used in each sampling project should be sought. Several studies set a precision range of 75-85% but there is no globally acceptable level (Ghaderi *et al*., 2012)[11]. Depending on the cost of the management alternative, the required number of nematode samples in tomato and cotton fields (Ferris *et al*., 1990)[10] was several-fold higher than that of previous recommendations by Ferris *et al*. (1981)[8] and would involve additional costs not factored into the calculations. Furthermore, precision levelacceptable as a basis for nematode management decisions may vary greatly depending on many factors such as the given sampling objective and nematode species. Therefore, allowing differentlevels of accuracy/precision can offer more options for a budget conscious choice via moreextensive and rational nematode pest management decisions. It is assumed that having severalreliability levels to choose from could also be most convenient to integrate other relevant factorssuch as expected and

previous crop yield relative to the common average yield in relation to thesignificance of the existing nematode species; their levels and expected losses as well as all management options to optimize the total costs. For example, assuming $\bar{x}$ of 10 and 20nematodes per sample, 40 and 30 samples should be taken, respectively to achieve almost thesame accuracy, i.e. E = 22-23% using TPL (Table 3). Yet, the costs are reduced from $ 400 to $300 using Egyptian prices of July, 2016. Given supposedly different nematode population levels, a decision maker having such economic options will consider, for example, not only enhancing the naturalenemies of phytonematodes needed via sustainable agriculture, but also the difficulty of relyingon bio-nematicides as confidently as chemical nematicides. Also considered, in some states, themore numbers of samples collected, or bioassays run, the cheaper is the charge per one sample.So, different levels of sampling reliability, nematicidal efficacy, environmental impact, andnematode population as well as relative sampling cost should be considered and compensatedwith other relevant factors. Considering different finance-based number of samples, decision makers may be able to do abetter compromise of a cost and benefit trade-off. In Egypt, as a case in point, it was found that acharge frequently equivalent to US $ 10 is the cost of collecting, processing, and counting thenematodes in one sample for a minimum of 5 samples (5 x 10 = US $ 50). This cost includessample transportation to the identification laboratory. Yet, if the number of samples increases,the price per sample decreases to one-half for 90-150 samples and probably up to 70% discountfor > 150 samples. Such costs were adopted in the calculations for sampling costs (Table 3).

Moreover, using the procedure exemplified in table (3) to indicate the precision associatedwith a fixed cost of sampling, we can analyze and explore further economic and technical factorsassociated with different precision levels as needs arise in a given sampling project. Samplingcosts can be substantially reduced by making sampling procedures more efficient and effective.It is a common mistake to assume that there is an everlasting linear relation between samplingcosts and sample size. Also, the variation due to sampling and laboratory procedures areunknown and may differ from one laboratory to another (Van den Berg *et al*,. 2014)[31] and so mayeven exceed field variation. In this case, one should rather improve and standardize methodsinstead of increasing samples.

Table3.Percentage level of accuracy as defined in terms of the standard error to mean ratio(E) and the ratio of the half-width of the confidence interval[x] to the mean (D) for stratified random sampling of *Meloidogyne* spp. in fields of berseem clover in Egypt.

Cost of Samples (US$)	Finance-based number of samples	ean nematode count per sample[y]	Level of accuracy/reliability[z]	
			D	E
Taylor's power law parameters: *a* =3.483, *b* =1.729				
150	15	40	63%	29%
200	20	30	55%	26%
250	25	20	51%	25%
300	30	20	48%	23%
400	40	10	44%	22%
200	20	1	87%	42%
250	25	1	77%	37%
750	150	1	30%	15%

[x]*The t-value at 95% confidence interval was obtained from:http://www.danielsoper.com/statcalc3/calc.aspx?id=10.*

[y]Based on a sample size of 100 gm soil (Abd-Elgawad and Hasabo, [27]).

[z]Thefractional values rounded up to nearesttwodecimals (i.e. percentage).

Acknowledgement

This study was supported in part by the US-Egypt Project cycle 17 (no. 172) and National Research Centre In-house project entitled 'Pesticide alternatives against soil borne pathogens attacking legume cultivation in Egypt'.

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