Construction of an Electrical Device for Sampling Earthworm Populations in the Field

S. L. Weyers, H. H. Schomberg, P. F. Hendrix, K. A. Spokas, D. M. Endale

Abstract. *Methods for the estimation of earthworm population densities range from laborious handsorting, through chemical applications, to electrical extraction. Of these methods, only the electrical extraction allows for sampling of earthworms without detrimental soil disturbance or contamination. However, a device to extract earthworms under controlled electronic conditions is not readily available to researchers. An improved design on the long-established electrical "octet" extraction device is presented. This improved design allows for hand-built construction of an apparatus that can be connected to external drive controls, including data loggers and PC-controlled drivers. This design also allows for modification of sampling settings to suit specific environmental conditions, with control of voltage, and operation with a static or dynamic electrical field being generated. Operational ability to extract earthworms was validated in field trials in both a forested area and an agricultural field. Earthworm sampling efficiencies calculated in comparison to hand-sorting averaged around 90% for the electrical device; however, because of limited field use in this instance, these efficiencies support the general functioning of the apparatus rather than an absolute assurance of quality. In using this hand-built device we established that this design is capable of extracting both native and exotic earthworms of various age and size class under various soil conditions, that soil disturbance and contamination can be avoided, and that the device can easily be transported into remote locations.*

Keywords. *Octet, Earthworms, Electrical extraction, Sampling, Disturbance, Conservation management, No-till.*

There are three commonly used methods for extracting earthworms from soil: irritant solutions, e.g. formaldehyde and 'hot' mustard (Raw, 1959; Gunn, 1992; Lawrence and Bowers, 2002; Zaborski, 2003); handsorting (Schmidt, 2001a); and electrical stimulation (Satchell, 1955; Rushton and Luff, 1984; Thielemann, 1986). Use of solutes and handsorting may not always be appropriate because of certain constraints on time and effort, environmental pollution concerns, or a desire to avoid soil disturbance. As reviewed by Lee (1985) and Edwards and Bohlen (1996) no single sampling method is 100% efficient as biases by species, soil type, temperature and moisture conditions exist. Sampling with solutes give limited results because the solution has to pass through soil pores and reach the organisms in order to initiate the irritation that causes them to surface. Use of solutes has a tendency to bias the sampling by numbers or total biomass extracted (Zaborski, 2003), or by species through selection of species constructing soil channels open to the surface, such as anecic species, allowing the infiltration of the solution (Edwards and Bohlen, 1996). Handsorting has been cited to be the best technique for sampling most species (Edwards and Bohlen, 1996) and is often the preferred technique to use in diversity studies. However, handsorting is the most labor intensive and due to the aggregated nature of most earthworm populations, can be less productive when trying to establish densities. A recent improvement in the methodology has reduced the sampling time (Schmidt, 2001a), nevertheless limitations still exist. Handsorting or chemical applications, such as formaldehyde, can not be applied in situations where soil disturbance or ground water contamination is a concern, such as under no-till treatments in an agricultural system or a protected watershed. Electrical stimulation, or "electroshocking," is a non-distructive method for sampling earthworms. Staddon et al. (2003) recognized the value of electroshocking in situations that can prohibit use of other sampling methodologies.

In 1986, Uli Thielemann published a report (Thielemann, 1986) and filed a German patent (DE3612464, available at www.espacenet.com) for an electrical apparatus to sample earthworm populations, which was an improved methodology for the circular electrode configuration originally presented by Rushton and Luff (1984). Electrical extraction has been as basic as connecting two pitch forks to a 12-V battery to as advanced as a commercially-available "Octet" device constructed by a German manufacturer. The

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The authors are **Sharon Lachnicht Weyers,** Research Soil Scientist, USDA Agricultural Research Service, North Central Soil Conservation Research Laboratory, Morris, Minnesota; **Harry H. Schomberg,** Research Ecologist, USDA Agricultural Research Service, J. Phil Campbell Sr. Natural Resource Conservation Center, Watkinsville, Georgia; **Paul F. Hendrix,** Professor, Institute of Ecology and Department of Crop and Soil Sciences, University of Georgia, Athens, Georgia; **Kurt A. Spokas,** Research Soil Scientist, USDA Agricultural Research Service, Soil and Water Management Research Unit, St. Paul, Minnesota; and **Dinku M. Endale, ASABE Member Engineer,** Agricultural Engineer, USDA Agricultural Research Service, J. Phil Campbell Sr. Natural Resource Conservation Center, Watkinsville, Georgia. **Corresponding author:** Sharon Lachnicht Weyers, USDA Agricultural Research Service, North Central Soil Conservation Research Laboratory, 803 Iowa Ave., Morris, MN 56267; phone: 320-589-3411 ext. 146; fax: 320-589-3787; e-mail: Sharon.Weyers@ars.usda.gov.

term "octet" refers to the eight probe octagonal configuration. An assessment of the commercially-available device was given by Schmidt (2001b). Schmidt (2001b) refers to Thielemann's electrical octet method as poorly documented and as one of the less well known methods for estimating earthworm populations. He notes its successful use in Germany and Switzerland but rather limited adoption and testing elsewhere. Limited adoption and testing of the octet method outside the European Union could be linked to poor dissemination of the research. Many of the citations referencing the electrical octet method, including Thielemann's original publication, are written in German, and available solely in German journals with limited distribution. Also, the commercial "octet" device is not available in many countries outside the European Union. Our objective is to provide a readily accessible schematic for an electrical earthworm sampling apparatus employing a modification to Thielemann's design. This schematic will facilitate the construction of a hand-built device that can operate with capabilities similar to the commercial device as reported and used by Schmidt (2001b). We validated the functionality of this construction by using our hand-built device for sampling earthworms in both a natural forested site and an agricultural site. Sampling efficiency of the electroshocker was established by comparison to handsorting at the forested site. Through this effort we hope to improve dissemination and adoption of this method for sampling earthworms.

Materials and Methods

Electroshocker Construction

The electroshocker was constructed to function in a mode similar to the capabilities reported by Thielemann (1986) and Schmidt (2001b). Eight soil probes were placed in an octagonal arrangement, demarcating an area of approximately 0.22 m^2 which permitted the generation of an electric field in the soil (fig. 1). This device connects with a standard power cord plug to an external power supply; for transport into the field 12V gel cell batteries connected to an electrical 12V DC to 120V AC power inverter can be used (as depicted in fig. 2). Alternatively, this device can be connected directly to an AC power outlet or other AC power generation units. From the power supply a voltage transformer increases the supply voltage from 120V to 480V, similar to the voltage output of the commercial device used by Schmidt (2001b), while maintaining amperage less than 1.0 Amp. A single-phase variable voltage controller (Model 18D, Payne Engineering, Scott Depot, W.V., www.payneng.com) is used to control voltage output (0-100%) to the soil probes, using an adjustable potentiometer (270° turn, VC knob pictured in fig. 1). The potentiometer on this device generates an electric field strength that is proportional to the corresponding voltage output. A multimeter is used to monitor the voltage and amperage (a switch toggles between the two readings, 'AV', fig. 1). The current is directed into eight standard optically isolated solid state relays (model HD6050, Crydom, San Diego, Calif., www.crydom.com). An additional 5VDC power source, such as a replaceable battery placed inside the

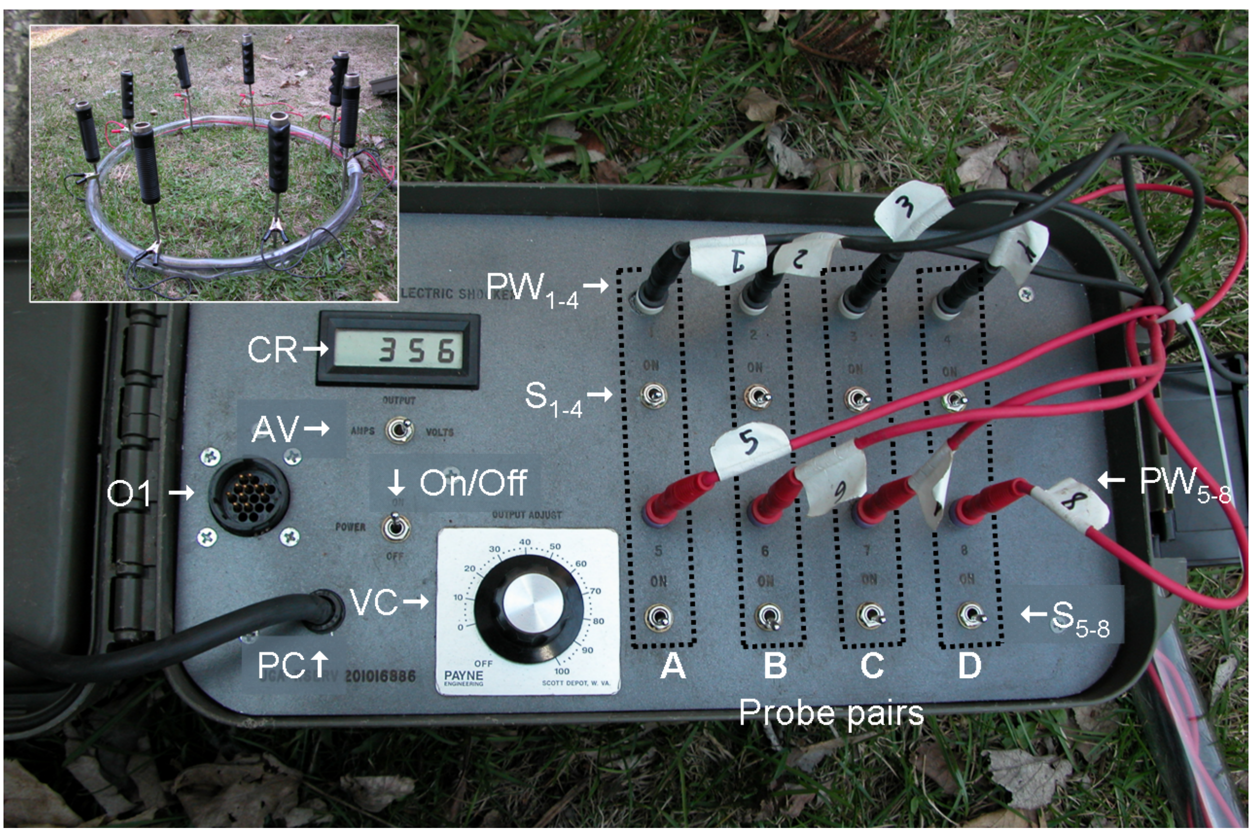

Figure 1. Hand-built electrical extraction device for sampling earthworms without soil disturbance. Showing power cord (PC), voltage control (VC), on/off switch, amps/volts toggle switch (AV), current reading (CR), switches 1-8 (S), probe wires and connections (PW), probe pairs (A-D), and optional digital drive control interface (OI). Inset shows probe field configuration and sampling ring.

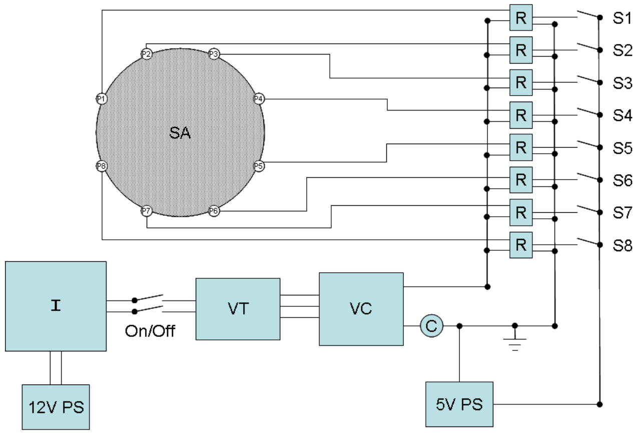

Figure 2. Schematic diagram for a hand built electrical extraction device for sampling earthworms without soil disturbance. I - Inverter, converts 12V DC into 120V AC; VT - Voltage transformer, 120V to 480V AC; VC - Single phase variable voltage controller, Payne Engineering Model 18D; C - Current meter, to measure voltage and amperage; R - optically isolated solid state relays; S1-8 - toggle switches to turn on/off electricity going out to soil probes; SA - Sample area defined by electrical field produced by soil probes; P1-8 - soil probes constructed of 60-cm long, 0.5-cm thick stainless steel rods. PS - Power supply, 12 V DC batteries connect to I, 5V DC power supply connection for R.

unit, is necessary for controlling the relays ('5V PS', fig. 2). The 5V power supply does not contribute to the electricity being transferred to the soil probes. Standard toggle switches operate the on/off function of the relays for connection to the soil probes. High-grade stainless steel rods insulated with plastic-covered handles of 6 mm in diameter and 65 cm length, are connected to the relays by standard electrical wire with insulated alligator clips. A standard sampling area can be demarcated with a large plastic tube of sufficient size which houses the wires (inset, fig. 1). Cuts made in the tube where the wires protrude aid in placement of soil probes. Alternatively, a hard plastic ring, e.g. acrylic, can be used to mark the sampling area (not shown).

The improvement provided for by our design for the electroshocker is the use of optically isolated solid state relays. The relays allow for additional connections, hard-wired into the switching apparatus, that will permit automated switching of the soil probes using a USB-based digital input/output module [digital input/output (DIO); these connections are not depicted in fig. 2]. This USB-based DIO was not available at the time we constructed our device, however, an 11-point pin output for connection to an external data logger was employed (shown as OI in fig. 1). With a laptop computer, the DIO can be programmed to operate with the standard eight step sequence or in the same way that the commercial octet device operates, which offers a constant cycling through each of the four pairs of opposing electrodes.

The electroshocker unit was constructed to fit inside a standard size tool box or fishing tackle box (see fig. 1) and weighed less than 25 lb (~11 kg). The total weight of the electroshocker, the inverter and battery units, as constructed here, was less than 60 lb (~27 kg). The use of smaller inverter units or additional batteries would subtract or add to the final weight. Each of the three units for the apparatus can be loaded into individual packs or all into a single heavy duty backpack for transport into the field. The length of time batteries last depends on soil conditions, i.e. batteries will last longer in dry conditions than in wet. Under optimal conditions two 12-V gel cell batteries may last about 5 h.

Operation

Eight stainless steel rods (soil probes) are placed as deep as soil conditions allow up to a 60-cm depth, or the length of the probe, in an octagonal arrangement so that sequential rods are 20 cm apart and opposing rods are 52 cm apart. The rods do not have to be at the exact same depth for the machine to function. Soil probes are connected to the electrical device in a clockwise sequence around the octagon. Power is supplied to the soil probes at three separate voltage increments at the 25%, 50%, and 100% settings on the potentiometer. Opposing probes are paired (1-5, 2-6, 3-7, and 4-8) and respectively designated A, B, C, and D. The electrical field is rotated within the sampling area following the patterns provided by Thielemann (1986), whereby soil probe pairs are electrified successively in the following eight sequences: AB, ABC, BC, BCD, CD, ACD, AD, ABD, for each of the three incremental voltage settings. The length of time each sequence was electrified ranged from 1 to 2.5 min. The longer time was used when the number of emerging earthworms was high, a shorter time was used when earthworm activity was low or had ceased. We used a minimum of a 0.5-min break in between sequences to allow time for partially surfaced earthworms to move out of the soil and to retrieve earthworms that had already surfaced. Only earthworms surfacing within the center area defined by the probes were collected. Earthworms may surface outside of this area, but should not be counted if population densities are to be calculated. In addition, soil voltage readings ('S' in tables 1 and 2) were taken with a stand-alone voltage meter to confirm electric flow into the ground. The positive and negative connections of the voltage meter were placed near the end points on a center transect between opposing probe pairs, for example, for the ABC setting, the voltage probes would be placed a few inches from either ends of the transect between probes two and six.

Field Validation Sites

The electrical device was tested at two sites, one natural forest and one agricultural site where long-term field experiments comparing conventional tillage to no-tillage were being conducted. Site one: Sampling was conducted in early June along an elevation gradient at the Coweta Hydrologic Laboratory, managed by the USDA Forest Service, Franklin County, North Carolina (CHL; 35°03' N by 83°25' W). Soils where sampling took place in the basin were mainly fine, sandy or gravelly loams, classified as Dystrudepts and Hapludults. Soils are extremely variable and multiple complexes exist, which include complexes of Tuckasegee, Cullasaja, Cleveland, Chestnut, Edneyville, Evard and Cowee series. Site two: Conventional and no-tillage plots with conventional inorganic fertilizer or poultry manure fertilizer were sampled at the Water Quality Research Site, managed by the USDA Agricultural Research Service, Watkinsville, Georgia (WQRS; 33°54' N by 83°24' W). Details on experimental design and management at this site are provided by Endale et al. (2002a, 2002b). Soils at the site are Cecil sandy loams classified as fine, kaolinitic, thermic Typic Kanhapludults. Efficiency of extraction was determined at CHL by counting residual earthworms by handsorting to the depth reached by the soil probes in the same sampling area after using the device. A comparison of earthworm populations in fields treated with different tillage and fertilizer management was determined at WQRS. Due to field management constraints, handsorting was not possible under the no-till management in the agricultural plots. Therefore, sampling efficiencies could not be established at the WQRS site.

RESULTS AND DISCUSSION

FIELD VALIDATION

Sampling at the CHL took place within the Ball Creek Watershed. The high elevation site (Pickens Nose) was on a slope, covered in pine needles, making a thick duff layer and the soil was dry. The soil depth was shallow (<0.25 m). We only obtained one earthworm during the first cycle (table 1). Since the soil was dry, increasing the voltage output did not increase the voltage measured in the soil. No additional earthworm activity was observed and no earthworms were found by hand-digging.

The first mid-elevation site was in a flat area. Soil moisture was moderate at the surface; however, higher soil moisture in the subsurface along with other undeterminable soil characteristics tripped an internal resetable fuse in the voltage transformer and prevented the operation of the machine at the next highest voltage setting. Only three earthworms were obtained by electroshocking and one additional by handsorting (table 1).

The second mid-elevation site was adjacent to a creek. Soil moisture was high, and soil depth was shallow with < 5 cm before hitting broken bedrock. The soil probes were also shallow and not evenly placed in the ground. At this site we were able to collect earthworms for the 25% and 50% voltage settings, which corresponded to 100V and 250V on the device, but only 4V and 10V measured in the soil (table 1). Earthworms collected at this site included specimens of a native species, *Diplocardia communis*. Only one additional earthworm was obtained by handsorting. However, due to the nature of the underlying bedrock, handsorting may not have been completely successful.

The final site examined was at the lowest elevation along the road, also in a flat area, but very near a stream. Soil conditions were conducive to all three voltage cycles. Soil probes and digging reached 10 cm into the mineral soil horizon. A total of 127 earthworms were obtained by electroshocking, the majority small juvenile lumbricids (*Lumbricus* spp., *Aporrectodea* spp.), surfacing at the higher voltage settings; only four additional earthworms (also exotic lumbricids) were obtained by handsorting (table 1).

Previous investigations for earthworms at CHL have yielded limited results on population densities and distributions, and only one report (Callaham et al., 2003) is available. Callaham et al. (2003) reported the occurrence of large numbers of *Amynthas agrestis* and eight other species collected by pitfall trapping; however, pitfall trapping is not a reliable method for establishing earthworm diversity or abundance. We have also documented native *Sparganophilis* spp. in and around streams. Because of the lack of information accurate method comparisons for this site can not be made.

At the WQRS, 12 plots arranged as three replicates in each of four treatments were sampled in spring and fall seasons when earthworm activity was expected to be at a peak, but on dates when soil temperatures and moisture contents varied in order to test the ability of the electroshocker to function under different conditions. We did not initially measure voltage on the machine or the soil when first using the device, but relied on the 25%, 50%, and 100% settings. On the second sample date, differences in soil moisture from plot to plot resulted in unstable voltage readings. We maintained a set gradient when sampling in each plot by using the 25%, 50%, and 100% voltage settings, however, the voltage readings on the device peaked at around 150V in the wetter plots but reached up to 350V in the drier plots. By the third and fourth sample dates, the voltage on the machine varied from 50 to 400V and soil voltage readings were at 20 to 160V. Voltage readings are highly dependent on soil properties, therefore were variable across the various sample dates. On the fourth sample date, voltage readings were the most stable in the soil, however device readings were still variable. We attributed the more stable soil readings to the drier soil conditions.

Substantially higher numbers of earthworms were extracted in October and March, when soil moisture was near optimum for earthworm activity; as can be seen in the data, substantial plot to plot and date to date variation existed (table 2). However, relative trends remained the same when averages within treatments were considered, whereby expected population levels were: no-till with poultry manure > no-till with conventional fertilizer > conventional till with poultry manure > conventional till with conventional fertilizer. The majority of earthworms sampled in the conventional tillage plots were *Microscolex* spp. and in the no-tillage plots were *Lumbricus rubellus* and *Aporrectodea* spp., thus not only were abundances higher, earthworm biomass was also higher under no-tillage.

Table 1. Soil temperature (°C), moisture (%M), voltage readings and number of earthworms collected for each of three cycles at voltage settings of 25%, 50%, and 100%, and extraction efficiency at the Coweeta Hydrologic Laboratory along an elevation gradient.[a]

			Cycle One 25%		Cycle Two 50%		Cycle Three 100%				
Location	°C	%M	V D / S	No.	V D / S	No.	V D / S	No.	Total Extracted No.	Additional Handsorted No.	Extraction Efficiency (%)
High elevation	15.2	10–15 Oct	75-129 / 3	1	--	--	--	--	1	0	100
Mid elevation - Flat	15.7	25-30	125-150 / 5-7	3	--	--	--	--	3	1	75
Mid elevation -Creek	17.4	30-40	100 / 4	9	250 / 10	3	--	--	12	1	92
Low elevation	18.6	20-40	75 / 3	7	125 / 5	80	150 / 6	40	127	4	97

[a] V – Voltage reading, D – device reading, S – soil reading; No. – number of earthworms extracted by the device or handsorted by digging
%M estimated on a volumetric basis; -- Not evaluated at next higher voltage due to inhibitory soil conditions.

Table 2. Environmental conditions, plot treatments, and total number of earthworms collected per sample location on each of four dates in the Water Quality Research Plots in Watkinsville, Ga.

			16 April	18 October	13 March	9 June	
Moisture[a]			14%M	85%FC	70%FC	--	
Temperature °C			20.7	17.9	14.3	--	
Voltage D/S		Cycle 1 25%	--	40-50	50 / 20-25	50-100 / 25	
		Cycle 2 50%	--	100-120	200 / 50-60	100-150 / 50	
		Cycle 3 100%	--	150-350	350-400 / 120-160	150-300 / 100	
Tillage[b]	Fertilization	Plot	No. of Earthworms Collected				Highest Density (ind. m^{-2})
CT	CF	2	5	0	0	2	23
CT	CF	9	2	6	0	0	27
CT	CF	12	0	0	0	0	0
CT	PL	1	4	1	5	2	23
CT	PL	10	5	49	0	1	223
CT	PL	11	1	0	0	0	5
NT	CF	4	0	83	31	2	377
NT	CF	6	2	4	8	0	36
NT	CF	8	7	60	3	1	273
NT	PL	3	8	87	33	4	395
NT	PL	5	2	1	21	1	95
NT	PL	7	20	65	103	11	468

[a] Moisture was measured by gravimetric methods on 16 April, then with a portable soil moisture meter calibrated to 100% field capacity (FC) on following dates.

[b] CT – conventional tillage; NT – no tillage; CF – conventional fertilizer, PL – poultry litter fertilizer.

Earthworm densities at the WQRS were comparable to densities found in nearby no-tillage and conventional tillage systems (Hendrix et al., 1992), as well as in organically and inorganically fertilized systems (Mijangos et al. 2006). Numerous studies have also shown significantly greater earthworm abundance under no-tillage or pasture compared to conventional tillage (Brown et al., 2003; Whalen, 2004; Reeleder et al., 2006; Ferreira da Silva et al., 2006) and/or greater abundance with organic matter or manure additions compared with inorganic fertilizers or no nutrient amendments (Butt et al., 2004; Jordan et al., 2004).

Factors Influencing Operation

Soil conditions, primarily moisture, have a great effect on the operation of the electroshocker. This was expected since Ruston and Luff (1984) established that soil moisture had an effect on extraction efficiency. However, what was unexpected was that the electroshocker would not operate at very high moisture in some locations (not described), because the conductivity of the soil limited the generated electric field. A potential remedy could be to extend the distance between the soil probes, increasing the size of the sampling area over which a voltage potential could be applied.

Soil compaction and heavy root mats may also limit successful use of electrical extraction. Butt et al. (2004) reported that electrical extraction could not be used because of soil compaction on a landfill site. We were unable to use the electroshocker in a pasture site with thick mats of pasture grass overlying highly compacted soil (data not presented). It was our determination that electricity was being conducted through the compacted soil; however, compaction limited the extent to which the probes could be inserted. Also it appeared that the earthworms were unable to move through the thick root layers of the pasture grass, either because of the density of roots preventing the earthworms from finding a pathway or, more likely, that the thick yet airy root layer prohibited the generation of a strong enough electric field necessary to expel the earthworms. As noted by Thielemann (1986) the size and aspect, in relation to the electric field generated, of earthworms in the ground will affect the sampling efficiency. Similarly to the use of solutes, the burrowing or non-burrowing habit of an earthworm, particularly as it may relate to compacted soil, may impact the ability of that earthworm to surface when put under electrical stress.

One aspect of using the electroshocker that needs to be addressed is the issue of the electric field generated in the soil. The field that is established is determined by the configuration of the soil probes as well as the voltage setting. Our design features a voltage/amperage meter that gives an indication of the characteristics of the voltage on the probes as well as the current moving through the machine. The main purpose of these meter readings is to indicate that the machine is operating within expected parameters given the particular parts employed in its construction. The following maybe observed: 1) a zero reading for voltage impling that there is no electric potential between the soil probes, however, current could still be moving from the machine into the soil, and 2) a change in voltage readings when moving the apparatus from one site to another indicating different field strengths as a function of soil properties, moisture contents, and probe-soil contact. Soil voltage readings will be different than readings on the machine, and will change depending on soil conditions, position of the meter's electrodes in relation to the soil probes from the apparatus, and the configuration of the probes (i.e. two pairs vs. three pairs). We operated this electroshocker using the soil probe configurations provided by Thielemann (1986). The field lines for electrical flow are similar; however Thiemann's design provides a return path and therefore limits the extent of the electrical field. In the current design, the field flows beyond the defined sample area, and therefore earthworms may emerge outside of this area but should not be counted.

Safety Emphasis

We recommend that a person knowledgeable in electronics be consulted in the construction of any hand-built electronics device. The parts employed in the construction of our apparatus have a built-in current limitation, which allowed for voltages to be increased, but limited the amperage produced to one amp or less. A self-resetting circuit breaker fuse should also be part of the construction. We make no assurances or guarantee for personal safety by use of these design plans. However, the following precautions should be employed in using this apparatus (this list is not exhaustive of all precautions a person may take): Do not operate this equipment alone; Do not wear loose jewelry or have other metal contacts on hands and feet; Do not sit directly on the ground while operating the apparatus; Do not touch at the same time the main body of the apparatus, any of the leads, or probes, and the ground while the apparatus is in operation, in other words, do not make a complete circuit between the machine or its parts and the ground with any body part; Turn off the voltage to the probes in order to collect emerging earthworms. Additional caution should be taken when transporting the instrument into the field and remote areas. We were able to construct this instrument in a standard size tool box or fishing tackle box, and we placed the inverter and batteries in a separate backpack sized carrier; should straps or handles fail injury may be incurred.

Conclusions

We have shown that an attempt to construct an electrical earthworm sampling apparatus to function with the parameters given by Thielemann (1986) and Schmidt (2001b), resulted in an apparatus that could function under a variety of field conditions to extract earthworms from the soil. The data presented give a limited indication that it can stimulate multiple species including exotics and natives. At the only sampling location with a high density of earthworms we had a high efficiency of extraction. This efficiency may have been induced solely because of the high number of earthworms; however, we did not confirm this result by sampling multiple high density sites. Although the efficiency of this machine is uncertain regarding the limited results presented here, the machine has been used extensively by other researchers who were satisfied with its performance (Bruce Snyder, personal communication). It is clear that our electroshocking methodology, at least when used in an agricultural setting, produced similar quantitative and qualitative results as compared to the higher time-consuming handsorting and formalin extraction methods used in other studies (Hendrix et al., 1992; Brown et al., 2003; Butt et al., 2004; Jordan et al., 2004; Whalen, 2004; Mijangos et al., 2006; Reeleder et al., 2006; Ferreira da Silva et al., 2006). The electroshocker method is more desirable than handsorting because it reduces the amount of labor involved and it is more environmentally friendly than chemical extraction.

In conclusion, the electroshocker is capable of producing the same qualitative and quantitative results as other traditional methods of handsorting or chemical expulsion. However, particularly for agricultural systems, its use may be restricted to times of year when soil conditions such as soil moisture are conducive to sampling. Use of this equipment could require the operator to establish workable parameters for each site. The design of the electroshocker is a modification of a previously published design. With this design, potential users can construct their own portable apparatus which can be valuable for sampling earthworm populations in remote areas. The best benefit of the electroshocker is that it enables sampling in areas where soil disturbance or contamination must be avoided. Similar benefits as well as some other drawbacks of using an electrical shocking device to sample earthworms are discussed by Schmidt (2001b).

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