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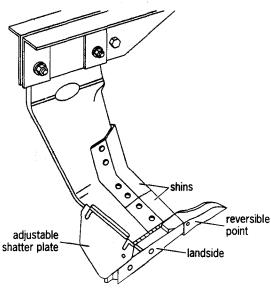**Suzanne W. B. Rapcavage**, Senior Production Supervisor

Agricultural soil and crop practices

Tillage is performed in arable cropping systems for many reasons, including burial of crop residues and weeds for disease and insect control; incorporation of fertilizers and chemicals; creation of aggregates and a condition of macroporosity for improved aeration, water infiltration, and root growth; promotion of soil drying and warming; and reduction of weed competition at planting and lay-by (final cultivation and spraying). Tillage depth can range from shallow operations that barely scrape the surface 1–2 cm (0.4–0.8 in.) of soil to deep operations that disturb or even invert soil to depths of 0.5 m (1.6 ft). Subsoiling (sometimes called ripping or deep chiseling) is deep tillage using implements that produce little or no inversion of the soil profile (see **illus.**).

Purpose of subsoiling. Subsoiling is noninversive tillage aimed solely at mitigating physical and chemical problems occurring deep in the soil. It generally has very little impact on properties of the surface soil layer, commonly called the plow layer (typically 0–20 cm or 0–8 in.). Noninversive tillage (such as subsoiling or chiseling) breaks up soil without moving appreciable amounts vertically from one layer to another (unlike plowing, which inverts the soil, transferring the soil on top to the bottom of the depth plowed, and vice versa). Subsoiling is performed where tillage-amendable soil constraints exist below the depth of primary surface tillage (typically 20–50 cm or 8–20 in.).

Subsoiling reduces rooting-restrictive or drainage-restrictive subsoil layering or compaction. Subsoil layers result from stratified deposition or in-place development of soils through weathering. Subsoil compaction can result from natural consolidation, or it can be caused by traffic and tillage transference of compressive forces to depths below the

Subsoiling implement with winglike broad-angle lifting surfaces for offset loosening of zones to one side of the shaft. (*The Tye Company*)

reach of primary surface tillage. Tillage-induced or traffic-induced compaction commonly results from field operations in the spring or fall when soils are wet. Although most farmers know that traffic and tillage on wet soils increase the risk of compaction, they are often forced by weather or other logistical or economic pressures to proceed within rigid time constraints. Thus, entry is forced onto wet soils, which have a greater potential for compaction.

Efficacy assessment. The effectiveness of subsoiling implements is assessed by measuring the changes in soil properties and the effects on crop performance. Subsoiling decreases profile bulk density (dry weight per unit volume) and soil strength, as measured by cone index or penetration resistance—the force required (megapascals) for penetration of a 13-mm-diameter (0.5-in.) 30° stainless steel cone. Subsoiling increases soil porosity and the rate and capacity of water infiltration, which may or may not result in improved crop performance, depending on the severity of subsoil limitations and the amount of crop stress during the growing season. One of the greatest difficulties in recommending subsoiling operations is the inadequacy of soil diagnostic criteria to predict subsoiling efficacy for a given crop, climate, and management system. Subsoiling is usually an annual requirement, because the environments and cropping systems prone to subsoil compaction tend to promote subsoil reconsolidation.

Subsoiling methods. Subsoiling can be done as a broadcast operation, that is, the entire subsoil is disrupted to a given depth. However, it often is restricted to the soil zone immediately beneath planted crop rows. This practice, known as in-row subsoiling, reduces subsoiling's costly horsepower and energy requirements.

In-row subsoiling. Horsepower/energy requirements and subsoiling effectiveness vary with soil properties and subsoiler design. The baseline power requirement increases with the depth, number, contact surface area, and perpendicularity to the direction of travel of the shanks, and with the bulk density, clay content, and dryness of the soil. For subsoilers penetrating 0.30–0.45 m (0.98–1.5 ft) into the soil, a range of approximately 2.2–3.0 W (30–40 horsepower) is typically required per subsoil shank.

In-row subsoiling is also used for deep injection of soil amendments or fertilizers. Slurried lime, for example, has been injected to improve the pH of acid subsoils. Nitrogen or phosphorous fertilizers injected into zones directly below the planted row can improve early nutrient interception by the rapidly expanding seedling root systems. Deep-injected organic sludges provide placement of broad-spectrum low-analysis (dilute) fertilizer that also helps preserve the improved tilth in the subsoil zone that has been shattered by the subsoiling operation.

Subsoiling can be an independent tillage operation, or it can be combined with other practices to

Table 1. Effect of zone subsoiling on furrow-irrigated Russet Burbank potato tuber yield and grade in Kimberly, Idaho

	Yield, metric ton/ha (ton/acre)		Grade no. 1, %		Grade no. 1 > 284g* (10 oz), %		Grade no. 1, 114–284 g† (4–10 oz),%	
	1989	1990	1989	1990	1989	1990	1989	1990
Zone-subsoiled	39.4 (17.5)	41.9 (18.7)	62.6	64.2	29.1	14.9	33.5	49.3
Nonsubsoiled	36.3 (16.2)	37.7 (16.8)	57.2	56.5	27.0	12.9	30.2	43.6
Probability, %	NS‡	0.08	3.58	5.94	NS	NS	2.29	6.03

* USDA standard market quality grade no. 1.
† Weight limits used by most packers and processors as cutoffs for premium pay categories when buying a farmer's potato crop.
‡ NS = not significant.
SOURCE: R. E. Sojka et al., Zone-subsoiling effects on infiltration, runoff, erosion, and yields of furrow-irrigated potatoes, *Soil Tillage Res.*, 25:351–368, 1993.

reduce the number (and hence cost) of equipment passes over the field. Since timing and spatial placement of subsoiling greatly affect its efficacy, it is often combined with row-crop planting. Although this practice requires specially modified planting equipment, it prevents disrupted subsoil from being recompacted by intervening preplant field operations (such as fertilizer spreading, chemical application, and secondary surface tillage). It also guarantees precision placement of the shattered zone directly below the planted row and maximizes subsoil disruption during seed germination and vigorous early root exploration of the soil profile.

Zone subsoiling. A technique known as zone subsoiling is a sophisticated variation on the theme of in-row subsoiling. This term was coined to describe the pattern of noninversive in-row profile disruption accomplished with a unique subsoiler that has a winglike configuration. Unlike the straight or curved shanks of more standard subsoilers, this subsoiler resembles a subterranean wing or lifting surface (see illus.). Its lower half is curved laterally from the line of travel, allowing the subsoiler to reach under planted rows from the side. This unique feature allows delay of the subsoiling operation until several days, or even 1–2 weeks, after planting of certain slowly germinating crops, thus extending the period of maximum soil disruption and allowing greater flexibility in accessing optimal soil conditions for subsoiling. Both in-row subsoiling and zone subsoiling permit subsoil disruption where it is needed, under the crop row, while leaving interrow spaces undisturbed to provide support and traction for tractors and other field equipment whose tires run between the rows.

Slit tillage. Where the subsoil restrictive layer is relatively shallow, and where it overlies more friable subsoil, the horsepower and energy requirements of standard subsoiling operations are sometimes avoided by using a unique concept known as slit tillage. This type of subsoiling does not disrupt a large volume of the soil profile; instead it creates a very narrow slit, penetrating to below the depth of a restrictive layer. Roots follow the narrow slit through the restrictive layer and then branch out extensively when they reach the more favorable environment below. The slits can be stabilized in a few years by the decomposing roots

of preceding crops. If combined with traffic-pattern control, slit tillage gradually improves crop performance, eventually matching the results of more disruptive subsoiling, without the larger power or energy requirements.

Advantages and disadvantages. Subsoiling of restrictive soils increases the extent of root exploration and improves water infiltration to the lower soil profile. These combined effects reduce plant water and nutrient stresses. More vigorous crop growth results, which generally increases yield and improves market quality at harvest (**Table 1**). Where subsoil restrictions to rooting and infiltration are particularly severe, the effects on yield can be directly related to the mean soil strength of the potential rooting volume.

Because subsoiling greatly increases infiltration, it can substantially reduce runoff from both rainfed and irrigated cropping systems. The result is an increase in the efficiency of water intake and a reduction in runoff and in the potential for soil erosion (**Table 2**).

Special precautions must be taken when subsoiling is performed on sloping ground in high-rainfall environments. Water can channel downslope through the subsoiler's openings. Thus, the surface soil behind the subsoil shank must be firmed sufficiently to prevent soil from washing away and seeds from washing away or subsiding deep into the soil when driving rain occurs before complete crop establishment.

Table 2. Effect of zone subsoiling on cumulative seasonal infiltration and soil loss for furrow-irrigated Russet Burbank potatoes grown in Kimberly, Idaho

	Infiltration, mm (in.)		Soil loss, kg/ha (lb/acre)	
	1989	1990	1989	1990
Zone-subsoiled	306 (11.9)	321 (12.6)	871 (976)	2604 (2918)
Nonsubsoiled	281 (11.1)	254 (10.0)	1154 (1293)	8450 (9469)
Probability, %	NS*	0.01	NS	0.10

* NS = not significant.
SOURCE: R. E. Sojka et al., Zone-subsoiling effects on infiltration, runoff, erosion, and yields of furrow-irrigated potatoes, *Soil Tillage Res.*, 25:351–368, 1993.

Subsoiling of soils with poor internal drainage (natural or artificial) in wet climates can increase infiltration enough to waterlog the soil profile, and thus can ultimately be more damaging to some crops than failure to disrupt root-restrictive layers. Damage may result either from direct effects of waterlogging on crop growth (restricted root aeration and increased disease susceptibility) or from indirect effects such as denitrification or leaching loss of applied fertilizers and chemicals or delayed warming of the wet soil.

Special considerations. Care must be exercised when selecting and configuring subsoiling equipment. The subsoiler must be compatible with other existing system components. In conservation tillage or no-till systems, the subsoiler must be designed to perform well in elevated amounts of plant residues, providing subsoil disruption with minimal surface disturbance. The subsoiler power requirements must be compatible with available equipment. If the cropping system includes rotation to crops at different row spacings, the subsoiler must be adjustable. If the land to be subsoiled contains buried tree stumps or rocks, the subsoiler will require sheer pins or tripping devices that allow subsoil shanks to ride over obstacles in order to avoid damage to planters, tool bars, tractor hitches, drive systems, and so forth. Subsoiler spacing must be close enough to disrupt soil sufficiently for the desired crop or soil response but far enough apart for soil to flow easily between the shanks. Finally, subsoiling should be restricted to the minimum depth needed to allow rooting and infiltration into unrestrictive subsoil. Excessively deep subsoiling needlessly increases tractor power (size) and fuel requirements, increasing operational costs, causing wheel-track surface compaction, and ultimately degrading surface soil aggregates and structure.

For background information SEE AGRICULTURAL SOIL AND CROP PRACTICES; SOIL in the McGraw-Hill Encyclopedia of Science & Technology.

Robert E. Sojka

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Aircraft noise

Several technologies, chiefly in the design of aircraft engines, have advanced so as to reduce aircraft noise to new levels of quiet, both in the environment surrounding the aircraft and within the passenger cabin. By permitting aircraft operations from noise-sensitive airports, quieter airliners can give travelers and cargo shippers freedom in departure times while relieving the surrounding community of noise.

Noise levels. An example is the McDonnell Douglas MD-90 midrange twin-engine airliner, which went into service in early 1995. The noise it produces is 22 dB below the Federal Aviation Administration's current noise requirements. The number refers to the cumulative total of the differences in sound level below a requirement for three measurements: approach, flyover, and sideline noise. The requirements themselves vary depending on the weight of the aircraft.

Testing to ascertain an aircraft's noise is done by flying carefully controlled flight paths over a calibrated array of microphones on the ground. These flights are conducted under stringent limitations on weather and background noise.

Engine design. Key to the low sound characteristics of a modern airliner such as the MD-90 are the engines and their installation. One factor in noise production is the length of the inlet, which is 38 cm (15 in.) longer on the MD-90 than needed, producing some weight and skin-friction drag penalties. The length increment cuts the forward projected noise by about 1–2 dB and provides straighter airflow into the engine. The inlet duct is treated to reduce sound emissions; its surface is perforated by small holes that lead to subsurface chambers. These cells absorb sound energy, functioning on the Helmholtz principle like some home audio enclosures that resonate at select frequencies, depending on hole and cavity geometry.

Acoustic treatment. Noise reduction features on the V2500-D5 turbofan engine for the MD-90 include the novel use of acoustic lining on surfaces surrounding the hot engine-core gas stream as well as the inlet. This lining is used on the surfaces of the central closing cone at the aft end of the engine core and the surrounding nozzle facing the cone. Low levels of particulates in the exhaust stream, resulting from more efficient combustion, allow the lining to remain clean and effective, thus reducing rearward noise on the order of 1–2 dB.

Nacelle. The engine nacelle also forms a continuous fan-airflow duct surrounding the core for its entire length and ending in a circular confluent nozzle. The nozzle muffles the high-speed core airflow by allowing it to mix with the slower, surrounding fan air for a lower overall velocity at the exit. The turbulence associated with this velocity relative to the outside air causes so-called jet noise. Earlier noise-reducing nozzle designs were less efficient, blocking the exhaust with assemblies that resembled cookie cutters, cambered surfaces that forced the flows to mix.

Turbomachinery. In designing the rotating turbomachinery for an inherently quiet engine, key parameters include the bypass ratio of fan-to-core airflow. The bypass ratio is determined mainly by