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# Tillage Practices in Potato (*Solanum tuberosum* L.) Production: A Review

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**Koffi Djaman [1*], Komlan Koudahe [2], Houteta D. Koubodana [3], Aminou Saibou [4], Samuel Essah [5]**

[1] New Mexico State University, Department of Plant and Environmental Sciences, Agricultural Science Center at Farmington, P.O. Box 1018, Farmington, NM 87499, USA; kdjaman@nmsu.edu

[2] Kansas State University, Biological and Agricultural Engineering Department, 1016 Seaton Hall, 920 N. 17th St., Manhattan, KS 66506, USA; koudahek@ksu.edu (K.K.)

[3] Institut Togolais de Recherche Agronomique, ITRA Route Nationale N°1, Km 10 Agoè Cacavéli BP 1163 Lomé, Togo; koubodana.d@edu.wascal.org

[4] Washington State University, Department of Crop and Soil Sciences, P.O. Box 646420, Pullman, WA 99164, USA; aminou.saibou@wsu.edu

[5] Colorado State University, Department of Horticulture and Landscape Architecture, San Luis Valley Research Center, 0249 E Rd. 9 N, Center, CO 81125, USA; Samuel.Essah@colostate.edu

* Correspondence: kdjaman@nmsu.edu; Tel.: +1 505 960 7757

**Abstract:** Potato is one of the main crops grown worldwide under different climatic conditions. Potato is conventionally produced under intensive tillage practices under the same or different soil types. Research has shown some contrasting effects of the tillage practices on the soil properties, crop growth, yield, and quality. Under the reducing available freshwater for food production, soil management practices are more targeting conservation and system sustainability. It is therefore critical to revisit literature on the tillage practices and their impact on the soil, crop, and crop yield. This review presents research results of studies conducted exclusively on potatoes comparing different types of tillage practices and is a valuable source of information for potato growers and scientists as it is not only focused on the impact of tillage practices on soil properties but also on potato tuber yield and grade, tuber specific gravity, and the impact of tillage practices on diseases in potatoes.

**Keywords**: potato; tillage types; soil properties; diseases; tuber yield; quality.

## Introduction

Potato (*Solanum tuberosum* L.) is worldwide grown and is very sensitive to soil and water conditions as it grows and produces better on deep and well-drained soils (Pierce and Gaye Burpee, 1995; Djaman et al., 2021). Potato is the fourth-largest crop produced worldwide after rice, wheat, and maize (FAOSTAT, 2021). Tillage at different planting and growth stages of potatoes is a requirement and necessary for preparing a seedbed and for weed control. Potato production is associated with different practices such as planting, diking, cultivation, hilling, and harvest that significantly disturb the soil environment with heavy machinery. Soil and water management in potatoes are therefore critical to assure optimal crop growth and development. Tillage practices are adopted to create the proper environment for potato growth and yield potential. Commercial potato production under traditional management practices involves heavy to very heavy machinery and equipment during seedbed preparation and dung the growing season for different operations such as cultivation, herbicide and pesticides application and harvest, exposing the soil to compaction. Compaction before and during planting can restrict root growth (Boone et al., 1978; Van Loon and Bouma, 1978; Bengough and Young, 1993; Van Oijen et al., 1995; Stalham et al., 2007, Ragassi et al., 2012; Djaman et al., 2021; Huntenburg et al., 2021). Stalham et al. (2007) reported that soil compaction delayed emergence, reduced rooting density and deep rooting, reduced rate of leaf appearance and ground cover expansion, shortened canopy cover duration, and restricted light interception, which consequently reduced tuber yield, particularly where compaction was shallow. Like other studies, Huntenburg et al. (2021) also found that potato shoot growth was restricted by adverse compacted soil conditions. Stalham et al. (2007) pointed that soil compaction in combination with drought can decrease plant water availability and limit biomass production and potato tuber dry weight (Kawakami et al., 2006; Huntenburg et al., 2021). Research studies have been investigating the impact of different tillage practices on potato growth, weed management and yield, and the overall trend is the adoption of reducing tillage up to no-till in potatoes for system sustainability (Grant and Epstein 1973; Ekeburg and Riley 1996; Wallace and Bellinder 1989; Lanfranconi et al. 1993; Pierce and Burpee, 1995; Sijtsma et al. 1998; Holmstrom et al., 1999; Carter and Sanderson, 2001, Carter et al., 2005, 2009; Carrera et al. 2005). Larney et al. (2016) reported that integration of conservation management practices led to yield and disease control benefits without negatively impacting tuber quality. Potato production is known as a major contributor to soil erosion and soil water quality degradation caused by high soil disturbance (Yang et al., 2009; Rees et al., 2011). Conservation tillage in potato rotations aims at reducing energy use; preventing soil structure degradation, improving soil biological properties, and reducing and or protecting the soil against erosion (Carter and Sanderson, 2001; Riley, 2006). However, contrasting results come from different tillage practices in potato crop and this review present an overview of the knowledge on this important topic which is adversely appreciated as commercial potato growers have their mindset and the small potato growers and different perception of the effect of tillage practices in potato production. For the present review, only the effects of tillage practices on soil properties, weed infestation, and potatoes characteristics were reported. The main characteristics in our review focus on tuber yield and grade, soilborne disease pressure on the potato plant and tubers, and specific gravity and dry matter content.

**Different types of tillage practices in Potato**

Tillage is defined as mechanical management of soil to provide a favorable environment for good germination of seeds and crop growth, weed control, and improved soil hydraulic properties. Plowing is a

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reliable soil management traditional practice that produces a straw-free surface and loosened soil in which a seedbed can be created and a new crop established. Ploughless tillage is usually called reduced tillage which reduces tillage compared with plowed systems. Ultra-shallow tillage is a tillage practice that fully cuts through the whole working horizon at only 2-3cm working depth. Ray Massey et al. (2018) defined the conventional till as <15% residue cover, reduced till with 15%-30% residue cover after planting, conservation tillage with >30% residue cover after planting, mulch till with full-width tillage involving one or more trips, no-till with soil left undisturbed from harvest to planting except for strips up to 1/3 of the row widths. Tillage practices in potato production target weed control, facilitate planting and increase the ease of later cultivation and harvest (Prestt and Carr, 1984). The conventional tillage is defined as a traditional tillage system, where a preliminary deep primary operation is followed by some secondary tillage for seedbed preparation (Soil Conservation Society of America, 2008). Conventional soil tillage for potato crops normally involves disc plowing, disc leveling, and sometimes, rotary hoe at various intensity levels according to soil type (Fontes, 1997). Conservation tillage is defined as any practice of soil cultivation that reduces runoff and increases infiltration by leaving the previous crop residues on the field (Derpsch, 2003), increasing the soil organic matter near the soil surface, improving the soil structure and biological properties in the potato crop (Carter et al., 2009). Conservation tillage is considered to be a generic term encompassing any tillage practice that reduces the loss of soil and water as compared to unridged or clean tillage. This includes (i) minimum tillage; considered to be the minimum amount of tillage required for seedbed preparation and plant establishment and (ii) no-tillage/zero tillage/direct drilling, which involve no seedbed preparation other than chemical preparation and soil-opening for seed placement (Baeumer and Bakerman 1973, Peters et al., 2004). Holland (2004) and van den Putte et al. (2010) defined the conservation tillage as a broad term that refers to a wide range of non-inversion tillage practices with the potential of reducing soil degradation and soil quality preservation. Basin tillage also called reservoir tillage, micro-basin tillage, furrow diking and furrow damming is a practice that increases the surface depression storage of a field, thereby conserving rainfall, reducing runoff and increasing water availability to crops. It may not, however, be suitable for areas with a high probability for large runoff events potentially causing ridge overtopping and accelerated erosion (Jones and Stewart, 1990; Jones and Stewart, 1990; Gordon et al., 2011). Zone tillage involves no autumn tillage and in the spring, only disturbs the land in the narrow zones where the crop is to be planted and does not involve autumn or spring tillage (Allmaras et al., 1985).

**Impact of tillage practices on soil properties**

Tillage practices involve machinery traffic which intensity varies with the type of management practice. The conventional tillage reduces the diameter of the soil aggregates by mechanical effect, produces a low quantity of organic residue (Carter & Sanderson, 2001), and promotes a rapid soil organic matter oxidation and CO2 flow to the atmosphere (Balota et al., 2004). Carter et al. (2009) compared the conservation to the conventional tillage and reported that the conservation tillage increased soil organic carbon, large water-stable macro-aggregates, and soil particulate carbon and nitrogen during the potato production year compared to other rotation crop years. Crop residue is concentrated near soil surface under conservation tillage and therefore increased soil organic matter content, improved soil hydraulic properties, protection of the soil from erosion (Carter et al., 1998; Holmstrom et al. 1999). Conservation tillage was reported to reduce up to 26% of the sediment yield and 11% of the surface runoff compared with intensive tillage (Uribe et al., 2018). Conservation tillage practices increase soil organic matter of the topsoil and can improve soil structure and soil biological properties during the potato growing season within the rotation cropping systems (Carter and Sanderson, 2001; Mallory and Porter, 2007; Riley et al., 2008). Quintero and Comerford (2013) investigated the effect of conservation tillage in the potato crop system in the Fuquene watershed and found that reduced tillage in potato-based crop rotations increased the soil carbon concentration and average C content in the whole profile by 50 and 33% respectively, as compared to conventional tillage practices. Ridge tillage improves soil nutrient management with 68% fewer nutrient losses under ridge tillage compared to conventional tillage (Romkens et al., 1973; Felsot et al. 1990). Deep soil tillage such as plowing and ridging promote plant growth and macronutrient (N, P, K, Ca, and Mg) uptake by potato plant and translocation in potato tubers (Boligowa and Glen 2003; Nunes et al. 2006). Erosion losses were greater from the chisel-plant treatment with a large-hill-no-cultivation during low rate rainstorms while runoff and soil losses were not affected by chiseling (Grant and Epstein, 1973). Carter et al. (2005) compared four tillage practices such as conventional autumn mouldboard plowing followed by spring secondary tillage, spring mouldboard plowing followed by secondary tillage, autumn chisel plowing followed by spring secondary tillage, and spring conservation tillage and found the tillage practices significantly affected soil water content across the upper 30 cm soil layer with conservation tillage generally showing the greatest soil water content before spring. Moreover, conservation tillage increased soil compaction at the 10-30-cm soil depth, but not to a level considered detrimental to root growth (Carter et al., 2005). Carter et al. (2005) concluded that the conservation tillage could be a viable management alternative to conventional tillage because this practice does not negatively affect field management or soil quality. While potato growers usually opt for deep plowing before seedbed preparation and ridging to ensure an adequate volume of loose-structured soil which is required for optimal tuber formation and quality, this intense soil preparation may be detrimental to soil structure, soil quality, and promote soil erosion (Drakopoulos et al. 2016). Several studies have demonstrated that reduced tillage is proven to be the alternative to the conventional tillage practices in potatoes (Carter and Sanderson 2001; Holmstrom et al. 2006; Carter et al., 2009ab; Drakopoulos et al., 2016). Gordon et al. (2011) compared the impact of conventional tillage, row shaper tillage, and basin tillage on runoff and nutrient loads from potato fields in

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Prince Edward Island and found that basin tillage had 78 and 75% less runoff than the conventional tillage and row shaper tillage, respectively. Similar findings were reported by Sojka et al. (1992).

Potato (*Solanum tuberosum* L.) is an intensively managed crop with yields often limited by subsoil compaction and tillage pans and the mechanical loosening of compacted soil via subsoiling is often believed to be a useful method to enhance root elongation and improve a crop's ability to access deeper soil water (Ghosh and Daigh, 2020). This is particularly important for potato because it is relatively more sensitive to water stress than many other crops. Holmstrom and Carter (2000) reported that fall subsoiling in potatoes provided a marginal improvement in soil physical conditions. Pierce and Burpee (1995) evaluated the effects of zone tillage, a system of in-the-row subsoiling, with cover crops and no-tillage in the inter-row, on soil properties and yield and quality of Russet Burbank potatoes in west-central Michigan on a McBride sandy loam and found that the zone tillage, subsoiling in the row with a Bush Hog Ro-till or Tye Paratill, decreased bulk density and soil strength, and increased the volume of large pores in the zone of compaction. Griffin et al. (2009) reported that delaying primary tillage until spring, immediately before planting potato, compared to the fall tillage, resulted in higher soil water content early in the growing season in some rotation cycles, and also provided nearly complete ground cover during potentially erosive periods in fall and early spring. Quintero and Comerford (2013) found that reduced tillage in potato-based crop rotations increased the soil C concentration and average C content in the whole soil profile by 50 and 33%, respectively, as compared to conventional farming practices while carbon content increased by 177% in the subsoil A2 horizon and most of the soil carbon was in the A1 horizon. The reduced tillage enhances soil carbon in Andisols which are already high in organic matter and the carbon in soil aggregates represented more than 80% of the total organic matter and it was positively affected by conservation practices (Quintero and Comerford, 2013).

Drakopoulos et al. (2018) investigated the effect of reduced tillage and standard tillage practices on soil quality indicators in organic potato (*Solanum tuberosum* L.) production system and found that soil temperature and soil moisture content were not found to be greatly affected by tillage practices; soil mineral N (NO3 and NH4+) concentrations showed similar decreasing patterns over time across both tillage systems during the potato production period, however, soil mineral N was overall higher in the upper 15 cm soil layer under reduced tillage and in the 15–30 cm soil layer under standard tillage. Moreover, soil bulk density was higher for reduced tillage than the standard tillage during the first, fourth, and seventh weeks after planting.

**Impact of tillage practices on weed management in potato**

Tillage practices and cultivation timing impact weed infestation and management in potato fields. Wallace and Bellinder (1989) compared conventional tillage to rye-stubble reduced-tillage systems for potatoes and found that redroot pigweed (*Amaranthus retroflexus*) populations were significantly greater in the reduced tillage than in conventional tillage plots while the populations of common lambsquarters (*Chenopodium album*) were equivalent, regardless of the tillage system. Liebman et al. (1996) investigated weed interference of potato fields under moldboard plowed and chisel plowed and found that seed density, plant density, and biomass of dominant weed species (*Chenopodium album* L. and *Brassica* and *Raphanus* spp.) that survived cultivation and hilling, were lower in moldboard plowed than in chisel plowed plots impacting average loss of U.S. No. 1 tubers by 12% with moldboard plowed, compared with 43% with chisel plowed relative to a weed-free plot. Several studies have shown that chisel plowing generally leaves seed bank produced during the previous growing seasons and left with the soil upper layer close to the surface than the moldboard plowing (Ball and Miller, 1990; Staricka et al., 1990; Yenish et al., 1992; Mohler, 1993; Liebman et al., 1993). Rasmussen (1999) indicated that weed numbers generally increase as the depth of tillage is decreased. Buhler (1992) reported that chisel plowing led to greater seedling densities of small-seeded weed species like *Chenopodium album* and redroot pigweed than the moldboard plowing. Carter et al. (2005) evaluated the impact of conventional autumn mouldboard plowing followed by spring secondary tillage, spring mouldboard plowing followed by secondary tillage, autumn chisel plowing followed by spring secondary tillage, and spring CT and found that conventional autumn mouldboard plowing followed by spring secondary tillage, spring mouldboard plowing followed by secondary tillage produced similar results and had no effect on the number of individual weed species, perennials, annuals, or total weeds. In 1997, autumn chisel plowing followed by spring secondary tillage resulted in reductions of barnyard grass (*Echinochloa crus-Galli*) at one site while in another site it resulted in lower amounts of hemp nettle *(Galeopsis tetrahit)*. Moreover, autumn chisel resulted in increased amounts of mouse-eared chickweed (*Cerastium vulgatum*) and perennial weeds in comparison to moldboard plowing during one season while it increased numbers of clover in comparison to autumn mouldboard and bindweed (*Convolvulus arvensis*) in comparison to all mouldboard practices and the barnyard grass and hemp nettle were reduced by autumn chisel plowing (Carter et al., 2005). Autumn plowing has the advantage of reducing weed infestations of the succeeding potato production season (Ekeberg and Riley 1996; Riley and Ekeberg 1998). Chitsaz and Nelson (1983) reported that cultivation helped control weeds but had no other apparent beneficial or adverse effect on potatoes. Nelson and Giles (2017) found that multiple cultivations provided better weed control in potatoes than the herbicide pendimethalin alone but not as good as pendimethalin and cultivation combined. Boydston and Vaughn (2017) compared fall-planted winter rye followed by metribuzin at 0.4 kg/ha applied in a band in the potato hill, followed by reservoir tillage, cultivation with tine-tooth harrow followed by hilling with shovels and rolling cultivators (total-cultivation weed management system, fall-planted rapeseed followed by reservoir tillage, and reservoir tillage alone, to the sole herbicide treatment and found that rye cover crop with herbicide-banded and reservoir-tilled weed management system performed the best and reduced early-season in-row weed density from 60 to

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70% and final weed biomass from 29 to 40% compared with a non-treated check. In the light of the aforementioned information, field cultivation early after crop emergence and or just before tuber initiation could be adopted for production sustainability and reduce environmental pollution while reducing the production cost compare to the classic herbicide program.

**Impact of tillage practices on potato tuber yield and quality**

The objective of the potato production system is optimizing marketable tuber yield which depends on several factors such as soil conditions, weed management, disease management, water and nutrient management, and other factors. Grant and Epstein (1973) evaluated chisel-plant, direct-plant, plow-plant, chisel-plant with large-hill-no-cultivation, control, and control with large-hill-no-cultivation and found that the six tillage practices did not appreciably affect yield while there were some differences in potato seed emergence. Alva et al. (2002) reported non-significant potato tuber yield differences under a conventional including raised ridges with dammer-dike; optimal as the lower depth of the tillage and shallow furrow, and reduced tillage consisting of flat planting during the first two years but the tuber yield was the lowest in flat planting management during the third year of management. Alva et al. (2010) found similar tuber yield, tuber size distribution between reduced and conventional tillage practices. Hou and Li (2018) investigated the impact of conventional tillage, subsoiling, and no-tillage in combination with transparent polythene film mulch, and maize [*Zea mays* L.] straw mulch, no mulch on soil moisture conservation in the fallow period, variations of soil moisture profile, topsoil temperature, growth in the seedling period, the potato (*Solanum tuberosum* L.) tuber yield and found that the highest mean potato tuber yields and marketable tuber yield were obtained under the case of subsoiling in combination with straw mulch and no-tillage in combination with straw mulch, which was significantly higher by 41.0%, 35.3%, and 13.7%, 6.5% than that of conventional tillage in combination with no mulch. The conservation tillage (no-tillage and subsoiling) combined with straw mulch has a great potential to be adopted in the semiarid Loess Plateau region. Grant and Epstein (1973) found that six soil preparation treatments namely chisel-plant, direct-plant, plow-plant, chisel-plant with large-hill-no-cultivation, control, and control with large-hill-no-cultivation did not appreciably affect yield regardless of some differences in emergence, soil firmness, soil water, and soil temperature. Sommerfeldt and Knutson (1968) reported that plant growth, nutrient uptake, and potato yields were affected by the different tillage regimes. Reduced tillage showed a yield decrease of 22% compared to the conventional tillage one year over two (Wallace and Bellinder, 1989). Potato tuber quality in terms of crude protein, fat, crude fiber, and carbohydrate was better under zero tillage planting with paddy straw mulching compared to ridge planting (Sangari et al., 2021). Essah and Honeycutt (2004) evaluated russet Burbank potato under fall raised bed, fall ridge-till, and spring chisel plow and found that potato total and marketable yield was higher under raised bed tillage. Similar findings were previously reported by Borrell

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et al. (1998) who found higher potato yield under raised beds compared to ridged soils. Drakopoulos et al. (2016) compared reduced tillage to standard tillage and found a decrease in tuber yield by 13.4 % under reduced tillage compared to standard tillage due to lower average tuber size which was related to higher soil bulk density and increased vulnerability to drought stress during tuber bulking. Gordon et al. (2011) reported no significant effect on marketable potato yield at different sites however, basin tillage was effective at reducing runoff and nutrient losses without affecting yield and appears to be an effective tool for decreasing environmental risks. Liu et al. (2019) indicated that spring moldboard plowing had negative effects on yield compared with fall moldboard plowing. Sojka et al. (1993) examined the ability of zone-subsoiling to reduce soil compaction and erosion and found that zone-subsoiling improved tuber grade or increased tuber size and consequently Russet potato tuber yield and quality in Pacific Northwest. Similar findings were reported by Pierce and Chase (1987) and Sojka et al. (1992). Hou and Li (2015) stated that the improved soil microenvironment could facilitate tuber formation to enhance the yield. Copas et al. (2009) investigated potato response to subsoil tillage and compacted soil and cone index profiles showed the potential for limited root growth below the compacted soil layer compared to subsoil tillage; premium potato tuber yield was not influenced by subsoil tillage however, subsoil tillage tended to decrease the proportion of tubers within the weight range from 113 to 170 g. For Ghosh and Daigh (2020), potato tuber yield and quality benefits from subsoiling are rare, temporary, and highly inconsistent. Larney et al. (2016) in a 12-year study compared conservation and conventional management for potato in 3- to 6-year rotations which also included dry bean, sugar beet, and soft wheat, oat, and timothy, and showed that the conservation management resulted in 18 % higher marketable tuber yield and reduced early dying than conventional management under a short term rotation. In contrast, Holmstrom and Carter (2000) found that Soil loosening by sub-soiling did not increase potato yield or quality. Pierce and Burpee (1995) reported that zone tillage in the spring generally increased marketable yields but not total yields, compared with conventional plowing the first potato growing season but zone tillage generally increased total and marketable yields of Russet Burbank potatoes in most years. Sojka et al. (1993) conducted studies in Southern Idaho at six locations on different soils and with different irrigation methods to assess the effects of zone-subsoiling immediately after planting on tuber yield and grade and found that zone-subsoiling consistently improved tuber grade or increased tuber size and increase total yield while reservoir-tillage improved yield and grade. A non-consistent 12% potato tuber yield reduction was observed when tillage was delayed until spring compared to fall tillage and which shows a relatively insensitive to differences in the timing of tillage operations before planting (Carter and Sanderson 2001; Carter et al. 2005; Griffin et al., 2009; Liebman et al. 1996). McDole (1975) observed that a plow pan restricted potato root growth to the plow layer in silt loam and coarser textured soils. Sojka et al., (1993) indicated that zone subsoiling of furrow-irrigated potato hills improved tuber yield and grade when the operation is practiced before plant emergence. From a literature review, Ghosh and Daigh (2020) concluded that potato yield and quality benefits from subsoiling are rare, temporary, and highly inconsistent and pointed that the only exception is when moisture is known to be the major limiting factor in a field. Henriksen et al. (2007) found that subsoiling increased potato marketable yield by a 48.5% increase in the dry year. Carter et al. (2005) evaluated the impact of conventional autumn mouldboard plowing followed by spring secondary tillage, spring mouldboard plowing followed by secondary tillage, autumn chisel plowing followed by spring secondary tillage, and spring CT and found that tillage practices did not affect potato yield and quality. Eddis et al. (2020) found a significant positive correlation between high compaction and the high proportion of small size potato tubers in Saudi Arabia, and a significant negative correlation between high compaction and the high proportion of large size tubers. Ochuodho et al. (2013) analyzed long-term land use data collected from the Black Brook Watershed in northern New Brunswick (Canada) and found that spring tillage increased potato yield while Frederick (2012) found that beneficial tillage practices, crop rotation practices, and their interaction did not significantly affect potato yield in a Nova Scotia watershed. In New Brunswick, Canada on clay loam to sandy loam in texture soils, spring moldboard plowing had negative effects on yield compared with fall mouldboard plowing (Liu et al., 2019). Yaroson et al. (2019) investigated potato response to ridges tillage, zero-tillage, mound tillage, and flat tillage in Nigeria and found that soil management practices had a significant effect on plant height, the number of leaves, leave the area, canopy cover, and tuber yield. Ridges tillage showed the highest yield followed by mound tillage, flat tillage, and zero tillage with the lowest tuber yield (Yaroson et al., 2019).

**Impact of tillage practices on potato diseases**

Potato diseases development is mostly conditioned by some environmental conditions such as high humidity, and abiotic stress. However, tillage management practices impact soil microbiome and disease intensity and spread in potatoes. Mechanical tillage, ridging, and harvesting entail intensive soil disturbance and modify the soil microbiome and its quantitative and qualitative characteristics (Vian 2009). Taylor (2005) found that plowing contributes to redistributing vertically the inoculum, which increases the probability of infection of potato plants and tubers. Leach et al. (1993) compared potato characteristics under moldboard plowing (22 cm) and chisel plowing (30 cm) and reported that chisel plowing significantly reduced the incidence and severity of stem lesions on potatoes caused by *Rhizoctonia solani* AG-3. The retention of crop residues in the surface soil layer (0 to 10 cm) under chisel plowing, promotes soil microbial activity with competition among microbial communities in the root zone resulting in a suppression of pathogen activity (Gudmestad et al. 1978; Leach et al. 1993). Peters et al. (2004) reported that the severity of common scab (*Streptomyces scabiei*) was low and not influenced by tillage practices while minimum tillage reduced potato diseases caused by *R. solani* and did not affect disease caused by other soil-borne

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pathogens. Griffin et al. (2009) reported that fall and spring tillage practices did not affect black scurf (*Rhizoctonia solani* Kühn) and common scab (*Streptomyces scabiei*) (Carter et al., 2003). Larney et al. (2016) reported that the conservation management practices led to disease control benefits without negatively impacting tuber quality. Powelson et al. (1993) recommended residue-incorporating tillage in the fall to reduce pathogen inoculum levels for common scab and Pythium seed piece decay.

Sturz et al. (2005) examined bacterial species – abundance relationships in the end root and associated exoroot (root zone soil) in potatoes (*Solanum tuberosum* L.) grown under conventional and minimum tillage systems and found that tillage management had no significant influence on species-abundance relationships in the endo- or exoroot but did influence the relative antibiosis ability of bacteria in vitro challenges against *S. scabies*, where bacteria sourced from minimum tillage systems were more likely to have antibiosis ability, however, bacterial community species richness and diversity indices were significantly greater in the exoroot than in the end root. While both endo- and exoroot communities possessed antibiosis ability against *Phytophthora erythroseptica*, *Streptomyces scabies*, and *Fusarium oxysporum*, a significantly greater proportion of the end root population demonstrated antibiosis ability than its exoroot counterpart against *P. erythroseptica* and *F. oxysporum*. The incidence of common scab was reduced from 7.8% to 6.9% under subsoiling when irrigation was reduced (Henriksen et al., 2007). The effects of subsoiling are affected by soil water status in the growing season, precipitation immediately before and after the subsoiling operation, and crop growth stage at the time of subsoiling (Henriksen et al. 2007). Ekelöf et al. (2015) found that inter-row subsoiling significantly improved Potato quality by a decrease in the incidence of common scab on soils with a documented plow pan at 25–30 cm in the intensive irrigation regime in southern Sweden. Riley (2006) found that potato yield was significantly reduced under conservation tillage compared to the conventional plowed system in long-term studies comparing in Norway on imperfectly drained loams soil.

**Impact of tillage practices on potato specific gravity and chemical content of the tubers**

Tillage practices showed contrasting effects on potato tuber yield and grade. Tuber yield, density, dry matter, specific gravity, and other characteristics are correlated. Potato tuber dry matter content is one of the main determinants of potato quality which is strongly linked with its specific gravity (Dale and Mackay, 1994; Haase, 2004). Specific gravity is a major characteristic of interest in the processing value chain. Potato tuber-specific gravity $\geq 1.08$ and its dry matter content $\geq 20\%$ are the standard references for the potato processing industries (Haase, 2004; Kirkman, 2007). The lower the specific gravity is, the higher the water content is and the costlier it is to process the potato. Alva et al. (2010) found no impact of reduced and conventional tillage practices on potato tuber-specific gravity. Pierce and Burpee (1995) found little impact of zone tillage on specific gravity while a small increase in the incidence of hollow heart was

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apparent under zone tillage while it was reduced by closer seed spacing. The reduced tillage positively affected nitrogen utilization and tuber quality in terms of specific gravity, dry matter, and starch contents (Drakopoulos et al., 2016). Ross (1986) pointed out that potato tuber-specific gravity was not affected by deep chiseling. Holmstrom et al. (2006) found no effect on tuber-specific gravity with reduced tillage systems and French fry color was not significantly affected by the tillage practices. Ojala et al. (1990) reported that specific gravity was not affected by different tillage practices on a fine sandy. Ghazavi et al. (2011) investigated the impact of moldboard, disk, improves disk, and chisel plows and found no significant effect of the tillage practices on dry material, density, carbohydrates content, pH, and organic acids. Carter (2001) also had previously found no significant effect of primary tillage tool on tubers dry matter and density. Holmstrom et al. (2006) reported no effect of reduced tillage systems on potato tuber-specific gravity.

Copas et al. (2009) found that subsoil tillage compared to compacted soil did not affect tuber glucose or sucrose concentrations at harvest or following storage for 120 days. Internal potato tuber defects were not affected by either soil preparation practices (Copas et a., 2009). Ekelöf et al. (2014) investigated the effects of inter-row subsoiling to a depth of 55 cm post-planting and irrigation on potato yield, tuber quality, and phosphorus use efficiency in southern Sweden on soils with a documented plow pan at 25-30 cm and found that inter-row subsoiling significantly increased average starch yield, phosphorus use efficiency and total uptake of phosphorus, however, the incidence of green tubers increased in the subsoiled plots.

Table 1: Tillage practices and their impact on soil properties, crop growth, potato tuber yield and quality under different environments

| **Tillage practices** | **Soil type** | **Impact on soil properties** | **Location** | **Reference** |
|---|---|---|---|---|
| Conventional tillage | fine sandy loam | Reduces the diameter of the soil aggregates, produces low quantity of organic residue | Prince Edward Island, Canada | Carter and Sanderson (2001) |
| Conventional tillage | Oxisol | Soil organic matter oxidation | Londrina, Brazil | Balota et al. (2004) |
| Conservation tillage | fine sandy loam | Increased soil organic carbon, large water-stable macro-aggregates | Prince Edward Island, Canada | Carter et al. (2009) |
| Conservation tillage | Prince Edward Island | Increased soil organic matter content, improved soil hydraulic properties, protection of the soil from erosion | Prince Edward Island, Canada | Carter et al. (1998) ; Holmstrom et al. (1999) |
| Conservation tillage | Caribou loam soil | Increased soil organic matter of the topsoil and can improve soil structure and soil biological properties | Maine, USA | Mallory and Porter (2007) |
| Ridge tillage | - | Improves soil nutrient management | Illinois, USA | Felsot et al. (1990) |
| Deep soil tillage | fine-loamy, micaceous, mesic | Promote plant growth and macronutrient (N, P, K, Ca, and Mg) uptake | Viçosa, Brazil | Nunes et al. (2006) |
| Conservation tillage | fine sandy loam | Increased soil compaction at the 10-30-cm soil depth | Prince Edward Island, Canada | Carter et al. (2005) |
| Basin tillage | sandy loam | 78 and 75% less runoff than the conventional tillage | Prince Edward Island, Canada | Gordon et al. (2011) |
| Zone tillage | McBride sandy loam | Decreased bulk density and soil Strength, and increased the volume of large pores in the zone of compaction | west central Michigan, USA | Pierce and Burpee (1995) |
| Reduced tillage | Andisols | Increased the soil C concentration and average C content in the whole soil profile by 50 and 33%, respectively | Colombian Andes | Quintero and Comerford (2013) |

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7 Table 2: Tillage practices and their impact crop growth, potato tuber yield and quality under different environments

| Tillage practices | Soil type | Impact on crop growth, tube yield and quality | Location | Reference |
|---|---|---|---|---|
| Conservation tillage (no-tillage and subsoiling) | Calcic Cambisol soil | Highest mean potato tuber yields and marketable tuber yield | Ningxia, China, | Hou and Li (2018) |
| Reduced tillage | - | Yield decreased by 22% compared to the conventional tillage | New York, USA | Wallace and Bellinder (1989) |
| Zero tillage | Coare saline soil | Potato tuber quality in terms of crude protein, fat, crude fiber and carbohydrate was better | Ganges Delta, Bangladesh | Sangari et al. (2021) |
| Raised bed tillage | Caribou gravelly loam | Higher potato total and marketable yield | Maine, USA | Essah and Honeycutt (2004), Borrell et al. (1998) |
| Reduced tillage | Sandy soil | Decrease in tuber yield by 13.4 % compared to standard tillage | Wageningen, the Netherlands | Drakopoulos et al. (2016) |
| Basin tillage | sandy loam | No significant effect on marketable potato yield | Prince Edward Island, Canada | Gordon et al. (2011) |
| Spring moldboard plowing | clay loam to sandy loam | Negative effects on yield compared with fall moldboard plowing | New Brunswick, Canada | Liu et al. (2019) |
| Conservation management | - | 18 % higher marketable tuber yield | southern Alberta, Canada | Larney et al. (2016) |
| Spring zone tillage | McBride sandy loam | Increased marketable yields | Michigan, USA | Pierce and Burpee (1995) |
| Zone-subsoiling | Different soil types | Improved tuber grade or increased tuber size | Southern Idaho | Sojka et al. (1993) |
| Subsoiling | sandy soil | Increased potato marketable yield by a 48.5% | Denmark | Henriksen et al. (2007) |
| Spring tillage | - | Increased potato yield | New Brunswick, Canada | Ochuodho et al. (2013) |
| Spring moldboard plowing | Clay loam to sandy loam | Negative effects on yield compared with fall moldboard plowing | New Brunswick, Canada | Liu et al. (2019) |
| Ridges tillage | | Highest yield | Nigeria. | Yaroson et al. (2019) |
| Zero tillage | | Lowest tuber yield | Nigeria. | Yaroson et al. (2019) |

8

**Conclusion**

This review explored the effects of tillage practices in potatoes on soil properties, crop growth, diseases, yield, and quality of potatoes. With contrasting results and non-transferable research findings, targeting one study objective can result in non-desirable or surprising results or create other problems. Commercial potato growers are more favorable to intensive tillage practices and the machinery traffic across the field may result in deep soil compaction incompatible with potato root growth, maximum tuber yield, and grade. Therefore, subsoiling may be necessary to break the soil pan and improve crop growth and yield. Potato producers should be aware of the contrasting results however, they should adopt integrated management of soil and potato crop contributing to the improvement of soil health including cover cropping, crop rotations, soil amendments, and conservation tillage that may enhance crop productivity, system sustainability, system vitality, economic profitability, and environmental quality (Shock et al., 1993; Carter et al., 2005; Magdoff et al., 2009; Larkin, 2015, Djaman et al., 2021a,b; Larkin et al., 2021).

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**Conflicts of Interest**

The authors declare no conflict of interest.

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