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Agricultural systems

Abstract

An agricultural implement includes at least one row unit having a plurality of support members, each of which is pivotably coupled to an attachment frame or another of the support members to permit vertical pivoting vertical movement of the support members, and a plurality of soil-engaging tools, each of which is coupled to at least one of the support members. A plurality of hydraulic cylinders are coupled to the support members for urging the support members downwardly toward the soil. A plurality of controllable pressure control valves are coupled to the hydraulic cylinders for controlling the pressure of hydraulic fluid supplied to the cylinders. A plurality of sensors produce electrical signals corresponding to predetermined conditions, and a controller is coupled to the sensor and the controllable pressure control valves. The controller receives the electrical signals from the sensors and produces control signals for controlling the pressure control valves.

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References Cited

U.S. PATENT DOCUMENTS

Patent No.	Issued Date	Patentee Name	U.S. Cl.	CPC
114002	12/1870	Godfrey	N/A	N/A
123966	12/1871	Wing	N/A	N/A
321906	12/1884	McOrmick	N/A	N/A
353491	12/1885	Hepworth	N/A	N/A
523508	12/1893	Bower	N/A	N/A
736369	12/1902	Pierce	N/A	N/A
803088	12/1904	Barker	N/A	N/A
1069264	12/1912	Keller	N/A	N/A
1134462	12/1914	Kendrick	N/A	N/A
1158023	12/1914	Beaver	N/A	N/A
1247744	12/1916	Trimble	N/A	N/A
1260752	12/1917	Casaday	N/A	N/A
1321040	12/1918	Hoffman	N/A	N/A
1391593	12/1920	Sweeting	N/A	N/A
1398668	12/1920	Bordsen	N/A	N/A
1442032	12/1922	Luce	N/A	N/A
1481981	12/1923	Boye	N/A	N/A
1791462	12/1930	Bermel	N/A	N/A

1844255	12/1931	Kaupke	N/A	N/A
1901299	12/1932	Johnson	N/A	N/A
1901778	12/1932	Schlag	N/A	N/A
1938132	12/1932	Broemmelsick	N/A	N/A
2014334	12/1934	Johnson	N/A	N/A
2044304	12/1935	James	N/A	N/A
2058539	12/1935	Welty	N/A	N/A
2213600	12/1939	Wetmore	N/A	N/A
2249637	12/1940	Rietz	N/A	N/A
2269051	12/1941	Cahoy	N/A	N/A
2285932	12/1941	Leavitt	N/A	N/A
2298539	12/1941	Mott	N/A	N/A
2330302	12/1942	Morkoski	N/A	N/A
2341143	12/1943	Herr	N/A	N/A
2505276	12/1949	Boroski	N/A	N/A
2561763	12/1950	Waters	N/A	N/A
2593176	12/1951	Patterson	N/A	N/A
2596527	12/1951	Bushong	N/A	N/A
2611306	12/1951	Strehlow	N/A	N/A
2612827	12/1951	Baggette	N/A	N/A
2664040	12/1952	Beard	N/A	N/A
2691353	12/1953	Secondo	N/A	N/A
2692544	12/1953	Jessup	N/A	N/A
2715286	12/1954	Saveson	N/A	N/A
2754622	12/1955	Rohnert	N/A	N/A
2771044	12/1955	Putifer	N/A	N/A
2773343	12/1955	Oppel	N/A	N/A
2777373	12/1956	Pursche	N/A	N/A
2799234	12/1956	Chancey	N/A	N/A
2805574	12/1956	Jackson, Jr.	N/A	N/A
2860716	12/1957	Flock	N/A	N/A
2878633	12/1958	Mullin	N/A	N/A
2925872	12/1959	Darnell	N/A	N/A
2960358	12/1959	Christison	N/A	N/A
3010744	12/1960	Hollis	N/A	N/A
3014547	12/1960	Van Der Lely	N/A	N/A
3038424	12/1961	Johnson	N/A	N/A
3042121	12/1961	Broetzman	N/A	N/A
3057092	12/1961	Curlett	N/A	N/A
3058243	12/1961	McGee	N/A	N/A
3065879	12/1961	Jennings	N/A	N/A
3080004	12/1962	McNair	N/A	N/A
3082829	12/1962	Buddingh	N/A	N/A
3103993	12/1962	Gies	N/A	N/A
3110973	12/1962	Reynolds	N/A	N/A
3115739	12/1962	Thoen	N/A	N/A
3122901	12/1963	Thompson	N/A	N/A
3123152	12/1963	Biskis	N/A	N/A
3188989	12/1964	Johnston	N/A	N/A
3213514	12/1964	Evans	N/A	N/A

3250109	12/1965	Spyridakis	N/A	N/A
3256942	12/1965	Van Sickle	N/A	N/A
3261150	12/1965	Fitzgerald, Sr.	N/A	N/A
3314278	12/1966	Bergman	N/A	N/A
3319589	12/1966	Moran	N/A	N/A
3351139	12/1966	Schmitz	N/A	N/A
3355930	12/1966	Fedorov	N/A	N/A
3368788	12/1967	Padula	N/A	N/A
3368789	12/1967	Helmut	N/A	N/A
3370450	12/1967	Scheucher	N/A	N/A
3397933	12/1967	Hatcher	N/A	N/A
3420273	12/1968	Greer	N/A	N/A
3433474	12/1968	Piret	N/A	N/A
3447495	12/1968	Miller	N/A	N/A
3498036	12/1969	Cowling	N/A	N/A
3500937	12/1969	Erickson	N/A	N/A
3507233	12/1969	Greig	N/A	N/A
3539020	12/1969	Andersson	N/A	N/A
3543603	12/1969	Gley	N/A	N/A
3561541	12/1970	Woelfel	N/A	N/A
3576098	12/1970	Brewer	N/A	N/A
3581685	12/1970	Taylor	N/A	N/A
3593720	12/1970	Botterill	N/A	N/A
D221461	12/1970	Hagenstad	N/A	N/A
3599403	12/1970	Gantz	N/A	N/A
3606745	12/1970	Girodat	N/A	N/A
3635495	12/1971	Orendorff	N/A	N/A
3650334	12/1971	Hagenstad	N/A	N/A
3653446	12/1971	Kalmon	N/A	N/A
3701327	12/1971	Krumholz	N/A	N/A
3708019	12/1972	Ryan	N/A	N/A
3711974	12/1972	Webb	N/A	N/A
3718191	12/1972	Williams	N/A	N/A
3749035	12/1972	Cayton	N/A	N/A
3753341	12/1972	Langlie	N/A	N/A
3766988	12/1972	Whitesides	N/A	N/A
3774446	12/1972	Diehl	N/A	N/A
3795291	12/1973	Naito	N/A	N/A
3906814	12/1974	Magnussen	N/A	N/A
3939846	12/1975	Drozhzhin	N/A	N/A
3945532	12/1975	Marks	N/A	N/A
3970012	12/1975	Jones, Sr.	N/A	N/A
3975890	12/1975	Rodger	N/A	N/A
3986464	12/1975	Uppiano	N/A	N/A
4008557	12/1976	Ruback	N/A	N/A
4009668	12/1976	Brass	N/A	N/A
4018101	12/1976	Mihalic	N/A	N/A
4044697	12/1976	Swanson	N/A	N/A
4055126	12/1976	Brown	N/A	N/A
4058171	12/1976	Van Der Lely	N/A	N/A

4063597	12/1976	Day	N/A	N/A
4069029	12/1977	Hudson	N/A	N/A
4096730	12/1977	Martin	N/A	N/A
4099576	12/1977	Jilani	N/A	N/A
4104851	12/1977	Perry	N/A	N/A
4122715	12/1977	Yokoyama	N/A	N/A
4129082	12/1977	Betulius	N/A	N/A
4135349	12/1978	Schwertner	N/A	N/A
4141200	12/1978	Johnson	N/A	N/A
4141302	12/1978	Morrison, Jr.	N/A	N/A
4141676	12/1978	Jannen	N/A	N/A
4142589	12/1978	Schlagenhauf	N/A	N/A
4147305	12/1978	Hunt	N/A	N/A
4149475	12/1978	Bailey	N/A	N/A
4157661	12/1978	Schindel	N/A	N/A
4161090	12/1978	Watts, Jr.	N/A	N/A
4173259	12/1978	Heckenkamp	N/A	N/A
4182099	12/1979	Davis	N/A	N/A
4187916	12/1979	Brown	N/A	N/A
4191262	12/1979	Sylvester	N/A	N/A
4194575	12/1979	Whalen	N/A	N/A
4196567	12/1979	Davis	N/A	N/A
4196917	12/1979	Davis	N/A	N/A
4206817	12/1979	Bowerman	N/A	N/A
4208974	12/1979	Dreyer	N/A	N/A
4213408	12/1979	Atkinson	N/A	N/A
4225191	12/1979	Knoski	N/A	N/A
4233803	12/1979	Davis	N/A	N/A
4233915	12/1979	Kordon	N/A	N/A
4241674	12/1979	Mellinger	N/A	N/A
4249613	12/1980	Scribner	N/A	N/A
4280419	12/1980	Fischer	N/A	N/A
4294181	12/1980	Smith	N/A	N/A
4295532	12/1980	Williams	N/A	N/A
4301870	12/1980	Carre	N/A	N/A
4307674	12/1980	Jennings	N/A	N/A
4311104	12/1981	Steilen	N/A	N/A
4317355	12/1981	Hatsuno	N/A	N/A
4359101	12/1981	Gagnon	N/A	N/A
4375837	12/1982	Van Der Lely	N/A	N/A
4377979	12/1982	Peterson	N/A	N/A
4384444	12/1982	Rossler, Jr.	N/A	N/A
4391335	12/1982	Birkenbach	N/A	N/A
4398608	12/1982	Boetto	N/A	N/A
4407371	12/1982	Hohl	N/A	N/A
4407660	12/1982	Nevens	N/A	N/A
4413685	12/1982	Gremelspacher	N/A	N/A
4430952	12/1983	Murray	N/A	N/A
4433568	12/1983	Kondo	N/A	N/A
4438710	12/1983	Paladino	N/A	N/A

4445445	12/1983	Sterrett	N/A	N/A
4461355	12/1983	Peterson	N/A	N/A
4481830	12/1983	Smith	N/A	N/A
4499775	12/1984	Lasoen	N/A	N/A
4506610	12/1984	Neal	N/A	N/A
4508178	12/1984	Cowell	N/A	N/A
4528920	12/1984	Neumeyer	N/A	N/A
4530405	12/1984	White	N/A	N/A
4537262	12/1984	Van Der Lely	N/A	N/A
4538688	12/1984	Szucs	N/A	N/A
4550122	12/1984	David	N/A	N/A
4553607	12/1984	Behn	N/A	N/A
4580506	12/1985	Fleischer	N/A	N/A
4592428	12/1985	Whitney	N/A	N/A
4596200	12/1985	Gafford	N/A	N/A
4598654	12/1985	Robertson	N/A	N/A
4603746	12/1985	Swales	N/A	N/A
4604906	12/1985	Scarpa	N/A	N/A
4619329	12/1985	Gorbett	N/A	N/A
4630773	12/1985	Ortlip	N/A	N/A
4643043	12/1986	Furuta	N/A	N/A
4646620	12/1986	Buchl	N/A	N/A
4646850	12/1986	Brown	N/A	N/A
4648466	12/1986	Baker	N/A	N/A
4650005	12/1986	Tebben	N/A	N/A
4669550	12/1986	Sittre	N/A	N/A
4671193	12/1986	States	N/A	N/A
4674578	12/1986	Bexten	N/A	N/A
4682550	12/1986	Joy	N/A	N/A
4703809	12/1986	Van Den Ende	N/A	N/A
4726304	12/1987	Dreyer	N/A	N/A
RE32644	12/1987	Brundage	N/A	N/A
4738461	12/1987	Stephenson	N/A	N/A
4744316	12/1987	Lienemann	N/A	N/A
4762075	12/1987	Halford	N/A	N/A
4765190	12/1987	Strubbe	N/A	N/A
4768387	12/1987	Kemp	N/A	N/A
4776404	12/1987	Rogers	N/A	N/A
4779684	12/1987	Schultz	N/A	N/A
4785890	12/1987	Martin	N/A	N/A
4819738	12/1988	Fountain	N/A	N/A
4825957	12/1988	White	N/A	N/A
4825959	12/1988	Wilhelm	N/A	N/A
4919211	12/1989	Cope	N/A	N/A
4920901	12/1989	Pounds	N/A	N/A
4926622	12/1989	McKee	N/A	N/A
4926767	12/1989	Thomas	N/A	N/A
4930431	12/1989	Alexander	N/A	N/A
4986367	12/1990	Kinzenbaw	N/A	N/A
4987841	12/1990	Rawson	N/A	N/A

4998488	12/1990	Hansson	N/A	N/A
5015997	12/1990	Strubbe	N/A	N/A
5022333	12/1990	McClure	N/A	N/A
5027525	12/1990	Haukaas	N/A	N/A
5033397	12/1990	Colburn, Jr.	N/A	N/A
5065632	12/1990	Reuter	N/A	N/A
5074227	12/1990	Schwitters	N/A	N/A
5076180	12/1990	Schneider	N/A	N/A
5092255	12/1991	Long	N/A	N/A
5113957	12/1991	Tamai	N/A	N/A
5129282	12/1991	Bassett	N/A	N/A
5136934	12/1991	Darby, Jr.	N/A	N/A
5190112	12/1992	Johnston	N/A	N/A
5220773	12/1992	Klaeger	N/A	N/A
5224553	12/1992	Heintzman	N/A	N/A
5234060	12/1992	Carter	N/A	N/A
5240080	12/1992	Bassett	N/A	N/A
5255617	12/1992	Williams	N/A	N/A
5269237	12/1992	Baker	N/A	N/A
5282389	12/1993	Faivre	N/A	N/A
5285854	12/1993	Thacker	N/A	N/A
5333694	12/1993	Roggenbuck	N/A	N/A
5337832	12/1993	Bassett	N/A	N/A
5341754	12/1993	Winterton	N/A	N/A
5346019	12/1993	Kinzenbaw	N/A	N/A
5346020	12/1993	Bassett	N/A	N/A
5349911	12/1993	Holst	N/A	N/A
5351635	12/1993	Hulicsko	N/A	N/A
5379847	12/1994	Snyder	N/A	N/A
5394946	12/1994	Clifton	N/A	N/A
5398771	12/1994	Hornung	N/A	N/A
5419402	12/1994	Heintzman	N/A	N/A
5427192	12/1994	Stephenson	N/A	N/A
5443023	12/1994	Carroll	N/A	N/A
5443125	12/1994	Clark	N/A	N/A
5461995	12/1994	Winterton	N/A	N/A
5462124	12/1994	Rawson	N/A	N/A
5473999	12/1994	Rawson	N/A	N/A
5474135	12/1994	Schlagel	N/A	N/A
5477682	12/1994	Tobiasz	N/A	N/A
5477792	12/1994	Bassett	N/A	N/A
5479868	12/1995	Bassett	N/A	N/A
5479992	12/1995	Bassett	N/A	N/A
5485796	12/1995	Bassett	N/A	N/A
5485886	12/1995	Bassett	N/A	N/A
5497717	12/1995	Martin	N/A	N/A
5497837	12/1995	Kehrney	N/A	N/A
5499042	12/1995	Yanagawa	N/A	N/A
5499683	12/1995	Bassett	N/A	N/A
5499685	12/1995	Downing, Jr.	N/A	N/A

5517932	12/1995	Ott	N/A	N/A
5524525	12/1995	Nikkel	N/A	N/A
5531171	12/1995	Whitesel	N/A	N/A
5542362	12/1995	Bassett	N/A	N/A
5544709	12/1995	Lowe	N/A	N/A
5562165	12/1995	Janelle	N/A	N/A
5590611	12/1996	Smith	N/A	N/A
5603269	12/1996	Bassett	N/A	N/A
5623997	12/1996	Rawson	N/A	N/A
5640914	12/1996	Rawson	N/A	N/A
5657707	12/1996	Dresher	N/A	N/A
5660126	12/1996	Freed	N/A	N/A
5685245	12/1996	Bassett	N/A	N/A
5704430	12/1997	Smith	N/A	N/A
5709271	12/1997	Bassett	N/A	N/A
5725057	12/1997	Taylor	N/A	N/A
5727638	12/1997	Wodrich	N/A	N/A
5730074	12/1997	Peter	N/A	N/A
5771669	12/1997	Langworthy	N/A	N/A
5809757	12/1997	McLean	N/A	N/A
5833011	12/1997	Boertlein	N/A	N/A
5852982	12/1997	Peter	N/A	N/A
5868207	12/1998	Langbakk	N/A	N/A
5878678	12/1998	Stephens	N/A	N/A
RE36243	12/1998	Roy	N/A	N/A
5953895	12/1998	Hobbs	N/A	N/A
5970891	12/1998	Schlagel	N/A	N/A
5970892	12/1998	Wendling	N/A	N/A
5988293	12/1998	Brueggen	N/A	N/A
6041582	12/1999	Tiede	N/A	N/A
6067918	12/1999	Kirby	N/A	N/A
6068061	12/1999	Smith	N/A	N/A
6079340	12/1999	Flamme	N/A	N/A
6082274	12/1999	Peter	N/A	N/A
6085501	12/1999	Walch	N/A	N/A
6091997	12/1999	Flamme	N/A	N/A
6145288	12/1999	Tamian	N/A	N/A
6164385	12/1999	Buchl	N/A	N/A
6176334	12/2000	Lorenzen	N/A	N/A
6223663	12/2000	Wendling	N/A	N/A
6223828	12/2000	Paulson	N/A	N/A
6237696	12/2000	Mayerle	N/A	N/A
6250747	12/2000	Hauck	N/A	N/A
6253692	12/2000	Wendling	N/A	N/A
6289829	12/2000	Fish	N/A	N/A
6295939	12/2000	Emms	N/A	N/A
6314897	12/2000	Hagny	N/A	N/A
6325156	12/2000	Barry	N/A	N/A
6330922	12/2000	King	N/A	N/A
6331142	12/2000	Bischoff	N/A	N/A

6343661	12/2001	Thompson	N/A	N/A
6347594	12/2001	Wendling	N/A	N/A
6382326	12/2001	Goins	N/A	N/A
6389999	12/2001	Duello	N/A	N/A
6453832	12/2001	Schaffert	N/A	N/A
6454019	12/2001	Prairie	N/A	N/A
6460623	12/2001	Knussman	N/A	N/A
6497088	12/2001	Holley	N/A	N/A
6516595	12/2002	Rhody	N/A	N/A
6526735	12/2002	Meyer	N/A	N/A
6530334	12/2002	Hagny	N/A	N/A
6575104	12/2002	Brummelhuis	N/A	N/A
6622468	12/2002	Lucand	N/A	N/A
6644224	12/2002	Bassett	N/A	N/A
6681868	12/2003	Kovach	N/A	N/A
6701856	12/2003	Zoske	N/A	N/A
6701857	12/2003	Jensen	N/A	N/A
6715433	12/2003	Friestad	N/A	N/A
6763773	12/2003	Schaffert	N/A	N/A
6786130	12/2003	Steinlage	N/A	N/A
6827029	12/2003	Wendte	N/A	N/A
6834598	12/2003	Jueptner	N/A	N/A
6840853	12/2004	Foth	N/A	N/A
6843047	12/2004	Hurtis	N/A	N/A
6853937	12/2004	Shibusawa	N/A	N/A
6886650	12/2004	Bremner	N/A	N/A
6889943	12/2004	Dinh	N/A	N/A
6892656	12/2004	Schneider	N/A	N/A
6907833	12/2004	Thompson	N/A	N/A
6908052	12/2004	Jacobson	N/A	N/A
6912963	12/2004	Bassett	N/A	N/A
6923390	12/2004	Barker	N/A	N/A
6968907	12/2004	Raper	N/A	N/A
6986313	12/2005	Halford	N/A	N/A
6997400	12/2005	Hanna	N/A	N/A
7004090	12/2005	Swanson	N/A	N/A
7044070	12/2005	Kaster	N/A	N/A
7063167	12/2005	Staszak	N/A	N/A
7159523	12/2006	Bourgault	N/A	N/A
7163227	12/2006	Burns	N/A	N/A
7222575	12/2006	Bassett	N/A	N/A
7249448	12/2006	Murphy	N/A	N/A
7290491	12/2006	Summach	N/A	N/A
7325756	12/2007	Giorgis	N/A	N/A
7347036	12/2007	Easley, Jr.	N/A	N/A
7360494	12/2007	Martin	N/A	N/A
7360495	12/2007	Martin	N/A	N/A
7438006	12/2007	Mariman	N/A	N/A
7451712	12/2007	Bassett	N/A	N/A
7497174	12/2008	Sauder	N/A	N/A

7523709	12/2008	Kiest	N/A	N/A
7540245	12/2008	Spicer	N/A	N/A
7540333	12/2008	Bettin	N/A	N/A
7575066	12/2008	Bauer	N/A	N/A
7584707	12/2008	Sauder	N/A	N/A
7665539	12/2009	Bassett	N/A	N/A
7673570	12/2009	Bassett	N/A	N/A
7743718	12/2009	Bassett	N/A	N/A
7870827	12/2010	Bassett	N/A	N/A
7900429	12/2010	Labar	N/A	N/A
7918285	12/2010	Graham	N/A	N/A
7938074	12/2010	Liu	N/A	N/A
7944210	12/2010	Fischer	N/A	N/A
7946231	12/2010	Martin	N/A	N/A
7975629	12/2010	Martin	N/A	N/A
8020629	12/2010	McFarlane	N/A	N/A
8146519	12/2011	Bassett	N/A	N/A
8151717	12/2011	Bassett	N/A	N/A
8171707	12/2011	Kitchel	N/A	N/A
D663326	12/2011	Allensworth	N/A	N/A
8327780	12/2011	Bassett	N/A	N/A
8359988	12/2012	Bassett	N/A	N/A
8380356	12/2012	Zielke	N/A	N/A
8386137	12/2012	Sauder	N/A	N/A
8393407	12/2012	Freed	N/A	N/A
8408149	12/2012	Rylander	N/A	N/A
8544397	12/2012	Bassett	N/A	N/A
8544398	12/2012	Bassett	N/A	N/A
8550020	12/2012	Sauder	N/A	N/A
8573319	12/2012	Casper	N/A	N/A
8634992	12/2013	Sauder	N/A	N/A
8636077	12/2013	Bassett	N/A	N/A
8649930	12/2013	Reeve	N/A	N/A
8746661	12/2013	Runkel	N/A	N/A
8763713	12/2013	Bassett	N/A	N/A
8770308	12/2013	Bassett	N/A	N/A
8776702	12/2013	Bassett	N/A	N/A
RE45091	12/2013	Bassett	N/A	N/A
8863857	12/2013	Bassett	N/A	N/A
8910581	12/2013	Bassett	N/A	N/A
8939095	12/2014	Freed	N/A	N/A
8985232	12/2014	Bassett	N/A	N/A
9003982	12/2014	Elizalde	N/A	N/A
9003983	12/2014	Roth	N/A	N/A
9055712	12/2014	Bassett	N/A	N/A
9107337	12/2014	Bassett	N/A	N/A
9107338	12/2014	Bassett	N/A	N/A
9113589	12/2014	Bassett	N/A	N/A
9144187	12/2014	Bassett	N/A	N/A
9148989	12/2014	Van Buskirk	N/A	N/A

9167740	12/2014	Bassett	N/A	N/A
9192088	12/2014	Bruce	N/A	N/A
9192089	12/2014	Bassett	N/A	N/A
9192091	12/2014	Bassett	N/A	N/A
9215838	12/2014	Bassett	N/A	N/A
9215839	12/2014	Bassett	N/A	N/A
9226440	12/2015	Bassett	N/A	N/A
9232687	12/2015	Bassett	N/A	N/A
9241438	12/2015	Bassett	N/A	N/A
9271437	12/2015	Martin	N/A	N/A
9307690	12/2015	Bassett	N/A	N/A
9392743	12/2015	Camacho-Cook	N/A	N/A
9504195	12/2015	Dinu	N/A	N/A
9504198	12/2015	Martin	N/A	N/A
9615497	12/2016	Bassett	N/A	N/A
9668398	12/2016	Bassett	N/A	N/A
9681601	12/2016	Bassett	N/A	N/A
9723778	12/2016	Bassett	N/A	N/A
9788472	12/2016	Bassett	N/A	N/A
9833520	12/2016	Li	N/A	N/A
9848522	12/2016	Bassett	N/A	N/A
9861022	12/2017	Bassett	N/A	N/A
9980421	12/2017	Hammes	N/A	N/A
10238024	12/2018	Bassett	N/A	N/A
10251324	12/2018	Martin	N/A	N/A
10251333	12/2018	Bassett	N/A	N/A
10433472	12/2018	Bassett	N/A	N/A
10444774	12/2018	Bassett	N/A	N/A
10477752	12/2018	Bassett	N/A	N/A
10477760	12/2018	Bassett	N/A	N/A
10485153	12/2018	Bassett	N/A	N/A
10506755	12/2018	Bassett	N/A	N/A
10548260	12/2019	Bassett	N/A	N/A
10582653	12/2019	Bassett	N/A	N/A
10645865	12/2019	Bassett	N/A	N/A
10721855	12/2019	Bassett	N/A	N/A
10806064	12/2019	Martin	N/A	N/A
10980174	12/2020	Bassett	N/A	N/A
11006563	12/2020	Bassett	N/A	N/A
11083134	12/2020	Bassett	N/A	N/A
11122726	12/2020	Bassett	N/A	N/A
11470754	12/2021	Bassett	N/A	N/A
11576295	12/2022	Bassett	N/A	N/A
2002/0021769	12/2001	Okanobu	N/A	N/A
2002/0073678	12/2001	Lucand	N/A	N/A
2002/0162492	12/2001	Juptner	N/A	N/A
2003/0141086	12/2002	Kovach	N/A	N/A
2003/0141088	12/2002	Kovach	N/A	N/A
2003/0177764	12/2002	Kamen	N/A	N/A
2004/0005929	12/2003	Piasecki	N/A	N/A

2004/0148917	12/2003	Eastwood	N/A	N/A
2005/0000202	12/2004	Scordilis	N/A	N/A
2005/0005704	12/2004	Adamchuk	N/A	N/A
2005/0045080	12/2004	Halford	N/A	N/A
2005/0199842	12/2004	Parsons	N/A	N/A
2006/0102058	12/2005	Swanson	N/A	N/A
2006/0118662	12/2005	Korus	N/A	N/A
2006/0191695	12/2005	Walker	N/A	N/A
2006/0213566	12/2005	Johnson	N/A	N/A
2006/0237203	12/2005	Miskin	N/A	N/A
2007/0044694	12/2006	Martin	N/A	N/A
2007/0272134	12/2006	Baker	N/A	N/A
2008/0093093	12/2007	Sheppard	N/A	N/A
2008/0173220	12/2007	Wuertz	N/A	N/A
2008/0236461	12/2007	Sauder	N/A	N/A
2008/0256916	12/2007	Vaske	N/A	N/A
2009/0133888	12/2008	Kovach	N/A	N/A
2009/0260902	12/2008	Holman	N/A	N/A
2010/0006309	12/2009	Ankenman	N/A	N/A
2010/0019471	12/2009	Ruckle	N/A	N/A
2010/0108336	12/2009	Thomson	N/A	N/A
2010/0180695	12/2009	Sauder	N/A	N/A
2010/0198529	12/2009	Sauder	N/A	N/A
2010/0282480	12/2009	Breker	N/A	N/A
2011/0101135	12/2010	Korus	N/A	N/A
2011/0147148	12/2010	Ripa	N/A	N/A
2011/0239920	12/2010	Henry	N/A	N/A
2011/0247537	12/2010	Freed	N/A	N/A
2011/0313575	12/2010	Kowalchuk	N/A	N/A
2012/0010782	12/2011	Grabow	N/A	N/A
2012/0023269	12/2011	Wilson	N/A	N/A
2012/0048159	12/2011	Adams	N/A	N/A
2012/0060730	12/2011	Bassett	N/A	N/A
2012/0060731	12/2011	Bassett	N/A	N/A
2012/0167809	12/2011	Bassett	N/A	N/A
2012/0186216	12/2011	Vaske	N/A	N/A
2012/0186503	12/2011	Sauder	N/A	N/A
2012/0210920	12/2011	Bassett	N/A	N/A
2012/0216731	12/2011	Schilling	N/A	N/A
2012/0232691	12/2011	Green	N/A	N/A
2012/0255475	12/2011	Mariman	N/A	N/A
2012/0305274	12/2011	Bassett	N/A	N/A
2013/0032363	12/2012	Curry	N/A	N/A
2013/0112121	12/2012	Achen	N/A	N/A
2013/0112124	12/2012	Bergen	N/A	N/A
2013/0146318	12/2012	Bassett	N/A	N/A
2013/0192186	12/2012	Bassett	N/A	N/A
2013/0213676	12/2012	Bassett	N/A	N/A
2013/0325267	12/2012	Adams	N/A	N/A
2013/0333599	12/2012	Bassett	N/A	N/A

2014/0000448	12/2013	Franklin, III	N/A	N/A
2014/0026748	12/2013	Stoller	N/A	N/A
2014/0034339	12/2013	Sauder	N/A	N/A
2014/0034343	12/2013	Sauder	N/A	N/A
2014/0034344	12/2013	Bassett	N/A	N/A
2014/0060864	12/2013	Martin	N/A	N/A
2014/0116735	12/2013	Bassett	N/A	N/A
2014/0165527	12/2013	Oehler	N/A	N/A
2014/0190712	12/2013	Bassett	N/A	N/A
2014/0197249	12/2013	Roth	N/A	N/A
2014/0214284	12/2013	Sauder	N/A	N/A
2014/0224513	12/2013	Van Buskirk	N/A	N/A
2014/0224843	12/2013	Rollenhagen	N/A	N/A
2014/0278696	12/2013	Anderson	N/A	N/A
2014/0303854	12/2013	Zielke	N/A	N/A
2015/0199748	12/2014	Hammock	N/A	N/A
2015/0216108	12/2014	Roth	N/A	N/A
2015/0237791	12/2014	Bassett	N/A	N/A
2015/0373901	12/2014	Bassett	N/A	N/A
2016/0066498	12/2015	Bassett	N/A	N/A
2016/0100517	12/2015	Bassett	N/A	N/A
2016/0100520	12/2015	Bassett	N/A	N/A
2016/0128263	12/2015	Bassett	N/A	N/A
2016/0128265	12/2015	Bassett	N/A	N/A
2016/0270285	12/2015	Hennes	N/A	N/A
2016/0309641	12/2015	Taunton	N/A	N/A
2017/0000006	12/2016	Raetzman	N/A	N/A
2017/0000013	12/2016	Raetzman	N/A	N/A
2017/0034985	12/2016	Martin	N/A	N/A
2017/0094889	12/2016	Garner	N/A	N/A
2017/0099769	12/2016	Badalini	N/A	N/A
2017/0127614	12/2016	Button	N/A	N/A
2017/0164548	12/2016	Bassett	N/A	N/A
2017/0181373	12/2016	Bassett	N/A	N/A
2017/0231145	12/2016	Bassett	N/A	N/A
2017/0300072	12/2016	Bassett	N/A	N/A
2017/0303467	12/2016	Simmons	N/A	N/A
2017/0318741	12/2016	Bassett	N/A	N/A
2017/0359940	12/2016	Bassett	N/A	N/A
2018/0000001	12/2017	Bassett	N/A	N/A
2018/0000002	12/2017	Bassett	N/A	N/A
2019/0059196	12/2018	Bourgault	N/A	N/A
2019/0183029	12/2018	Martin	N/A	N/A
2019/0343042	12/2018	Button	N/A	N/A
2020/0060058	12/2019	Bassett	N/A	N/A
2020/0128785	12/2019	Bassett	N/A	N/A
2020/0146208	12/2019	Bassett	N/A	N/A
2020/0315082	12/2019	Bassett	N/A	N/A
2021/0007264	12/2020	Martin	N/A	N/A
2021/0161062	12/2020	Bassett	N/A	N/A

2021/0315149	12/2020	Bassett	N/A	N/A
2021/0329884	12/2020	Bassett	N/A	N/A

FOREIGN PATENT DOCUMENTS

Patent No.	Application Date	Country	CPC
551372	12/1955	BE	N/A
530673	12/1955	CA	N/A
2096775	12/1991	CN	N/A
335464	12/1920	DE	N/A
1108971	12/1960	DE	N/A
2402411	12/1974	DE	N/A
2710142	12/1977	DE	N/A
3830141	12/1989	DE	N/A
102007005801	12/2007	DE	N/A
1143784	12/2000	EP	N/A
2497348	12/2011	EP	N/A
3150045	12/2016	EP	N/A
2891692	12/2006	FR	N/A
1574412	12/1979	GB	N/A
2056238	12/1980	GB	N/A
2160401	12/1984	GB	N/A
S5457726	12/1978	JP	N/A
5457726	12/2013	JP	N/A
392897	12/1972	SU	N/A
436778	12/1973	SU	N/A
611201	12/1977	SU	N/A
625648	12/1977	SU	N/A
1410884	12/1987	SU	N/A
1466674	12/1988	SU	N/A
0123241	12/2000	WO	N/A
2009145381	12/2008	WO	N/A
2009146780	12/2008	WO	N/A
2011161140	12/2010	WO	N/A
2012149367	12/2011	WO	N/A
2012149415	12/2011	WO	N/A
2012167244	12/2011	WO	N/A
2013025898	12/2012	WO	N/A
2016073964	12/2015	WO	N/A
2016073966	12/2015	WO	N/A
2016205424	12/2015	WO	N/A
2019180329	12/2018	WO	N/A
2019191618	12/2018	WO	N/A
2019216005	12/2018	WO	N/A
2019216018	12/2018	WO	N/A

OTHER PUBLICATIONS

Acu-Grain“Combine Yield Monitor 99% Accurate? ‘You Bet Your Bushels!!’” date estimated as early as Feb. 1993 (2 pages). cited by applicant
Borgelt, Steven C., “Sensor Technologies and Control Strategies for Managing Variability,” University of Missouri, Apr. 14-16, 1992 (15 pages). cited by applicant

Buffalo Farm Equipment All Flex Cultivator Operator Manual, Apr. 1990 (7 pages). cited by applicant
Buffalo Farm Equipment Catalog on Models 4600, 4630, 4640, and 4620date estimated as early as Feb. 1992 (4 pages). cited by applicant
Case Corporation Brochure, Planters 900 Series Units/Modules Product InformationAug. 1986 (4 pages). cited by applicant
Exner, Rick, “Sustainable Agriculture: Practical Farmers of lowa Reducing Weed Pressure in Ridge-Till,” Iowa State University University Extension, http://www.extension.iastate.edu/Publications/SA2.pdf, Jul. 1992, Reviewed Jul. 2009, Retrieved Nov. 2, 2012 (4 pages). cited by applicant
Finck, Charlene, “Listen to Your Soil,” Farm Journal Article, Jan. 1993pp. 14-15 (2 pages). cited by applicant
Gason, 3 Row Vineyard Mower Brochure, http://www.fatcow.com.au/c/Gason/Three-row-vineyard-mower-a-world-firt-p23696, Jul. 2010 (1 page). cited by applicant
Hiniker 5000 Cultivator Brochure, date estimated as early as Feb. 1992 (4 pages). cited by applicant
Hiniker Company, Flow & Acreage Continuous Tracking System Monitor Demonstration Manuel, date estimated as early as Feb. 1991 (7 pages). cited by applicant
Hiniker Series 5000 Row Cultivator Rigid and Folding Toolbar Operator's Manual, date estimated as early as Feb. 1992 (5 pages). cited by applicant
John Deere, New 4435 Hydro Row-Crop and Small-Grain Combinedate estimated as early as Feb. 1993 (8 pages). cited by applicant
John Deere, New Semi-Active Sea Suspension, http://www.deere.com/en-US/parts/agparts/semiactiveseat.html, date estimated as early as Jan. 2014, retrieved Feb. 6, 2014 (2 pages). cited by applicant
John Deere, Seat Catalog, date estimated as early Sep. 2011 (19 pages). cited by applicant
Martin Industries, LLC Paired 13″ Spading Closing Wheels Brochure, date estimated as early as Jun. 6, 2012pp. 18-25 (8 pages). cited by applicant
Moyer, Jeff, The Rodal Cover Crop Roller, http://www.youtube.com/watch?v=PW4mwVjPS9A, retrieved from the internet May 22, 2019 (2 pages). cited by applicant
Orthman Manufacturing, Inc., Rowcrop Cultivator Bookletdate estimated as early as Feb. 1992 (4 pages). cited by applicant
Rodale Institute, “No-Till Revolution,” http://www.rodaleinstitute.org/no-till_revolution, retrieved from the internet May 3, 2019 (4 pages). cited by applicant
Russnogle, John, “Sky Spy: Gulf War Technology Pinpoints Field and Yields,” Top Producer, A Farm Journal Publication, Nov. 1991pp. 12-14 (4 pages). cited by applicant
Shivvers, Moisture Trac 3000 Brochure, Aug. 21, 1990 (5 pages). cited by applicant
The New Farm, “New Efficiencies in Nitrogen Application,” Feb. 1991, p. 6 (1 page). cited by applicant
The New Farm, Farmer-to-Farmer Know-How from the Rodale Institute, “Introducing a cover crop roller with all the drawbacks of a stalk chopper”, http://www.newfarm.org/depts/NFfield_trials/1103/notillroller.shtml, retrieved from the internet May 3, 2019 (4 pages). cited by applicant
Vansichen, R. et al.“Continuous Wheat Yield Measurement on a Combine,” date estimated as early as Feb. 1993 (5 pages). cited by applicant
Vogt, Willie, “Revisiting Robotics,” http://m.farmindustrynews.com/farm-equipment/revisiting-robotics, Dec. 19, 2013 (3 pages). cited by applicant
Yetter 2010 Product Catalogdate estimated as early as Jan. 2010 (2 pages). cited by applicant
Yetter Catalog, date estimated as early as Feb. 1992 (4 pages). cited by applicant
Yetter Cut and Move Manual, Sep. 2010 (28 pages). cited by applicant
Yetter Screw Adjust Residue Manager Operator's Manual, labeled “2565-729_REV_D” and dated

Sep. 2010 on p. 36, retrieved Mar. 10, 2014 from the internet, available online Jul. 13, 2011, at https://web.archive.org/web/20110713162510/http://www.yetterco.com/help/manuals/Screw_Adjust_Residue_ Manager2.pdf. cited by applicant

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS (1) This application is a continuation of U.S. patent application Ser. No. 17/343,534, filed Jun. 9, 2021, which is a continuation of U.S. patent application Ser. No. 16/673,884, filed Nov. 4, 2019, now U.S. Pat. No. 11,122,726, which is a continuation of U.S. patent application Ser. No. 15/695,785, filed Sep. 5, 2017, now U.S. Pat. No. 10,506,755, which is a continuation of U.S. patent application Ser. No. 14/974,087, filed Dec. 18, 2015, which is a continuation of U.S. patent application Ser. No. 14/146,822, filed Jan. 3, 2014, now U.S. Pat. No. 9,232,687, which is a continuation-in-part and claims priority to: (2) (1) U.S. patent application Ser. No. 13/893,890, filed May 14, 2013, now U.S. Pat. No. 9,107,338; and (3) (2) U.S. patent application Ser. No. 13/758,979, filed Feb. 4, 2013, now U.S. Pat. No. 9,055,712.

FIELD OF THE INVENTION
(1) The present invention relates generally to agricultural equipment and, more particularly, to row crop implements having automatic control systems.
SUMMARY
(2) In accordance with one embodiment, an agricultural implement is provided for use with a towing frame hitched to a tractor having a hydraulic system for supplying pressurized hydraulic fluid to the implement. The implement includes at least one row unit having (1) an attachment frame adapted to be rigidly connected to the towing frame, (2) a plurality of support members, each of which is pivotably coupled to the attachment frame or another of the support members to permit vertical pivoting vertical movement of the support members, (3) a plurality of soil-engaging tools, each of which is coupled to at least one of the support members, (4) a plurality of hydraulic cylinders, each of which is coupled to one of the support members for urging the respective support member downwardly toward the soil, each of the hydraulic cylinders including a movable ram extending into the cylinder, (5) a plurality of hydraulic lines, each of which is coupled to one of the hydraulic cylinders for supplying pressurized hydraulic fluid to the respective cylinders, (6) a plurality of controllable pressure control valves, each of which is coupled to one of the hydraulic lines for controlling the pressure of hydraulic fluid supplied by the respective hydraulic lines to the respective cylinders, (7) a plurality of sensors, each of which produces an electrical signal corresponding to a predetermined condition, and (8) at least one controller coupled to the sensor and the controllable pressure control valves, the controller being adapted to receive the electrical signal from the sensors and produce a control signal for controlling the pressure control valves.
(3) In one implementation, the plurality of sensors include at least one sensor selected from the group consisting of a pressure sensor detecting the force applied by one of the hydraulic cylinders to the support member to which that cylinder is coupled.
(4) In accordance with another embodiment, an agricultural row unit attachable to a towing frame for movement over a field having varying hardness conditions, comprises a soil-penetrating tool, a gauge wheel mounted for rolling engagement with the soil surface, and a sensor coupled to the tool and the gauge wheel for detecting changes in the difference between the vertical positions of the tool and the gauge wheel, and producing an output corresponding to the changes. A controllable

actuator is coupled to the tool for applying a downward pressure on the tool, and a control system is coupled to the actuator and receiving the output of the sensor for controlling the actuator and thus the downward pressure on the tool.
(5) In one implementation, the agricultural row unit is a planting row unit that includes an opening device for opening a furrow into which seeds can be planted, and the soil-penetrating tool is at least one closing wheel for closing the furrow after seeds have been deposited into the furrow.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) The invention may best be understood by reference to the following description taken in conjunction with the accompanying drawings, in which:
(2) FIG. **1** is a perspective view of a planting row unit attached to a towing frame.
(3) FIG. **2** is a partially sectioned side elevation of the planting row unit of FIG. **1** with the linkage that connects the row unit to the towing frame in a level position.
(4) FIG. **3** is the same side elevation shown in FIG. **1** but with the linkage tilted upwardly to move the row unit to a raised position.
(5) FIG. **4** is the same side elevation shown in FIG. **1** but with the linkage tilted downwardly to move the row unit to a lowered position.
(6) FIG. **5** is a top plan view of the hydraulic cylinder and accumulator unit included in the row unit of FIGS. **1-4**.
(7) FIG. **6** is a vertical section taken along line **6-6** in FIG. **5**.
(8) FIG. **7** is a side elevation of the unit shown in FIGS. **5** and **6** connected to a pair of supporting elements, with the support structures and the connecting portions of the hydraulic cylinder shown in section.
(9) FIGS. **8**A and **8**B are enlarged cross sectional views of the supporting structures shown in section in FIG. **7**.
(10) FIG. **9** is an enlarged perspective of the right-hand end portion of FIG. **1** with a portion of the four-bar linkage broken away to reveal the mounting of the hydraulic cylinder/accumulator unit.
(11) FIG. **10** is a schematic diagram of a first hydraulic control system for use with the row unit of FIGS. **1-9**.
(12) FIG. **11** is a schematic diagram of a second hydraulic control system for use with the row unit of FIGS. **1-9**.
(13) FIG. **12** is a diagram illustrating one application of the hydraulic control system of FIG. **11**.
(14) FIG. **13** is a side elevation of a modified embodiment having the hydraulic control unit coupled to the closing wheels of the row unit;
(15) FIG. **14** is a side elevation of a further modified embodiment having the hydraulic control unit coupled to the closing wheels of the row unit;
(16) FIG. **15** is yet another modified embodiment having the hydraulic control unit coupled to the closing wheels of the row unit;
(17) FIG. **16** is a side elevation of another modified embodiment of a hydraulic control unit;
(18) FIG. **17** is an enlarged section taken along the line **17-17** in FIG. **16**; and
(19) FIG. **18** is a schematic diagram of the hydraulic circuit in the unit of FIGS. **16** and **17**.
(20) FIG. **19** is a perspective view of a standard configuration of a hydraulic system.
(21) FIG. **20**A is an exploded view of a standard configuration of a hydraulic assembly.
(22) FIG. **20**B is an assembled perspective view of FIG. **20**A.
(23) FIG. **21** is a perspective view of a hose connection manifold.
(24) FIG. **22**A is a top cross-sectional view of FIG. **20**B.
(25) FIG. **22**B is a side cross-sectional view of FIG. **20**B.

(26) FIG. **23** is a rear perspective view of an alternative configuration of the hydraulic system of FIG. **19**.
(27) FIG. **24**A is an exploded view of an alternative configuration of a hydraulic assembly.
(28) FIG. **24**B is an assembled perspective view of FIG. **24**A.
(29) FIG. **25**A is a perspective view of a control manifold.
(30) FIG. **25**B is a left cross-sectional view of the control manifold of FIG. **25**A.
(31) FIG. **25**C is a right cross-sectional view of the control manifold of FIG. **25**A.
(32) FIG. **26** is a top plan view of a hydraulic cylinder for a row unit.
(33) FIG. **27**A is a vertical section taken along line **27**A-**27**A in FIG. **26**.
(34) FIG. **27**B is an enlarged view of a ram leading area that is shown in FIG. **27**A.
(35) FIG. **28**A is a side elevation of a hydraulic control system with double-acting ram for use with a row unit.
(36) FIG. **28**B is an enlarged view illustrating a hydraulic control unit of the hydraulic control system of FIG. **28**A.
(37) FIG. **29** is a perspective view of an agricultural opener device with integrated controller.
(38) FIG. **30** is a schematic diagram of a hydraulic control system having integrated controllers in one or more row units.
(39) FIG. **31** is a schematic diagram of a hydraulic control system for use with a row unit.
(40) FIG. **32** is a partial perspective of a linkage assembly with two actuators for controlling a row unit.
(41) FIG. **33** is a side illustration of the linkage assembly of FIG. **32**.
(42) FIG. **34** illustrates an actuator having two energy storage devices.
(43) FIG. **35** illustrates a tractor towing a plurality of row units having status indicators.
(44) FIG. **36** is a perspective view of a soil-hardness sensing device attached to a planting row unit.
(45) FIG. **37** is a schematic side elevation illustrating the soil-hardness device attached to the planting row unit.
(46) FIG. **38** is a schematic diagram illustrating the determination of hydraulic pressures for a planting row unit.
(47) FIG. **39**A is a side elevation of an agricultural system moving over soft soil conditions.
(48) FIG. **39**B is a side elevation of the agricultural system of FIG. **39**A in which a soil-hardness sensing device is moving over hard soil conditions.
(49) FIG. **39**C is a side elevation of the agricultural system of FIG. **39**B in which a planting row unit is moving over the hard soil conditions.
(50) FIG. **40**A is a schematic side elevation illustrating sensing of soil conditions and determining of hydraulic pressures for a planting row unit.
(51) FIG. **40**B is a flowchart of an algorithm for adjusting a pressure applied to a soil-hardness sensing device.
(52) FIG. **40**C is a flowchart of an algorithm for adjusting a user-defined variable associated with a pressure applied to a planting row unit.
(53) FIG. **40**D is a flowchart of an algorithm for adjusting a user-defined variable associated with a pressure applied to a row-clearing unit.
(54) FIG. **41**A is a top elevation illustrating an agricultural system in which a plurality of planting row units are adjusted by two soil-hardness sensing devices.
(55) FIG. **41**B is a side elevation illustrating the agricultural system of FIG. **41**B.
(56) FIG. **42** is a side elevation illustrating an alternative embodiment of the soil-hardness sensing device with modular actuators.
(57) FIG. **43** is a perspective view illustrating an alternative modular unit.
(58) FIG. **44**A is side elevation illustrating an alternative embodiment of the soil-hardness sensing device with a modified blade arm.
(59) FIG. **44**B is an enlarged exploded illustration of a distal end of the blade arm.

(60) FIG. **44**C is a side elevation of a row unit having a ground hardness sensor integrated with a furrow-closing device that includes a pair of toothed wheels and a ground gauge wheel.
(61) FIG. **44**D is an enlarged sectional view of a proximity sensing device included in the ground hardness sensor in the row unit shown in FIG. **44**C.
(62) FIG. **44**E is the same side elevation shown in FIG. **44**C, with the closing wheels at a higher elevation than shown in FIG. **44**C.
(63) FIG. **44**F is an enlarged sectional view of the proximity sensor shown in FIG. **44**D, with the closing wheels in the position shown in FIG. **44**E.
(64) FIG. **44**G is an enlarged exploded perspective view of the closing wheel support arm shown in FIGS. **44**C-**44**F, and the sensing device coupled to the upper end of that support arm.
(65) FIG. **45** is a schematic diagram of a hydraulic control system for controlling the hydraulic pressure in a hydraulic cylinder.
(66) FIG. **46**A is a schematic diagram of a modified hydraulic control system for controlling the hydraulic pressure in a hydraulic cylinder.
(67) FIG. **46**B is a waveform diagram illustrating different modes of operation provided by the hydraulic control systems of FIGS. **45** and **46**A.
(68) FIG. **46**C is a diagrammatic illustration of an electrical control system for use with the hydraulic control systems of FIGS. **45** and **46**A.
(69) FIG. **47** is a side elevation of a planting row unit and a row-clearing unit, both attached to a towing frame, with the row-clearing unit in a lowered position.
(70) FIG. **48** is the same side elevation shown in FIG. **47** with the row-clearing unit in a raised position.
(71) FIG. **49** is an enlarged perspective of the row-clearing unit shown in FIGS. **47** and **48**.
(72) FIGS. **50**, **51** and **52** are side elevations of the main components of the row-clearing unit shown in FIGS. **47-49** in three different vertical positions.
(73) FIGS. **53**, **54**, and **55** are side elevations of the hydraulic cylinder of the row-clearing unit shown in FIGS. **47-52** with the cylinder rod in three different positions corresponding to the positions shown in FIGS. **51**, **52** and **50**, respectively.
(74) FIG. **56** is a schematic diagram of a first hydraulic control system for use in controlling the row-clearing unit shown in FIGS. **47-52**.
(75) FIG. **57** is a schematic diagram of a second hydraulic control system for use in controlling the row-clearing unit shown in **47-52**.
(76) FIG. **58** is a functional block diagram of a hydraulic control system for use with multiple row units.
(77) FIG. **59** is a perspective view similar to that of FIG. **49** but modified to include a pressure sensor, in the form of a load cell.
(78) FIG. **60** is an enlarged section view taken longitudinally through the middle of the load cell shown in FIG. **59**.
(79) FIG. **61** is a side elevation of a modified embodiment having multiple control systems.
(80) FIG. **62** is a block diagram of the multiple control systems for multiple row units of the type illustrated in FIG. **61**, and a display coupled to the control systems in the multiple row units.
(81) FIG. **63** is a block diagram of a slightly simplified version of the system illustrated in FIG. **62**.
(82) FIG. **64** is a block diagram of a further simplified version of the system illustrated in FIG. **62**.
(83) FIG. **65** is a block diagram of multiple control valves for multiple row units arranged in multiple groups or sections.
(84) FIG. **66**A is an exemplary display configured to depict real-time graphics when an implement is moving across a field.
(85) FIG. **66**B is an exemplary display depicting real-time graphics of one or more performance metrics relating to a tool as it is moving across a field.
(86) FIG. **66**C is an exemplary display depicting a modified screen for monitoring one or more

parameters associated with one or more tools across all the row units of a planter.
(87) FIG. **66**D shows an exemplary number keypad that can be used by the operator to quickly select a row unit for immediate monitoring as the row units are being moved across a field.
(88) FIG. **66**E is an exemplary display depicting an exemplary row diagnostics screen with tool parameter monitor windows.
(89) FIG. **67** is a series of plots representing the variations in electrical parameters representing the performance of an implement as it traverses an agricultural field.
(90) FIG. **68** is an exemplary touch-screen display depicting a control panel for use by an operator to select the type of tool to be monitored on the display.
(91) FIG. **69** is exemplary display depicting an interactive map screen.
(92) FIG. **70** is a flowchart of an algorithm that can be used in connection with FIG. **40**B.
DETAILED DESCRIPTION OF ILLUSTRATED EMBODIMENTS
(93) Although the invention will be described in connection with certain preferred embodiments, it will be understood that the invention is not limited to those particular embodiments. On the contrary, the invention is intended to cover all alternatives, modifications, and equivalent arrangements as may be included within the spirit and scope of the invention as defined by the appended claims.
(94) Turning now to the drawings, a planting row unit **10** includes a furrow-opening device for the purpose of planting seed or injecting fertilizer into the soil. In the illustrated embodiment, the furrow-opening device is a V-opener **11** formed by a pair of conventional tilted discs depending from the leading end of a row unit frame **12**. It will be understood that other furrow-opening devices may be used. A conventional elongated hollow towing frame **13** (typically hitched to a tractor by a draw bar) is rigidly attached to the front frame **14** of a conventional four-bar linkage assembly **15** that is part of the row unit **10**. The four-bar (sometimes referred to as “parallel-bar”) linkage assembly **15** is a conventional and well known linkage used in agricultural implements to permit the raising and lowering of tools attached thereto.
(95) As the planting row unit **10** is advanced by the tractor, the V-opener **11** penetrates the soil to form a furrow or seed slot. Other portions of the row unit **10** then deposit seed in the seed slot and fertilizer adjacent to the seed slot, and close the seed slot by distributing loosened soil into the seed slot with a pair of closing wheels **16**. A gauge wheel **17** determines the planting depth for the seed and the height of introduction of fertilizer, etc. Bins **18***a* and **18***b* on the row unit carry the chemicals and seed which are directed into the soil. The planting row unit **10** is urged downwardly against the soil by its own weight, and, in addition, a hydraulic cylinder **19** is coupled between the front frame **14** and the linkage assembly **15** to urge the row unit **11** downwardly with a controllable force that can be adjusted for different soil conditions. The hydraulic cylinder **19** may also be used to lift the row unit off the ground for transport by a heavier, stronger, fixed-height frame that is also used to transport large quantities of fertilizer for application via multiple row units.
(96) The hydraulic cylinder **19** is shown in more detail in FIGS. **5** and **6**. Pressurized hydraulic fluid from the tractor is supplied by a hose **20** to a port **21** that leads into a matching port **22** of a housing **23** that forms a cavity **24** of a hydraulic cylinder containing a ram **25**. The housing **23** also forms a side port **26***a* that leads into cavity **26***b* that contains a gas-charged hydraulic accumulator **27**. The lower end of the cavity **24** is formed by the top end surface of the ram **25**, so that the hydraulic pressure exerted by the hydraulic fluid on the end surface of the ram **25** urges the ram downwardly (as viewed in FIG. **6**), with a force determined by the pressure of the hydraulic fluid and the area of the exposed end surface of the ram **25**. The hydraulic fluid thus urges the ram **25** in an advancing direction (see FIG. **4**).
(97) As can be seen most clearly in FIG. **9**, the hydraulic cylinder **19** and the accumulator **27** are mounted as a single unit on the front frame **14**, with the lower end of the ram **25** connected to a cross bar **30** that is joined at one end to a vertical link **31**. The upper and lower ends of the link **31** are pivotably attached to upper and lower links **15***a* and **15***b*, respectively, on one side of the four-

bar linkage **15**. The other end of the cross bar **30** is angled upwardly and pivotably attached to the upper link **15***c* on the opposite side of the four-bar linkage **15**. With this mounting arrangement, retracting movement of the ram **25** into the cavity **24** tilts the linkage assembly **15** downwardly, as depicted in FIG. **3**, thereby lowering the row unit. Conversely, advancing movement of the ram **25** tilts the linkage assembly **15** upwardly, as depicted in FIG. **4**, thereby raising the row unit.
(98) The accumulator **27** includes a diaphragm **28** that divides the interior of the accumulator into a hydraulic-fluid chamber **29***a* and a gas-filled chamber **29***b*, e.g., filled with pressurized nitrogen. FIG. **2** shows the ram **25** in a position where the diaphragm **28** is not deflected in either direction, indicating that the pressures exerted on opposite sides of the diaphragm are substantially equal. In FIG. **3**, the ram **25** has been retracted by upward movement of the row unit, and the diaphragm **28** is deflected downwardly by the hydraulic fluid forced into the accumulator **27** by the retracting movement of the ram **25**. In FIG. **4**, the ram **25** has been moved to its most advanced position, and the diaphragm **28** is deflected upwardly by the air pressure as hydraulic fluid flows from the accumulator into the cavity **24**. The use of this compact hydraulic down-force unit with an integral accumulator on each row unit provides the advantages of quick response and remote adjustability of a hydraulic down-force control system. If an obstruction requires quick movement, oil can flow quickly and freely between the force cylinder and the adjacent accumulator, without exerting force on other actuators in the system.
(99) As can be seen in FIG. **4**, advancing movement of the ram **25** is limited by engagement of stops **40**, **42** on the lower links of the four-bar linkage **15**, with the row unit frame **12**. This prevents any further advancement of the ram **25**. Advancing movement of the ram **25** expands the size of the cavity **24** (see FIG. **4**), which causes the diaphragm **28** in the accumulator **27** to deflect to the position illustrated in FIG. **4** and reduce the amount of hydraulic fluid in the accumulator **27**. When the ram **25** is in this advanced position, the row unit is in its lowermost position.
(100) In FIG. **3**, the ram **25** has been withdrawn to its most retracted position, which can occur when the row unit encounters a rock or other obstruction, for example. When the ram **25** is in this retracted position, the row unit is in its uppermost position. As can be seen in FIG. **3**, retracting movement of the ram **25** is limited by engagement of stops **40**, **42** on the lower links of the four-bar linkage **15**, with the row unit frame **12**.
(101) Retracting movement of the ram **25** reduces the volume of the cavity **24** (see FIG. **3**), which causes a portion of the fixed volume of hydraulic fluid in the cylinder **19** to flow into the chamber **29***a* of the accumulator **27**, causing the diaphragm **28** to deflect to the position illustrated in FIG. **3**. This deflection of the diaphragm **28** into the chamber **29***b* compresses the gas in that chamber. To enter the chamber **29***a*, the hydraulic fluid must flow through a port **32** in the top of the accumulator **27**, which limits the rate at which the hydraulic fluid flows into the accumulator. This controlled rate of flow of the hydraulic fluid has a damping effect on the rate at which the ram **25** retracts or advances, thereby avoiding sudden large movements of the moving parts of the row unit, including the V-opener **11**. This effect also minimizes vibration to improve accuracy of seed metering.
(102) When the external obstruction causing the row unit **10** to rise is cleared, the combined effects of the pressurized gas in the accumulator **27** on the diaphragm **28** and the pressure of the hydraulic fluid return the ram **25** to a lower position. This downward force on the V-opener **11** holds it in the soil and prevents uncontrolled bouncing of the V-opener **11** over irregular terrain. The downward force applied to the V-opener **11** can be adjusted by changing the pressure of the hydraulic fluid supplied to the cylinder **19**.
(103) As can be seen in FIGS. **5** and **6**, the single unitary housing **23** forms both the cavity **26***b* that contains the accumulator **27** and the cavity **24** of the hydraulic cylinder **19** and the fluid passageway **24** that connects the cavity **24** of the hydraulic cylinder **19** to the cavity **27** of the accumulator. By integrating the hydraulic cylinder **19** and the accumulator **27** in a single housing, there is no relative motion possible between the cylinder **19** and the accumulator **27**, with minimal

possibility for fluid passageways to act like orifices. The cylinder **19** and the accumulator **27** remain in fixed positions relative to each other regardless of the movements of the planter row unit via the linkage assembly **15**. In this way the upward motion of the ram **25** that occurs when the planter row unit rolls over an obstruction is directly converted into compression of the gas in the accumulator **27** without restriction. It also allows the accumulator **27**, which is by definition an energy storage device, to be mounted in a fully enclosed and safe housing. The accumulator **27** can be securely mounted to avoid puncture or rapid discharge (if it comes loose), or damage from hitting another part of the implement or a foreign object. The integrated cylinder and accumulator is also a convenient single package for installation and replacement and minimizes the number of hydraulic hoses and adapters (potential leakage points).
(104) FIGS. **7**, **8**A and **8**B illustrate in more detail how the illustrative hydraulic cylinder/accumulator unit is attached to the front frame **14** and the linkage assembly **15**. The top of the unitary housing **23** forms a stem **41** that projects upwardly through a hole **51** in a bracket **50** attached to the front frame **14**. The outer surface of the stem **41** is threaded to receive a nut **52** that connects the housing **23** to the bracket **50**. The hole **51** is oversized and a rubber washer is installed on the stem **41** between the nut **52** and the bracket **50** to allow a limited amount of tilting movement of the housing relative to the bracket **50**. At the base of the stem **41**, beneath the bracket **50**, the housing **23** forms a shoulder **43** that engages a conical bearing ring **53** that also engages a mating lower surface of a washer **54**. Thus, the housing **23** can be tilted relative to the axis of the hole **51**, with the shoulder **43** sliding over the lower surface of the bearing ring **53**.
(105) A similar arrangement is provided at the lower end of the ram **25**, where a stem **60** extends downwardly through a hole **61** in the cross bar **30** that is pivotably attached to the linkage assembly **15**. A nut **62** is threaded onto the stem **60** to connect the ram to the cross bar **30**. The hole **61** is oversized and a rubber washer is installed on the stem **60** between the nut **62** and the cross bar **30** to allow a limited amount of tilting movement of the ram **25** relative to the cross bar **30**. Above the cross bar **30**, a flange **63** on the ram **25** forms a curved conical surface **64** that engages a mating surface of a curved conical bearing ring **65** that also engages a mating upper surface of a washer **66**. Thus, the ram **25** can be tilted relative to the axis of the hole **61**, with the flange **63** sliding over the upper surface of the bearing ring **65**.
(106) The use of a hydraulic system permits on-the-go adjustments to be made very rapidly because the hydraulic fluid is incompressible and therefore acts more directly than an air system. In addition, hydraulic fluids typically operate at higher pressures, which allow greater changes in applied forces. The accumulator **27** allows the fluid system to flex and float with the changing terrain and soil conditions. The accumulator **27** is preferably centrally mounted so that when any single row unit moves over an obstruction, the down-pressure cylinder **19** moves to displace the hydraulic fluid along a common set of lines connecting all row units. The gas in the accumulator is compressed at the same time, allowing for isolation among the row units so that upward movement of one row unit does not cause downward movement of other row units. Although the illustrative hydraulic ram is single-acting, it is also possible to use a double-acting ram, or a single-acting ram in combination with a return spring.
(107) Another advantage of the compact hydraulic cylinder/accumulator unit is that it can be conveniently mounted to the same brackets that are provided in many row units for mounting an air bag, to control the down pressure on the row unit. For example, in FIG. **9**, the brackets **50** and **51** on which the hydraulic cylinder/accumulator is mounted are the brackets that are often connected to an air bag, and thus the same row unit can be used interchangeably with either an air bag or the hydraulic cylinder/accumulator to control the down pressure on the row unit.
(108) FIG. **10** is a schematic of a hydraulic control system for supplying pressurized hydraulic fluid to the cylinders **19** of multiple row units. A source **100** of pressurized hydraulic fluid, typically located on a tractor, supplies hydraulic fluid under pressure to a valve **101** via supply line **102** and receives returned fluid through a return line **103**. The valve **101** can be set by an electrical control

signal S**1** on line **104** to deliver hydraulic fluid to an output line **105** at a desired constant pressure. The output line **105** is connected to a manifold **106** that in turn delivers the pressurized hydraulic fluid to individual feed lines **107** connected to the ports **21** of the respective hydraulic cylinders **19** of the individual row units. With this control system, the valve **101** is turned off, preferably by a manually controlled on/off valve V, after all the cylinders **19** have been filled with pressurized hydraulic fluid, to maintain a fixed volume of fluid in each cylinder.
(109) FIG. **11** is a schematic of a modified hydraulic control system that permits individual control of the supply of hydraulic fluid to the cylinder **19** of each separate row unit via feed lines **107** connected to the ports **21** of the respective cylinders **19**, or to control valves for those cylinders. Portions of this system that are common to those of the system of FIG. **10** are identified by the same reference numbers. The difference in this system is that each separate feed line **107** leading to one of the row units is provided with a separate control valve **110** that receives its own separate control signal on a line **111** from a controller **112**. This arrangement permits the supply of pressurized hydraulic fluid to each row unit to be turned off and on at different times by the separate valve **110** for each unit, with the times being controlled by the separate control signals supplied to the valves **110** by the controller **112**. The individual valves **110** receive pressurized hydraulic fluid via the manifold **106**, and return hydraulic fluid to a sump on the tractor via separate return line **113** connected to a return manifold **114** connected back to the hydraulic system **100** of the tractor.
(110) FIG. **12** illustrates on application for the controllable hydraulic control system of FIG. **11**. Modern agricultural equipment often includes GPS systems that enable the user to know precisely where a tractor is located in real time. Thus, when a gang of planting row units **120** towed by a tractor **121** begins to cross a headland **122** in which the rows **123** are not orthogonal to the main rows **124** of a field, each planting row unit **120** can be turned off just as it enters the headland **122**, to avoid double-planting while the tractor **121** makes a turn through the headland. With the control system of FIG. **11**, the hydraulic cylinder **19** of each row unit can also be separately controlled to turn off the supply of pressurized hydraulic fluid at a different time for each row unit, so that each row unit is raised just as it enters the headland, to avoid disrupting the rows already planted in the headland.
(111) One benefit of the system of FIG. **11** is that as agricultural planters, seeders, fertilizer applicators, tillage equipment and the like become wider with more row units on each frame, often 36 30-inch rows or 54 20-inch rows on a single 90-foot wide toolbar, each row unit can float vertically independently of every other row unit. Yet the following row units still have the down force remotely adjustable from the cab of the tractor or other selected location. This permits very efficient operation of a wide planter or other agricultural machine in varying terrain without having to stop to make manual adjustment to a large number of row units, resulting in a reduction in the number of acres planted in a given time period. One of the most important factors in obtaining a maximum crop yield is timely planting. By permitting remote down force adjustment of each row unit (or group of units), including the ability to quickly release all down force on the row unit when approaching a wet spot in the field, one can significantly increase the planter productivity or acres planted per day, thereby improving yields and reducing costs of production.
(112) On wide planters or other equipment, at times 90 feet wide or more and planting at 6 mph or more forward speed, one row unit must often rise or fall quickly to clear a rock or plant into an abrupt soil depression. Any resistance to quick movement results in either gouging of the soil or an uncleared portion of the field and reduced yield. With the row unit having its own hydraulic accumulator, the hydraulic cylinder can move quickly and with a nearly constant down force. Oil displaced by or required by quick movement of the ram is quickly moved into or out of the closely mounted accumulator which is an integral part of each row unit. The accumulator diaphragm or piston supplies or accepts fluid as required at a relatively constant pressure and down force as selected manually or automatically by the hydraulic control system. By following the soil profile

closely and leaving a more uniform surface, the toolbar-frame-mounted row unit permits the planter row unit following independently behind to use less down force for its function, resulting in more uniform seed depth control and more uniform seedling emergence. More uniform seedling stands usually result in higher yields than less uniform seedling stands produced by planters with less accurate row cleaner ground following.

(113) FIGS. **13-15** illustrate modified embodiments in which the hydraulic cylinder **200** urges the closing wheels **16** downwardly with a controllable force that can be adjusted for different conditions. Referring first to FIG. **13**, pressurized hydraulic fluid from the tractor is supplied by a hose **201** to a port **202** of a housing **203** that forms a cavity of a hydraulic cylinder **204** containing a ram **205**. The housing **203** also forms a side port **206** that leads into a cavity **207** that contains a gas-charged hydraulic accumulator **208**. The lower end of the cavity **204** is formed by the top end surface of the ram **205**, so that the hydraulic pressure exerted by the hydraulic fluid on the end surface of the ram **205** urges the ram downwardly (as viewed in FIG. **13**), with a force determined by the pressure of the hydraulic fluid and the area of the exposed end surface of the ram **205**. The hydraulic fluid thus urges the ram **205** in a downward direction.

(114) The hydraulic cylinder **204** and the accumulator **208** are pivotably mounted as a single unit on the row unit frame **210**, with the lower end of the ram **205** pivotably connected to a linkage **211** that carries the closing wheels **16**. With this mounting arrangement, advancing movement of the ram **205** in the cylinder **204** tilts the linkage **211** downwardly, thereby urging the closing wheels **16** downwardly. Conversely, retracting movement of the ram **205** tilts the linkage **211** upwardly, thereby raising the closing wheels **16**.

(115) FIG. **14** illustrates an arrangement similar to FIG. **13** except that the hydraulic cylinder **204** is charged with a pressurized gas in chamber **212** on the side of the ram **205** that is not exposed to the pressurized fluid from the hose **201**. Thus, as the ram **205** is retracted by increasing the hydraulic pressure on one side of the ram, the gas on the other side of the ram is compressed and thus increases the resistance to retracting movement of the ram. The hydraulic cylinder **204** is positioned such that advancing movement of the ram **205** in the cylinder **204** tilts the linkage **211** upwardly, thereby raising the closing wheels **16**. Conversely, retracting movement of the ram **205** tilts the linkage **211** downwardly, thereby urging the closing wheels **16** downwardly with an increased force. To increase the downward pressure on the closing wheels **16**, the hydraulic pressure must overcome the gas pressure that increases as the ram **205** is retracted, but upward movement of the closing wheels (e.g., when an obstruction is encountered) requires only that the ram be advanced with sufficient pressure to overcome that of the hydraulic fluid.

(116) In FIG. **15**, the arrangement is the same as in FIG. **14**, but the hydraulic control unit has an added biasing element **220** on the side of the ram **205** that is not exposed to the pressurized hydraulic fluid. This biasing element **220** may be in addition to, or in place of, pressurized gas in the hydraulic cylinder **204**. The biasing element **220** may be formed by various types of mechanical springs, such as a compressed coil spring, or may be pressurized air, nitrogen or other gas.

(117) FIGS. **16-18** illustrate a modified hydraulic control unit that includes a hydraulic cylinder **300** containing a ram **301** that can be coupled at its lower end to a device on which the down pressure is to be controlled. Pressurized hydraulic fluid is supplied to the upper end of the cylinder **301** through a port **304**. The cylinder **300** includes a side port **302** leading to an accumulator **303** of the type described above in connection with FIGS. **5** and **6**. The entry port **305** to the accumulator **303** is equipped with a check valve **306** and restriction **307** as illustrated in FIG. **18**. When the ram **301** is in a lowered position that opens the port **302**, and is moved upwardly by an upward force applied by engagement of the controlled device with a rock or other obstruction, hydraulic fluid flows from the cylinder **300** into the accumulator **303** via the restriction **307**. The restriction acts as a damper to reduce the shock on the equipment and avoid excessive upward movement of the ram **301**. When the upward force on the ram has been removed, hydraulic fluid flows from the accumulator back into the cylinder **300** via the check valve **306**, which allows unrestricted flow in this direction so

that the controlled device quickly re-engages the ground with the down pressure exerted by the hydraulic fluid on the upper end of the ram **301**. The check valve unit can be easily installed in the accumulator entry port **305**. Additionally, the check valve unit can have an orifice system that is bidirectional for damping motion, both in and out.

(118) The term row unit refers to a unit that is attached to a towing frame in a way that permits the unit to move vertically relative to the towing frame and other units attached to that same towing frame. Most row units are equipped to form, plant and close a single seed furrow, but row units are also made to form, plant and close two or more adjacent seed furrows.

(119) Referring to FIG. **19**, a hydraulic system **400** includes a hydraulic assembly **401**, a front frame **404**, and a four-bar linkage assembly **406**. The four-bar linkage assembly **406** is generally similar to the four-bar linkage assembly **15** described above in reference to FIGS. **1-9**. The four-bar linkage assembly **406** includes a pair of parallel lower links **408***a*, **408***b*, a pair of parallel upper links **410***a*, **410***b*, and a cross bar **412**. The hydraulic assembly **401** is rigidly attached to the four-bar linkage assembly **406** on a row-unit side, and the front frame **404** is pivotably attached to the four-bar linkage assembly **406** on a towing side.

(120) The hydraulic assembly **401** includes a hydraulic cylinder **402**, an accumulator protective cover **420**, and a hose connection manifold **424**. The hydraulic cylinder **402** is generally similar to the hydraulic cylinders **19**, **204** described above in reference to FIGS. **1-9** and **13-18**, and includes an upper end **413***a* and a lower end **413***b*. The upper end is mounted to a bracket **414** of the linkage assembly **406**, and the lower end **413***b* is mounted to the cross bar **412** of the linkage assembly **406**. A gland and securing nut **418** (with internal seals) is interposed at the lower end **413***b* between the hydraulic cylinder **402** and the cross bar **412**.

(121) The accumulator protective cover **420** is mounted adjacent to and between a left upper link **410***b* and the hydraulic cylinder **402**. The accumulator protective cover **420** shields from environmental contaminants and physical damage an accumulator **422** (shown in FIG. **20**A). In addition to protecting the accumulator **422**, the accumulator protective cover **420** itself is provided with protection from physical damage, e.g., caused by debris, rocks, etc., by being located between the pair of upper links **410***a*, **410***b*. Although the upper links **410**, **410***b* do not completely shield the accumulator protective cover **420**, the upper links **410**, **410***b* provide some protection from physical damage while, simultaneously, allowing ease of access for servicing and/or replacing the accumulator **422**.

(122) The hose connection manifold **424**, which is described in more detail below in reference to FIG. **21**, is mounted adjacent to and between a right upper link **410***a* and the hydraulic cylinder **402**. The hose connection manifold **424** is configured such that it does not interfere with any of the other components of the hydraulic system **400**, including the right upper link **410***a*, the hydraulic cylinder **402**, and the accumulator protective cover **420**. The hose connection manifold **424** is coupled at a distal end to a pair of hydraulic fluid hoses, including an inlet hose **426** and an outlet hose **428**. Assuming a configuration in which a plurality of units are arranged in a parallel (or side-by-side) configuration, the inlet hose **426** receives and delivers hydraulic fluid from an adjacent row unit, and the outlet hose **428** connects to another adjacent row unit.

(123) The attachment of the hoses **426**, **428** to the hose connection manifold **424**, in a position that is spaced away from the relatively more-cluttered area of the hydraulic cylinder **402** and bracket **414**, facilitates easy field servicing of the hoses **426**, **428**. For example, a user can easily couple/uncouple the hoses **426**, **428** to/from the hose connection manifold **424** by having a clear path directly to the hose connection manifold **424**.

(124) Referring to FIGS. **20**A and **20**B, the accumulator protective cover **420** includes a right cover **420***a* and a left cover **420***b* that are fastened to each other via a plurality of small nuts **434** and bolts **436**. Enclosed within the accumulator protective cover **420** is the accumulator **422**, which has an accumulator end **430** that is inserted into a accumulator receiver **432** of the hydraulic cylinder **402**. The accumulator receiver **432** extends from a main body **433** of the hydraulic cylinder **402** a

sufficient distance to permit the mounting of the accumulator protective cover **420** without interfering with the hose connection manifold **424** (as further illustrated in FIG. **22**A).
(125) The main body **433** of the hydraulic cylinder **402** receives a spherical rod **438** for axial mounting below the accumulator receiver **432**. The gland **418** is threaded into the hydraulic cylinder **402** after the spherical rod **438** is installed on the hydraulic cylinder **402**. The gland **418** contains internal seals and wear rings to hold pressure and seal out contaminants.
(126) The hydraulic cylinder **402** further includes a mounting interface **440** extending from the main body **433** in an opposite direction relative to the accumulator receiver **432**. The hose connection manifold **424** is mounted directly to the mounting interface **440** via a plurality of long bolts **442** that are received, respectively, in a plurality of threaded holes **444**. An O-ring seal **441** is positioned between the control manifold **424** and the hydraulic cylinder **402** to prevent leakage of hydraulic fluid. The hose connection manifold **424** has a mounting face **456** (shown in FIG. **21**) that is aligned, when mounted, in contact with a receiving face **443** of the mounting interface **440**. As illustrated in the exemplary embodiment, the mounting face **456** of the hose connection manifold **424** and the receiving face **443** of the mounting interface **440** are configured such that they are complementary mating faces with the O-ring seal **441** holding pressure between the components.
(127) The mounting interface **440** further facilitates a modular exchange between hose connection manifolds of different types. In the current illustration, the hose connection manifold **424** is an example of a standard configuration in which the manifold functions solely to attach hydraulic hoses and to circulate hydraulic fluid between the hydraulic source and the hydraulic cylinder **402**. In an alternative configuration, described in more detail below in reference to FIGS. **23-25**C, the same mounting interface **440** (without reliance on additional components or tools) is used to attach a manifold of a different type. This modular exchange between different manifold types is beneficial for quick and easy replacement of the manifolds based on current planting needs, which can quickly change in real time due to weather conditions, terrain conditions, etc.
(128) A pair of hose ends **446**, **448** are attached to the hose connection manifold **424** at a distal end **450** for coupling the inlet and outlet hoses **426**, **428**. Specifically, an inlet hose-end **446** is coupled to the inlet hose **426** and an outlet hose-end **446** is coupled to the outlet hose **428**. The hose ends **446**, **448** are attached to the distal end **450** in a generally parallel configuration relative to a central axis of the hydraulic cylinder **402**. As discussed above, the attachment configuration of the hose ends **446**, **448** to the hose connection manifold **424** facilitates easy access and servicing of the inlet and outlet hoses **426**, **428**.
(129) Referring to FIG. **21**, the hose connection manifold **424** is a valve-less manifold that lacks a control valve or a control module (in contrast to the integrated control manifold **524** discussed below in reference to FIGS. **23-25**C). The hose connection manifold **424** has a mounting end **452** that is separated from the distal end **450** by a manifold arm **454**. The manifold arm **454** includes a curved section that offsets the mounting face **456** of the mounting end **452** by a distance D from an exterior surface **466** of the distal end **450**. The offset distance D is helpful in minimizing space requirements for mounting the hose connection manifold **424** within the space defined by the upper links **410**, **410***b* of the linkage assembly **406**. The manifold arm **454** is positioned generally parallel to the accumulator **422**.
(130) The mounting face **456** includes a plurality of mounting holes **458** arranged in a concentric pattern around a central hydraulic hole **459**, through which hydraulic fluid is delivered to the hydraulic cylinder **402**. The pattern of the mounting holes **458** matches a pattern of the threaded holes **444** of the mounting interface **440**. When the hose connection manifold **424** is mounted to the hydraulic cylinder **402**, the long bolts **442** are received through the mounting holes **458**.
(131) The hydraulic hole **459** is internally connected to an inlet port **460** and an outlet port **462** via an internal channel **464** (illustrated in FIG. **22**A). The inlet port **460** is adapted to receive the inlet hose-end **446**, to which the inlet hose **426** is coupled, and the outlet port **462** is adapted to receive

the outlet hose-end **446**, to which the outlet hose **428** is coupled. The inlet and outlet ports **460**, **462** are aligned with a central axis of the internal channel **464** and are oriented perpendicular to the orientation of the hydraulic hole **459**. Additionally, the spacing between the inlet port **460** and the outlet port **462** facilitates parallel coupling of the two hose ends **446**, **448** adjacent to each other.

(132) Referring to FIGS. **22**A and **22**B, the configuration of the hydraulic assembly **401** facilitates delivery of hydraulic fluid to the hydraulic cylinder **402** in a relatively space-constrained environment while still providing easy access to main components, including the accumulator **422** and the hose connection manifold **424**, for service and replacement. For example, referring specifically to FIG. **22**A, hydraulic fluid circulates unrestricted between the hose connection manifold **424**, the hydraulic cylinder **402**, and the accumulator **422** via the internal channel **464**. The geometric configuration of the hose connection manifold **424** facilitates mounting the accumulator protective cover **420** close to the distal end **450** of the hose connection manifold **424** at a relatively small distance Z, thus minimizing required mounting space, without causing interference between the hose connection manifold **424** and the accumulator protective cover **420**.

(133) In addition to the offset distance D, the distal end **450** is further defined by a distance X that separates two extreme points of a central axis of the internal channel **464**. Specifically, distance X is defined by a point of the central axis near the distal end **450** and a point of the central axis near the mounting end **452**. Although the offsetting of the two ends **450**, **452** does not impact the flow of hydraulic fluid, the offsetting helps increase clearance space between the hose connection manifold **424** and the linkage assembly **406**.

(134) Referring more specifically to FIG. **22**B, the inlet hose **426** and the outlet hose **428** can be easily and quickly removed, in the field, based at least on their parallel upward attachment to the hose connection manifold **424**. Optionally, the inlet hose **426** and the outlet hose **428** can be daisy chained when using a typical side-by-side arrangement of row units. For example, in one illustrative example, a first row unit is connected directly to the hydraulic source via its inlet hose and directly to the inlet port of an adjacent second row unit via its outlet hose. Thus, the second row unit receives hydraulic fluid, indirectly, from the hydraulic source via the first row unit. The second row unit, is further daisy chained to an adjacent third row unit such that the outlet hose of the second row unit is directly connected to the inlet port of the third row unit. This type of daisy-chain configuration can continue with dozens of row units. To change the configuration to a standard hose routing, one of the two ports **460**, **462** is plugged and a tee is placed in front of the row unit such that a single hose is connected to the hydraulic cylinder **402**.

(135) Referring to FIG. **23**, in an alternative configuration of the hydraulic system **400** the hose connection manifold **424** has been replaced with the integrated control manifold **524** that includes both an electronic control module **525** and a connection manifold **527** (both shown in FIGS. **24**A and **24**B). The control manifold **524** is configured to fit within the upper links **410***a*, **410***b* next to the accumulator protective cover **420**, similar to the hose connection manifold **424**. Thus, similarly to the hose connection manifold **424**, the control manifold **524** does not interfere with any components of the hydraulic system **400**. Additionally, easy access is provided for a user to couple/uncouple the inlet and outlet hoses **426**, **428** to/from the control manifold **524**. The control manifold **524** is further connected to a control signal wire **529** for receiving control signals from a central processing unit.

(136) One benefit of the control manifold **524** is that each row unit of a plurality of adjacent row units (in a side-by-side arrangement of row units) has its own pressure control valve. Assuming that the control manifold **524** is mounted in each of the plurality of row units, the down pressure in each row unit can be individually controlled. To achieve individual control, both the inlet hose **426** and the outlet hose **428** of each row unit are connected to the hydraulic source in parallel. For example, the inlet hose of a first row unit is connected to the tractor for supplying constant pressure to the first row unit, and the outlet hose of the first row unit is also connected to the tractor for returning hydraulic fluid from the first row unit. Similarly, the inlet hose of a second row unit is connected to

the tractor for supplying constant pressure to the second row unit, and the outlet hose of the second row unit is also connected to the tractor for returning hydraulic fluid from the second row unit. According to this example, the pressure in the first and second row units can be independently controlled.

(137) Referring to FIGS. **24**A-**24**B, the control manifold **524** is mounted to the hydraulic cylinder **402** using the same long bolts **442**, which are fastened to the threaded holes **444**. The control manifold **524** has a mating face **556** (shown in FIGS. **25**A-**25**C) that is generally similar (if not identical) to the mating face **456** of the hose connection manifold **424**. The mating face **556** is configured as a mating face for facilitating attachment of the control module **524** to the mounting interface **440** (similar to the attachment of the hose connection manifold **424** to the mounting interface **440**). An O-ring seal **541** is positioned between the control manifold **524** and the hydraulic cylinder **402** to prevent leakage of hydraulic fluid.

(138) The hose ends **446**, **448** are received in respective inlet and outlet ports **560**, **562** for facilitating coupling of the hoses **426**, **428** to the control module **542**. In contrast to the inlet and outlet ports **460**, **462** of the hose connection manifold **424**, the inlet and outlet ports **560**, **562** of the control manifold **524** are oriented perpendicular to (not parallel to) the central axis of the hydraulic cylinder **402**. Nevertheless, a user can still reach with relative ease the connection between hoses **426**, **428** and the ports **560**, **562** for service-related needs.

(139) The control module **525** includes a hydraulic valve cartridge **531** for reducing and/or relieving pressure in hydraulic cylinder **402**. The valve cartridge **531** is enclosed within the control module **525** and has one end inserted in a cartridge port **533** of the connection manifold **527**. In response to receiving a control signal, via the control signal wire **529** and the electrical connector **537**, the valve cartridge **531** reduces pressure in the hydraulic cylinder **402** and, optionally, acts as a relief valve relieving any shocks or surges that may occur between the hydraulic source and the hydraulic cylinder **402**. The control module **525** optionally includes a pressure transducer **535** and/or other embedded electronics.

(140) For ease of access, an integrated electronic connector **537** of the control module **525** is positioned above the valve cartridge **531** for receiving electrical power via an electrical cable (not shown). The electronic connector **537** is angled towards the accumulator protective cover **420** to provide sufficient space for connecting all the required cables and hoses to the control module **525**, e.g., the inlet and outlet hoses **426**, **428**, the control signal wire **529**, and the electrical cable.

(141) Referring to FIGS. **25**A-**25**C, the connection manifold **527** is configured to facilitate the integral combination with the control module **525**. For example, the connection manifold **527** has a mounting face **556** that is aligned, when mounted with the receiving face **443** of the mounting interface **440**. The mounting face **556** of the connection manifold **527** is generally similar (if not identical) to the mounting face **456** of the hose connection manifold **424**. For example, the mounting face **556** includes a plurality of mounting holes **558** arranged in a concentric pattern around a central hydraulic hole **559**, through which hydraulic fluid is delivered to the hydraulic cylinder **402**. The pattern of the mounting holes **558** matches a pattern of the threaded holes **444** of the mounting interface **440**. When the connection manifold **527** is mounted to the hydraulic cylinder **402**, the long bolts **442** are received through the mounting holes **558**.

(142) The hydraulic hole **559** is internally connected to the inlet port **560**, the outlet port **562**, the cartridge port **533**, and a transducer port **539**. In contrast to the hose connection manifold **424**, the connection manifold **527** includes the additional cartridge port **533** for coupling to the valve cartridge **531** (which controls output of fluid pressure from the hydraulic cylinder **402**) and the transducer port **539** for coupling to the pressure transducer **535**. The ports are positioned along a control face **541**, which is generally perpendicular to the mounting face **556**. Thus, although the connection manifold **527** and the hose connection manifold **424** share some similarities (e.g., sharing the modular mounting interface **440**), they are different in type at least based on the connection manifold **527** being configured geometrically to facilitate the integration with the

control module **525**.

(143) Referring generally to FIGS. **26-27**B, a hydraulic cylinder **619** and energy storage device **627** are generally similar to the hydraulic cylinder **19** and accumulator **27** described and illustrated above in reference to FIGS. **5** and **6**. Referring specifically to FIG. **27**A, a single unitary housing **623** forms a cavity **624** in which the hydraulic cylinder **619** and the energy storage device **627** are enclosed, at least in part. The hydraulic cylinder **619** contains a ram **625** that advances towards a housing port **622** or retracts towards a stem **660**.

(144) Referring specifically to FIG. **27**B, the ram **625** has a leading edge **650** near which a wear ring **652** is mounted. The wear ring **652** is mounted on the ram **625** concentric with a central axis Z of the ram **625** and in physical contact (or close to being in physical contact) with a cylinder wall **654**. The wear ring **652** can be a seal or some other component that can provide a barrier zone between the ram **625** and the cylinder wall **654**. The wear ring **652** can have a cylindrical cross-sectional profile (as illustrated in FIG. **27**B) or any other cross-sectional profile.

(145) The wear ring **652** guides the ram **625** within the cylinder wall **654** of the hydraulic cylinder **619**, absorbing transverse forces. The wear ring **652** further prevents (or reduces) metal-to-metal contact between the ram **625** and the cylinder wall **654** and, thus, optimizes the performance of the hydraulic cylinder **619**. As such, one benefit of the wear ring **652** is that it prevents or reduces wear of the ram **625** due to frictional contact with the cylinder wall **654**. Another benefit of the wear ring **652** is that it tends to act as a seal component (although not necessarily specifically intended to be a seal component). For example, especially during high-speed movement of the ram **625**, tight tolerances between the ram **625** and the cylinder wall **654** help achieve a sealing function that prevents, or greatly reduces, undesired fluid flow between the ram **625** and the cylinder wall **654**. According to one example, the tight tolerances can range between 0.01 inches and 0.03 inches.

(146) The ram **625** further includes a plurality of intersecting internal passageways, including an axial passageway **660** and a radial passageway **662**. The axial passageway **660** starts at the leading edge **650** and continues partially within the ram **624**, along the central axis Z, until it intersects with the radial passageway **662**. The radial passageway **662** extends perpendicular to the central axis Z between the central axis Z and a peripheral wall of the ram **625**.

(147) Similar to a shock absorber, the internal passageways **660**, **662** provide a dampening feature to the hydraulic cylinder **610**. Specifically, the internal passageways **660**, **662** equalize pressure on either side of the wear ring **652** (which tends to act as a seal at high-speed ram velocities). While the hydraulic cylinder **619** is intended to generate pressure, the internal passageways **660**, **662** integrate into the hydraulic cylinder **619** damping to control unwanted movement and or pressure. As such, the internal passageway **660**, **662** are helpful in preventing damage to the hydraulic cylinder **619** by controlling the damping of the hydraulic cylinder **619**. Optionally, in addition to acting as orifices for controlling damping, the internal passageways **660**, **662** can be used for mounting check valves to the ram **625**. The check valves can further control the damping in the hydraulic cylinder **619**. Accordingly, the internal passageways **660**, **662** provide a hydraulic cylinder with an integrated damping-control system.

(148) Referring to FIGS. **28**A and **28**B, a planting row unit **710** is generally similar to the planting row unit **10** described above. The planting row unit **710** includes a V-opener **711**, a row unit frame **712**, a pair of closing wheels **716**, and a gauge wheel **717** that are assembled and function similarly to the similarly numbered components of the planting row unit **10**. The planting row unit **710** also includes a hydraulic cylinder **700** that urges the closing wheels **716** downwardly with a controllable force that can be adjusted for different conditions.

(149) The hydraulic cylinder **700** includes a double-acting ram **705** (which further exemplifies the double-acting ram embodiment identified above in reference to the ram **25**) that can move in opposing directions based on fluid pressure received from either a first hose **701***a* or a second hose **701***b*. As such, hydraulic fluid is received via the hoses **701***a*, **701***b* to act alternately on both sides of the double-acting ram **705** and, consequently, apply alternate pressure in both directions of

arrows A-A′. The hydraulic cylinder **700** can, optionally, further includes a biasing element **720** (e.g., mechanical spring, compressed coil spring, pressurized gas) to further add pressure in addition to the pressure provided by the double-acting ram **705**. The biasing element **720** can be added on either side of the double-acting ram **705**.

(150) One benefit of the double-acting ram **705** is that it can provide both down pressure or up pressure, as needed, for the planting row unit **710**. For example, if additional pressure is required to cause the V-opener **711** to penetrate the soil to a required depth, down pressure would be applied. If, for example, the planting row unit **710** is too heavy and the V-opener **711** penetrates the soil in excess of the required depth, then up pressure would be applied (without requiring an additional hydraulic cylinder).

(151) Referring to FIG. **29**, a disk opener **800** is adapted for attachment to a row unit, such as planting row unit **10** described above in reference to FIG. **1**. The disk opener **800** includes a support **802** to which a swing arm **804** is mounted for attaching a disk **806** and a gauge wheel **808**. The disk **806** penetrates the soil to a planting depth for forming a furrow or seed slot, as the row unit is advanced by a tractor or other towing vehicle. The gauge wheel **808** determines the planting depth for seeds and/or height of introduction of fertilizer.

(152) The disk opener **800** further includes a down-pressure cylinder **810**, with an integrated control valve **812**, that is mounted to a bracket **814**. The down-pressure cylinder **810** is generally similar to the hydraulic cylinder **402** (e.g., illustrated in FIG. **19**) and the integrated control valve **812** is generally similar to the control module **525** (e.g., illustrated in FIG. **24**A). The control valve **812** includes a solenoid **816** that is generally similar to the electronic connector **537** (e.g., illustrated in FIG. **24**A).

(153) In addition, the disk opener **800** includes a programmable-logic controller (PLC) or other computer control unit **818** that is also mounted to the bracket **814**. Optionally, the control unit **818** is directly integrated into the control valve **812**, e.g., into the solenoid **816**. According to this optional embodiment, the control unit **818** would be generally similar to the embedded electronics integrated with and described above in reference to the control module **525**. The control unit **818** is coupled to a power supply via a control wire **820** and to the control valve **812** via a valve wire **822**. The control wire **820** optionally functions to connect the control unit **818** with a control interface such as found in a tractor.

(154) An advantage of mounting the control unit **818** to the row unit, via the disk opener **800**, is that it provides better, and specific, control over the control valve **812**. As such, for example, each row unit in an arrangement having a plurality of side-by-side row units (such as illustrated below in FIG. **30**) can be individually controlled to apply a desired down pressure specific to the corresponding row unit. Thus, the control unit **818** runs a control algorithm that takes inputs and determines an output signal for the control valve **812**.

(155) Referring to FIG. **30**, a hydraulic control system supplies pressurized hydraulic fluid to cylinders of multiple row units. A source **900** of pressurized hydraulic fluid, typically located on a tractor, supplies hydraulic fluid under pressure to an optional main valve **901** via a supply line **902** and receives returned fluid through a return line **903**. The main valve **901** can be set by an electrical control signal S**1** on line **904** to deliver hydraulic fluid to an output line **905** at a desired constant pressure. The output line **905** is connected to a manifold **906** that, in turn, delivers the pressurized hydraulic fluid to individual feed lines **907** (which are connected to ports of respective hydraulic cylinders of the individual row units). Optionally, the main valve **901** is turned off after all cylinders have been filled with pressurized hydraulic fluid to maintain a fixed volume of fluid in each cylinder.

(156) Each of the individual feed lines **907** leads to one of the row units and is provided with a separate control valve **910** that receives its own separate control signal on a line **911** from a respective controller **912** (which is integrated in the respective row unit as described above in reference to FIGS. **24**A and **30**). The separate control valve **910** is provided in addition to or instead

of the valve **901**. This arrangement permits the supply of pressurized hydraulic fluid to each row unit to be turned off and on at different times by the separate control valve **910** for each row unit, with the times being controlled by the separate control signals supplied to the valves **910** by the respective controllers **912**. The individual valves **910** receive pressurized hydraulic fluid via the manifold **906**, and return hydraulic fluid to the tractor via separate return lines **913** connected to a return manifold **914**, which is connected back to the hydraulic system **900** of the tractor. Optionally, one or more of the individual integrated controllers **912** are connected to a main controller **915** that provides control input for at least one of the integrated controllers **912**.

(157) Referring to FIG. **31**, an alternative configuration is illustrated in reference to the hydraulic control system described above in FIG. **30**. The alternative configuration includes a tractor **950** that generates hydraulic auxiliary power bifurcated into two power subsets: a tractor hydraulic system (THS) **952** and a tractor power take-off (PTO) **954**. The tractor hydraulic system **952** is coupled to a hydraulically-driven electrical generator **956** for generating electricity for row unit components such as the control valves **910** and/or other control modules (e.g., controllers **912**, **915**). The tractor PTO **954** is mechanical power that runs a hydraulic pump **958** to provide mechanical power for row unit components such as hydraulic cylinders connected to the individual feed lines **907**.

(158) Providing both the hydraulic system **952** and the tractor PTO **954** helps provide additional electrical power for electrical components that previously were not included in an agricultural system. For example, adding controllers **912**, **915** and control valves **910** to each row unit results in an increased need of electrical power relative to agricultural systems that, for example, lacked individual row-unit control. The electrical generator **956** compensates for and provides the required increased electricity.

(159) Referring to FIGS. **32** and **33**, a hydraulic cylinder system includes two hydraulic cylinders **1019***a*, **1019***b*, instead of a single actuator as described above in reference to the hydraulic cylinder **19** (which is illustrated, for example, in FIG. **9**). Each of the hydraulic cylinders **1019***a*, **1019***b* is generally similar to the hydraulic cylinder **19**. However, instead of coupling the single hydraulic cylinder **19** between a front frame and a linkage assembly, this alternative embodiment illustrates coupling the two hydraulic cylinders **1019***a*, **1019***b* between a front frame **1014** and a linkage assembly **1015**.

(160) The hydraulic cylinders **1019***a*, **1019***b* are both mounted at one end to a cross bar **1030**, which has been modified in this illustrative embodiment and relative to the cross bar **30** of FIG. **9** to have generally a Z-shape. Specifically, a first hydraulic cylinder **1019***a* is mounted such that it can apply down pressure D to the row unit and a second hydraulic cylinder **1019***b* is mounted such that it can apply up pressure U to the row unit.

(161) One advantage of having two cylinders **1019***a*, **1019***b* is that the row unit can be controlled both up and down with more precision. For example, the controlled row unit may have a heavy weight that results in a furrow depth exceeding the desired planting depth. To counter the weight, the second hydraulic cylinder **1019***b* is used to raise the row unit such that the shallower depth is achieved. As such, the second hydraulic cylinder **1019***b* acts to subtract (or counter) at least some of the row-unit weight. If the row unit has a light weight that results in a shallower depth than desired, the first hydraulic cylinder **1019***a* is used to lower the row unit such that the deeper depth is achieved. As such, the first hydraulic cylinder **1019***a* acts to artificially add weight to the row unit.

(162) Referring to FIG. **34**, a hydraulic cylinder **1119** includes two storage energy devices, which are illustrated in the form of a first accumulator **1127***a* and a second accumulator **1127***b*. Each of the two accumulators **1127***a*, **1127***b* is generally similar to the accumulator **27** (illustrated, for example, in FIG. **6**). The hydraulic cylinder **1119** includes a ram **1125** that acts similar to the double-acting ram **705** illustrated in FIGS. **28**A and **28**B. The ram **1125** can provide both down pressure and up pressure, as needed, for a planting row unit (e.g., planting row unit **710**). The accumulators **1127***a*, **1127***b* act as shock absorbers to help relieve pressure based on the direction of

the applied pressure by the double-acting ram **1125**. For example, the first accumulator **1127***a* relieves pressure when the double-acting ram **1125** applies pressure in a first direction D**1** (e.g., down pressure), and the second accumulator **1127***b* relieves pressure when the double-acting ram **1125** applies pressure in a second direction D**2** (e.g., up pressure).

(163) The use of this hydraulic cylinder **1119**, as a compact hydraulic down-force unit with integral accumulators **1127***a*, **1127***b* on each row unit, provides the advantages of quick response and remote adjustability of a hydraulic down-force and up-force control system. If an obstruction requires quick movement, oil can flow quickly and freely between the force cylinder **1119** and the respective adjacent accumulator **1127***a*, **1127***b*, without exerting force on other actuators in the system.

(164) Referring to FIG. **35**, a controllable hydraulic control system **1200** includes a plurality of row units **1202** that are towed by a vehicle **1204** through a field. Each of the row units **1202** includes a status indicator **1206** for signaling performance-related issues. According to one example, the status indicators **1206** are light-emitting diodes (LED) that provide an easily discernable way to visually inspect the performance of the row units **1202**. For example, the LED status indicators **1206** can flash a red color R to indicate improper tilling or a malfunction. If everything performs as intended, the status indicators **1206** can flash a green color G.

(165) The status indicator **1206** can be a single (larger) LED or a plurality of LEDs of various sizes. Alternatively, the status indicator **1206** can include in addition to or instead of the LED an audible indicator to signal a malfunction or other condition of the system **1200**.

(166) Optionally, the status indicators **1206** can be integrated with control electronics of the row units **1202** (e.g., control module **525** illustrated in FIG. **23**) and can provide a status-check of the electronics. Thus, the status indicators **1206** are attached to each individual row unit **1202** to provide a person that is far away from the row units **1202** a quick visual check on the performance status of the system **1200**, including the performance status of an electronic controller.

(167) In another example, the status indicators **1206** are particularly helpful in a system **1200** that is a human-less farming system. The human-less farming system is a system in which robotic machines are moving about in the field to perform tilling, planting, and/or other agricultural functions. Such a system is monitored by a farm manager that is standing, for example, a quarter-mile away from the system. The status indicators **1206** provide the farm manager with quick and easy visual signals that indicate the performance of the system.

(168) Optionally, the system **1200** further emits a wireless signal **1208** for communicating status performance to an online monitoring system. The performance of the system **1200** can be, then, evaluated using an electronic device such as a smartphone.

(169) Referring to FIG. **36**, an agricultural system **2100** includes a soil-hardness sensing device **2102** attached in front of an agricultural row unit **2104** (also referred to as a planting row unit) via a towing frame **2106**. The towing frame **2106** is generally a common elongated hollow frame that is typically hitched to a tractor by a draw bar. The towing frame **2106** is rigidly attached to a front frame **2108** of a four-bar linkage assembly **2110** that is part of the row unit **2104**. The four-bar (sometimes referred to as "parallel-bar") linkage assembly **2110** is a conventional and well known linkage used in agricultural implements to permit the raising and lowering of tools attached thereto.

(170) As the planting row unit **2104** is advanced by the tractor, a pair of cooperating toothed clearing wheels **2122** clear residue from the soil and then other portions of the row unit, such as a V-opener disk **2112**, part the cleared soil to form a seed slot, deposit seed in the seed slot and fertilizer adjacent to the seed slot, and close the seed slot by distributing loosened soil into the seed slot with a pair of closing wheels **2114**. According to one example, the closing wheels **2114** are CUVERTINE™ closing wheels sold by the assignee of the present application. The CUVERTINE™ closing wheel is an efficient toothed wheel in-between a spading wheel and a rubber wheel.

(171) A gauge wheel **2116** of the planting row unit **2104** determines the planting depth for the seed

and the height of introduction of fertilizer, etc. One or more bins **2118** on the planting row unit **2104** carry the chemicals and seed that are directed into the soil.
(172) The planting row unit **2104** is urged downwardly against the soil by its own weight. To increase this downward force, or to be able to adjust the force, a hydraulic or pneumatic actuator **2120** (and/or one or more springs) is added between the front frame **2108** and the four-bar linkage assembly **2110** to urge the planting row unit **2104** downwardly with a controllable force. Such a hydraulic actuator **2120** may also be used to lift the row unit off the ground for transport by a heavier, stronger, fixed-height frame that is also used to transport large quantities of fertilizer for application via multiple residue-clearing and tillage row units. According to one example, the hydraulic actuator **2120** is an RFX™ system sold by the assignee of the present application. The RFX™ system includes a down-pressure actuator that is a compact, fast action actuator, and that is remotely controlled. The RFX™ system includes a nitrogen pressure-vessel that is integrated with the down-pressure actuator. According to other examples, the hydraulic or pneumatic actuator **2120** may be controlled to adjust the downward force for different soil conditions such as is described in U.S. Pat. Nos. 5,709,271, 5,685,245 and 5,479,992.
(173) The planting row unit **2104** further includes a row-clearing unit **2122** having a pair of rigid arms **2124** adapted to be rigidly connected to the towing frame **2106**. According to one example, the row-clearing unit **2122** is a GFX™ system (i.e., ground effects row cleaner), which is sold by the assignee of the present application, that is a hydraulically-controlled row cleaner. The GFX™ system is a hydraulically-controlled row cleaner with spring upward pressure and hydraulic down pressure. Furthermore, the GFX™ system is remotely adjusted.
(174) At the bottom of the row-clearing unit **2122**, the pair of cooperating toothed clearing wheels **2126** are positioned in front of the V-opener **2112** of the planting row unit **2104**. The clearing wheels **2126** are arranged for rotation about transverse axes and are driven by engagement with the underlying soil as the wheels are advanced over the soil. The illustrative clearing wheels **2126** are a type currently sold by the assignee of the present invention under the trademark TRASHWHEEL™. The clearing wheels **2126** cooperate to produce a scissors action that breaks up compacted soil and simultaneously clears residue out of the path of planting. The clearing wheels **2126** kick residue off to opposite sides, thus clearing a row for planting. To this end, the lower edges are tilted outwardly to assist in clearing the row to be planted. This arrangement is particularly well suited for strip tilling, where the strip cleared for planting is typically only about 10 inches of the 30-inch center-to-center spacing between planting rows.
(175) The soil-hardness sensing device **2102** has a first linkage **2130** with an attached blade **2132** and a second linkage **2134** with an attached gauge wheel **2136**. According to one example, the linkages are medium FREEFARM™ linkages sold by the assignee of the present application. The FREEFARM™ linkages are generally modular sets of parallel linkages used for different purposes. Also, according to one example, the soil-hardness sensing device **2102** is a FORESIGHT AND CFX™ ground hardness sensor that is sold by the assignee of the present application.
(176) The two linkages **2130**, **2134** are parallel to each other and each has a down hydraulic pressure that is controlled independently. Under constant hydraulic pressure, when the soil-hardness sensing device **2102** is moved through the field, the blade **2132** penetrates the soil deeper in soft soil and shallower in hard soil. However, the wheel **2136** rides on the soil surface regardless of the type of soil.
(177) Each linkage **2130**, **2134** has a high quality all-stainless steel linear position sensor **2138**, **2140** enclosed in a protecting housing, with a cable **2142**, **2144** routed to a central processing unit (CPU) **2146**, which includes a memory device for storing instructions and at least one processor for executing the instructions. When the blade **2132** or the wheel **2136** moves, a corresponding change in position is detected by the respective position sensors **2138**, **2140**. The two values from the position sensors **2138**, **2140** are outputted as fast as approximately 1,000 times/second and are fed as soil-hardness signals to the CPU **2146**, which is a rugged outdoor-rated programmable logic

controller that measures the difference in the two values in real time.
(178) In the illustrated example, the CPU **2146** is positioned on the planting row unit **2104**. However, in other embodiments the CPU **2146** may be positioned remote from the planting row unit **2104**, e.g., in a tractor cabin, on a different planting row unit of a side-by-side row unit arrangement, etc. Furthermore the processor and the memory device of the CPU **2146** can be located in the same place, e.g., on the planting row unit **2104**, or in different places, e.g., the processor can be located on the planting row unit **2104** and the memory device can be located in the tractor cabin.
(179) The CPU **2146** averages the values over a predetermined time period (e.g., 0.25 seconds), executes an algorithm with filtering effects (e.g., removes conditions in which a rock is hit by the soil-hardness sensing device **2102**), and provides real-time measurement of the soil hardness. The CPU **2146** optionally receives other user-controllable variables for adjusting/tuning the agricultural system **2100**. For example, the user-controllable variables may include values for different residue levels, different initial conditions, etc.
(180) Referring to FIG. **37**, the agricultural system **2100** receives hydraulic fluid from a hydraulic source, typically located in the tractor, at a hydraulic input pressure P**0**. The hydraulic fluid is directed to each one of a plurality of hydraulic control valves V**1**-V**3**. The CPU **2146** outputs respective signals S**1**-S**3** to the respective control valves V**1**-V**3**, which create a proportional output/change in the pressure of hydraulic circuits, virtually instantaneously changing the pressure in real time as the agricultural system **2100** moves through a field. The pressure changes are useful, for example, when the agricultural system **2100** encounters hardened soil areas in which combines or grain carts have previously compacted the soil. The agricultural system **2100** optimizes the pressure to achieve a desired depth control by applying the right amount of pressure at the right time.
(181) To achieve the right amount of pressure for each controllable component (e.g., the row-unit actuator **2120**, the row-clearing-unit actuator **2122**, and the soil-hardness sensing device **2102**), the CPU **2146** outputs the respective signals S**1**-S**3** to the associated control valves V**1**-V**3**. For example, in response to receiving a first signal S**1** from the CPU **2146**, a first control valve V**1** outputs a proportional first pressure P**1** to the hydraulic actuator **2120** (e.g., RFX™ system) for urging the planting row unit **2104** downwardly. Similarly, in response to receiving a second signal S**2** from the CPU **2146**, a second control valve V**2** outputs a proportional second pressure P**2** to the row-clearing unit **2122** (e.g., GFX™ system). The RFX™ system **2120** and the GFX™ system **2122** are controlled independently because residue typically exhibits non-linear behavior. In other words, the independent control of the two systems **2120**, **2122** is likely to achieve better depth-control results.
(182) A third control valve V**3** receives a third signal S**3** from the CPU **2145**, in response to which the third control valve outputs a proportional third pressure P**3** to the soil-hardness sensing device **2102** (e.g., FORESIGHT AND CFX™ system). The control valves V**1**-V**3** return hydraulic fluid to the hydraulic source at a return pressure PR. Respective transducers for each of the control valves V**1**-V**3** may be used to verify that hydraulic output pressures match the desired values. If a hydraulic output pressure does not match the desired value, the hydraulic output pressure is corrected. Furthermore, each of the control valves V**1**-V**3** has a respective valve response time T**1**-T**3**, as discussed in more detail below in reference to determining the timing of applying the appropriate pressures P**1**-P**3**.
(183) The CPU **2146** further receives an input speed signal SQ indicative of a speed Q of the agricultural system **2100**, which moves typically at about 6 miles per hour, i.e., about 8.8 feet per second. As discussed in more detail below, the speed signal SQ is used to determine the desired values of pressures P**1**-P**3** based on current soil conditions. Furthermore, as discussed in more detail below, the CPU **2146** further outputs two signals, a sensor signal SCFX to the soil-hardness sensing device **2102** and a closing wheel signal SCW to the closing wheel **2114**.

(184) The soil-hardness sensing device **2102** is positioned in front of the planting row unit **2104** at a distance D (which is measured generally from a center line of the blade **2132** to a center line of the V-opener **2112**), which can be obtained based on the following formula:

Q(speed)=D(distance)/T(time interval) Equation 1

Thus, the distance D is calculated as follows:

$D=Q*T$ Equation 2

(185) If D is a known distance (e.g., the distance between the sensed position and position where seed-depositing position) and the speed Q is also known, changes in soil conditions can be anticipated in real time prior to the time when each individual tool on the planter row unit **2104** arrives at any particular soil-change area. For example, assuming that Q is approximately 8.8 feet per second and T is approximately 0.25 seconds, D should be approximately equal to or greater than 2.2 feet. In other words, the minimum distance for D should be approximately 2.2 feet. If D is greater than the minimum value (e.g., D is greater than 2.2 feet), the agricultural system **2100** is calibrated to account for the additional distance. For example, the CPU **2146** will send the respective signals S**1**, S**2** to the associated control valves V**1**, V**2** only after a predetermined period of time Tact, as discussed in more detail below.

(186) Pressures P**1** and P**2** are continually matched with the corresponding soil conditions. For example, P**1** and P**2** are increased exactly at the time when harder soil conditions are encountered directly below the clearing wheels **2126**. To properly time the change in pressures P**1** and P**2** correctly, a time variable R refers to the latent processing speed of CPU **2146** and accounts for the time between (a) receiving an input signal by the CPU **2146**, (b) sending output signals S**1**, S**2** by the CPU **2146**, and (c) responding to the output signals S**2**, S**2** by the control valves V**1**, V**2** with respective outputting pressures P**1**, P**2**.

(187) It is noted that each of the control valves V**1**, V**2** has a minimum input time Tmin, and that the distance D (e.g., as measured between the center of the blade **2232** and the center of the V-opener **2212**) is directly proportional to the speed Q multiplied by the minimum input time Tmin of the respective control valve V**1**, V**2**. It is further noted that a theoretical time Ttheor is directly proportional to the distance D divided by the speed Q (i.e., D/Q), and that an actual time Tact is directly proportional to the theoretical time Ttheor minus the time variable R (i.e., Ttheor−R). Based on these conditions, for outputting pressures P**1** and P**2**, the CPU **146** holds in memory output signals S**1** and S**2** for a time duration that is equal to the actual time Tact. After the actual time Tact has elapsed, the CPU **146** outputs signals S**1** and S**2**, respectively, to the control valves V**1**, V**2**, which respond by outputting pressures P**1**, P**2**. Optionally, signals S**1** and S**2** are outputted as signals ranging between 0-10 volts.

(188) Referring to FIG. **38**, a global positioning system (GPS) provides a GPS signal indicative of the speed Q to the tractor. Optionally, for example, the speed Q can be generated from a radar system. The speed Q is inputted to the CPU **2146**, along with the soil-hardness signals received from the position sensors **2138**, **2140**. Based on the speed Q and the soil-hardness signals, the CPU **2146** outputs signals S**1** and S**2** to the control valves V**1**, V**2**, which output proportional pressures P**1** and P**2** for adjusting, respectively, the RFX™ system **2120** and the GFX™ system **2122**.

(189) Referring to FIGS. **39**A-**39**C, the agricultural system **2100** encounters various types of soil-hardness conditions, which, for ease of understanding, will include soft soil conditions and hard soil conditions. The soft soil conditions exemplify typical soil conditions, and the hard soil conditions exemplify compacted soil areas, e.g., areas compacted by tire tracks of tractors or combines.

(190) Referring specifically to FIG. **39**A, the agricultural system **2100** is moving forward at a speed Q over an initial soil area having only soft soil conditions. Based on the soft soil, the blade **2132** penetrates the soil at a distance X**1** lower than the wheel **2136** (which rides on the soil surface). The distance X**1** is the difference between the position sensors **2138**, **2140**. In accordance with the distance X**1**, which is associated with soft soil conditions, corresponding pressures P**1** and P**2** are

applied to the hydraulic actuator **2120** and the row-clearing unit **2122**.
(191) Referring specifically to FIG. **39**B, the blade **2132** and the wheel **2136** (but not the planting row unit **2104**) are now moving over a soil area of hard soil conditions. Because the soil is now much harder than the previous soil area, the blade **2132** cannot penetrate the soil as much as in the previous soil area. As such, the blade **2132** rises higher relative to the soil surface and penetrates the soil only at a distance X**2** lower than the wheel **2136** (which continues to ride on the soil surface). The distance X**2** is the distance determined by the CPU **2146** based on the corresponding change in values outputted by the position sensors **2138**, **2140**. However, although the distance X**2** (which is associated with hard soil conditions) is different from the previous distance X**1** (which is associated with soft soil conditions), the corresponding pressures P**1** and P**2** are not changed, yet, because the planting row unit **2104** has not reached the hard-soil area.
(192) Referring specifically to FIG. **39**C, the planting row unit **2104** is now moving over the hard-soil area, which the blade **2132** and the wheel **136** have already passed. At this point in time, and only at this point in time, the pressures P**1** and P**2** are increased to maintain the desired depth level. Thus, although the soil-hardness sensing device **2102** has reached, again, soft soil conditions that allow the blade **2132** to penetrate the soil at the previous distance X**1**, the pressures P**1** and P**2** are adjusted in accordance with the hard soil conditions.
(193) Referring to FIG. **40**A, another exemplary soil-hardness sensing device **2202** is attached to a towing frame **2206** which in turn is attached to a planting row unit **2204** having a V-opener disk **2212**, a pair of closing wheels **2214**, and a row-unit gauge wheel **2216**. The planting row unit **2204** further includes a hydraulic actuator **2220** that responds to a pressure P**1** and a row-clearing-unit actuator **2222** that responds to a pressure P**2**. The soil-hardness device **2202** and the planting row unit **2204** are generally similar to the soil-hardness device **2102** and the planting row unit **2104** described above in reference to FIGS. **1**-**4**C, except for any changes described below.
(194) In this embodiment the soil-hardness device **2202** can be a device that is already included in the planting row unit **2204**, such as a cutting coulter running directly in-line with the planter row unit or a fertilizer opener positioned off to a side of the planted area. Thus, assuming a side-by-side arrangement of row units, the soil-hardness device can include a fertilizer opener or a no-till cutting coulter in front of every row unit.
(195) The soil-hardness device **2202** includes a blade **2232** and a soil-hardness gauge wheel **2236**. The blade **2232** is attached to a blade arm **2260**, and the soil-hardness gauge wheel **2236** is attached to a wheel arm **2262**. The wheel arm **2262** is biased down by a spring **2264** and pivots relative to the blade arm **2260**. An angular encoder **2266** measures changes in an angle θ between the blade arm **2260** and the wheel arm **2262**. The angle θ is directly proportional to the depth of the blade **2232** relative to the soil-hardness gauge wheel **2236**.
(196) The angle θ, represented by a signal S**4**, is sent to a CPU **2246** which executes an algorithm to determine corresponding pressure values for the planting row unit **2204**. A minimum angle θmin is equal to angle θ when both the blade **2232** and the soil-hardness gauge wheel **2236** are on the soil surface, e.g., when passing over very hard soil conditions or a concrete floor. A depth variable Z indicates a desired blade depth, i.e., blade **2232** penetration into the soil. The angle θ is directly proportional to the depth variable Z, which has a range between an actual (or current) depth value Zact and a theoretical depth value Ztheor.
(197) By way of comparison, in the soil-hardness device **2202** of the current embodiment a controllable pressure P**3**, which is applied to the soil-hardness device **2202**, is varied, but the angle θ between the blade **2232** and the soil-hardness gauge wheel **2236** is maintained generally constant, with the blade **2232** penetrating the soil at a desired blade depth Z. In contrast, in the soil-hardness device **2102** described above in reference to FIGS. **39**A-**39**C the difference between the blade **2132** and the wheel **2136** is varied (e.g., distances X**1** and X**2**), but the pressure applied to the soil-hardness device **2102** is maintained generally constant.
(198) According to one aspect of the algorithm illustrated in FIG. **40**B, the angle θ is measured

(**2270**A) and the actual depth value Zact is calculated (**2270**B). Based on the actual depth value Zact and an inputted theoretical depth value Ztheor (**2270**C), a determination is made whether the actual depth value Zact is equal to the theoretical depth value Ztheor (**2270**D):

If Zact=Ztheor=>end Equation 3

If the actual depth value Zact is equal to the theoretical depth value Ztheor (i.e., Zact=Ztheor), the algorithm ends (until the next value is received) (**2270**H). Optionally, if angle θ is less than minimum angle θmin (i.e., θ<θmin), algorithm ignores changes because those values typically illustrate that the soil-hardness sensing device **2202** has hit a rock.

(199) If the actual value of the depth variable Z is greater than the theoretical value of the depth variable Z (i.e., Zact>Ztheor) (**2270**E), the controllable pressure P**3** that is being applied to the soil-hardness device **2202** is decreased until the actual value of the depth variable Z is equal to the theoretical value of the depth variable Z (i.e., Zact=Ztheor) (**2270**F):

If Zact>Ztheor=>decrease P3 until Zact=Ztheor Equation 4

If the actual value of the depth variable Z is smaller than the theoretical value of the depth variable Z (i.e., Zact<Ztheor), then the controllable pressure P**3** is increased until the actual value of the depth variable Z is equal to the theoretical value of the depth variable Z (i.e., Zact=Ztheor) (**2270**G):

If Zact<Ztheor=>increase P3 until Zact=Ztheor Equation 5

(200) Thus, according to this algorithm, the desired depth Z of the blade **2232** is maintained constant by varying the pressure P**3** in response to detected changes in the angle θ. To vary the pressure P**3**, a user-defined variable M (similar to the user-defined variables K and J described below) is increased or decreased to modify an actual value P**3**act of the pressure P**3** until the desired depth variable Z is achieved. As such, assuming that a theoretical value P**3**theor of the pressure P**3** is being applied to the blade **2232** when the desired depth Ztheor is achieved, and further assuming that P**3**theor is directly proportional to M*P**3**act, M is modified until M*P**3**act is equal to P**3**theor (and, consequently, the desired depth variable Z is achieved). For example, if the depth variable Z is too small, i.e., the blade **2232** is running too shallow into the soil (e.g., the blade **2232** is moving through a heavily compacted soil area), as detected by a change in the angle θ, M is increased until the actual pressure value P**3**act is equal to the theoretical value P**3**theor. Once the theoretical value P**3**theor is reached, the increased pressure forces the blade **2232** into the soil at the desired depth. Furthermore changes to the pressure P**1** and the pressure P**2** can be effected based on M*P**3**act being directly proportional to P**1** and P**2**.

(201) According to another aspect of the algorithm, illustrated in FIG. **40**C, if feedback is desired from the row-unit gauge wheel **2216**, to verify that the system is performing as desired (e.g., to verify that the appropriate pressure values are being applied to the planting row unit **2204**), a weight variable W is set in accordance with a desired weight. In this example, the pressure P**1** applied to the hydraulic actuator **2220** of the planting row unit **2204** is directly proportional to a user-defined variable K multiplied by the pressure P**3** applied to the soil-hardness device **2202** (i.e., P**1** is directly proportional to K*P**3**).

(202) A signal S**5** (illustrated in FIG. **40**A), which is directly proportional to the weight variable W, is outputted by a gauge wheel load sensor **2280** (illustrated in FIG. **5**A) and averaged over a time period Tgauge. After measuring the actual weight value Wact (**272**A) and receiving the theoretical weight value Wtheor (**2272**B), a determination is made whether the actual weight value Wact is equal to the theoretical weight value Wtheor (**2272**C):

If Wact=Wtheor=>end (Equation 6)

If the actual weight value Wact is equal to the theoretical weight value Wtheor (i.e., Wact=Wtheor), the algorithm ends (**2272**G) until the next measurement.

(203) If the actual weight value Wact is greater than the theoretical weight value Wtheor (i.e., Wact>Wtheor), then the user-defined variable K is decreased (**2272**E) until the actual weight value Wact is equal to the theoretical weight value Wtheor:

If *W*act>*W*theor=>decrease *K* (Equation 7)
(204) If the actual weight value Wact is less than the theoretical weight value Wtheor (i.e., Wact<Wtheor), then the user-defined variable K is increased (**2272**F) until the actual weight value Wact is equal to the theoretical weight value Wtheor:
If *W*act<*W*theor=>increase *K* (Equation 8)
The user-defined variable K can be set manually by a user or automatically via a load pin **2282**.
(205) Similarly, referring to FIG. **40**D, the pressure P**2** applied to the row-cleaner unit **2222** can be adjusted by adjusting a user-defined variable J. Specifically, in this example, the pressure P**2** is directly proportional to the user-defined variable J multiplied by the pressure P**3** (i.e. P**2** is directly proportional to J*P**3**). After measuring the actual weight value Wact (**2274**A) and receiving the theoretical weight value Wtheor (**2274**B), a determination is made whether the actual weight value Wact is equal to the theoretical weight value Wtheor (**2274**C):
If *W*act=*W*theor=>end (Equation 9)
If the actual weight value Wact is equal to the theoretical weight value Wtheor (i.e., Wact=Wtheor), the algorithm ends (**2274**G) until the next measurement.
(206) If the actual weight value Wact is greater than the theoretical weight value Wtheor (i.e., Wact>Wtheor), then the user-defined variable J is decreased (**274**E) until the actual weight value Wact is equal to the theoretical weight value Wtheor:
If *W*act>*W*theor=>decrease *J* (Equation 10)
(207) If the actual weight value Wact is less than the theoretical weight value Wtheor (i.e., Wact<Wtheor), then the user-defined variable J is increased (**2274**F) until the actual weight value Wact is equal to the theoretical weight value Wtheor:
If *W*act<*W*theor=>increase *J* (Equation 11)
The user-defined variable J can also be set manually by a user or automatically via the load pin **282**.
(208) Referring to FIGS. **41**A and **41**B, an agricultural system **2300** includes a tractor **2301**, two soil-hardness sensing devices **2302**A, **2302**B, a planting device **2303**, and a plurality of planting row units **2304**A-**2304**L, which are configured in a side-by-side arrangement. In this example, each of the planting row units **2304**A-**2304**L has at least one respective control Valve A-L, which is adjustable based on signals received from the soil-hardness sensing devices **2302**A, **2302**B.
(209) The tractor **2301** moves at a speed Q, pulling the soil-hardness sensing device **2302**A, **2302**B, the planting device **2303**, and the planting row units **2304**A-**2304**L along a soil area that includes five soil areas **2305**A-**2305**E. Specifically, the soil areas **2305**A-**2305**E includes a right-side outside area **2305**A, a right-side wheel area **2305**B, a central area **2305**C, a left-side wheel area **2305**D, and a left-side outside area **2305**E. The right-side wheel area **2305**B and the left-side wheel area **2305**D have soil conditions that are harder than the right-side outside area **2305**A, the central area **2305**C, and the left-side outside area **305**E. The harder soil conditions are caused by the wheels of the tractor **2301** and/or planting device **2303**, which form a compacted path as the tractor **301** moves along the soil area. Thus, each of the right-side wheel area **2305**B and the left-side wheel area **2305**D are areas compacted by the wheels of vehicles.
(210) A first soil-hardness sensing device **2302**A controls only the planting row units **2304**E, **2304**H that are positioned inside the compacted paths of the right-side wheel area **2305**B and the left-side wheel area **2305**D. A second soil-hardness sensing device **2302**B controls all the other planting row units **2304**A-**2304**D, **2304**F-**2304**G, and **2304**I-**2304**L, i.e., all the planting row units positioned outside the compact paths of the right-side wheel area **2305**B and the left-side wheel area **2305**D (and within the right-side outside area **305**B, the central area **2305**C, and the left-side outside area **2305**E). Optionally, any number of soil-hardness sensing devices and any number of planting row units can be used. For example, each of the planting row units **2304**A-**2304**L can have its own designated soil-hardness sensing device.
(211) The soil-hardness sensing devices **2302**A, **2302**B are positioned at a distance D in front of the

planting row units **2304**A-**2304**L. Optionally, each of the soil-hardness sensing devices **2302**A, **2302**B can be positioned at a different distance in front of the planting row units **2304**A-**2304**L. For example, the first soil-hardness sensing device **2302**A can be positioned at a distance X**1** in front of the planting row units **2304**A-**2304**L and the second soil-hardness sensing device **2302**B can be positioned at a distance X**2** in front of the planting row units **2304**A-**2304**L. As currently illustrated in FIGS. **41**A-**41**B, the distances X**1** and X**2** are equal to each other (being effectively distance D). Furthermore, the first soil-hardness sensing device **2302**A is positioned inside the compacted path of the left-side wheel area **2305**D and the second soil-hardness sensing device **2302**B is positioned inside the left-side outside area **2305**E (i.e., outside the compacted path of the bottom wheel area **305**D).

(212) The soil-hardness sensing devices **2302**A, **2302**B and the attached planting row units **2304**A-**2304**L are generally configured to sense soil conditions and adjust corresponding hydraulic pressures of Valves A-L as described above in reference to FIGS. **36-40**. The configuration of having multiple soil-hardness sensing devices **2302**A, **2302**B increases precision in adjustment of hydraulic pressures, based on current soil conditions, because it accounts for differences between compacted and non-compacted paths in a field that is being planted. Thus, for example, the soil-hardness sensing devices **2302**A, **2302**B provides signals to corresponding control valves for increasing and/or decreasing hydraulic pressures of the planting row units **2304**A-**2304**L.

(213) The soil-hardness sensing devices discussed above can be remotely controlled. For example, the soil-hardness sensing devices **2302**A, **2302**B can be remotely controlled with a handheld radio-frequency remote controller. By way of example, the remote controller can be used to manually increase and/or decrease the hydraulic pressures in one or more of the soil-hardness sensing devices **2302**A, **2302**B.

(214) Referring to FIG. **42**, the soil-hardness device **2202** illustrated in FIG. **40**A has been modified to include modular actuators **2220***a*-**2220***d*. Each of the modular actuators **2220***a*-**2220***d* is identical (or nearly identical) to each other as a modular unit that allows the same unit to be used for movement of different components of the soil-hardness device **2202**. According to one example, the modular actuators **2220***a*-**2220***d* include the hydraulic actuator **2220** described above and illustrated in FIG. **40**A or the hydraulic actuator **2120** described above and illustrated in FIG. **36**.

(215) Each of the modular actuators **2220***a*-**2220***d* provides controllable pressure for urging the respective components downwardly and/or upwardly, based on the mounting and type of actuator. For example, the modular actuators **2220***a*-**2220***d* can include a double-acting actuator in which the controllable pressure can be applied to urge the planting row **2104**, alternately, both upwards and downwards.

(216) A first modular actuator **2220***a* is configured and mounted to apply a controllable downward force on the entire planting row unit **2204** attached to the rear side of the towing frame **2221**. A second one of the modular actuators **2220***b* is configured and mounted to urge the blade **2232** with a controllable force. A third one of the modular actuators **2220***c* is configured and mounted to urge the row-clearing unit **2222** with a controllable force. A fourth one of the modular actuators **2220***d* is configured and mounted to urge the closing wheel **2214** with a controllable force. Thus, for each of the four independently movable components—the planting row unit **2204**, the blade **2232**, the row-clearing unit **2222**, and the closing wheel **2214**—the same modular actuator **2220***d* is configured to achieve the desired force.

(217) One exemplary benefit of having interchangeable actuators **2220***a*-**2220***d* is that a reduced number of spare parts is required for maintaining the system, thus, reducing cost. Another exemplary benefit is that a farmer or operator does not have to learn how to use and/or replace a separate and distinct type of actuator for each movable component. For example, knowing how to replace or maintain the first actuator **2220***a* means that the farmer knows how to replace or maintain each of the other three actuators **2220***b*-**2220***d*. As such, the general result of having interchangeable actuators is reduced cost and a simpler system.

(218) According to alternative embodiments, any number of modular actuators can be adapted for mounting in any agricultural systems. For example, the soil-hardness device **2202** can include two modular actuators of a first type and two modular actuators of a second type. By way of a specific example, the first and second actuators **2220***a*, **2220***b* can include a double-acting actuator for applying both upwards and downwards pressure, and the third and fourth actuators **2220***c*, **2220***d* can include a single-acting actuator for applying either upward or downward pressure. In other embodiments, the modular actuators are used in systems that lack soil-hardness sensing capabilities.
(219) Referring to FIG. **43**, an alternative modular unit **2400** includes a mounting bracket **2402** attached to an upper support **2404**. A gauge arm **2406** is pivotably attached at a proximal end **2407** to a swing arm **2408**, which is attached to the upper support **2404**. The gauge arm **2406** is attached at a distal end **2409** to a gauge wheel **2410**, and the swing arm **2408** is further attached to a blade **2432**.
(220) The modular unit **2400** includes a modular actuator **2420** that is removably attached to the upper support **2404** at a fixed end **2422** and to the swing arm **2408** at a movable piston end **2424**. The modular actuator **2420** is illustrated in this exemplary embodiment as a pressure-applying device for the blade **2432**. However, to convert the modular actuator **2420** for use with a different component (e.g., to apply pressure to the row-clearing unit **2222**), the modular actuator **2420** is removed by removing, for example, an assembly bolt **2426** and/or any other fastener holding the modular actuator **2420** in place relative to the upper support **2404** and the swing arm **2408**. Then, the same modular actuator **2420** (without the requirement for additional components) can be fastened to a different component of the soil-hardness device **2202** (e.g., the row-clearing unit **2222**). Thus, removal and/or assembly of the modular actuator **2420** is easily achieved with minimal effort and a small number of fasteners.
(221) Referring to FIGS. **44**A and **44**B, according to an alternative configuration, the blade arm **2260** has a distal end **2502** in which a ground-hardness sensor **2500** is integrated. The ground-hardness sensor **2500** is fixed relative to the blade arm **2260** in a metallic cam **2501** that includes an aperture **2504** through which a rotating shaft **2506** protrudes. The rotating shaft **2506** is coupled to the gauge wheel **2236** via the wheel arm **2262**. As the soil-hardness sensing device **2202** travels over soil of varying conditions (e.g., from hard soil to soft soil), the gauge wheel **2236** causes the shaft **2506** to rotate. In turn, the ground-hardness sensor **2500** detects the rotational movement of the shaft **2506** within the aperture **2504** and provides output indicative of an angular change between the supporting arms for the gauge wheel **2236** and the blade **2232**.
(222) The ground-hardness sensor **2500** also includes an indicator **2508** that is configured to indicate a performance condition. For example, the indicator **2508** is a light-emitting diode (LED) that displays a continuous green light when the ground-hardness sensor **2500** is functioning properly and a flashing red light when a malfunction occurs.
(223) The ground-hardness sensor **2500** is shielded from the environment with a cover **2510**, which is mounted to the distal end **2502** to enclose within the cam **2501**. The cover **2510** consists of a translucent or transparent material, such as a clear plastic material, to readily allow visual inspection of the ground-hardness sensor **2500**. Thus, one benefit of the cover **2510** is that an operator is not required to remove any parts to determine whether the ground-hardness sensor **500** is operating properly.
(224) The ground-hardness sensor **2500** is provided in addition to or instead of the encoder **266** described above in reference to FIG. **40**A. As described above, as the shaft **2506** rotates, the ground-hardness sensor **2500** measures changes in the angle θ between the blade arm **2260** and the wheel arm **2262** to determine the depth Z of the blade **2232** relative to the soil-hardness gauge wheel **2236**. Then, the angle θ is sent to the CPU **2246** for executing the algorithm to determine corresponding pressure values for the planting row unit **2204**. The angle θ is directly proportional to the depth of the blade **2232** relative to the soil-hardness gauge wheel **2236**.

(225) The ground-hardness sensor **2500** can be any analog or digital sensor that is capable of measuring an angular displacement. For example, the ground-hardness sensor **2500** can be a linear inductive distance sensor, which is an analog device.

(226) The blade arm **2260** further includes a torsion spring **2512** that engages the shaft **2506** to rotationally bias the shaft **2506** toward an equilibrium point when the shaft **2506** applies a rotational force. The torsion spring **2512** can be attached instead of or in addition to the spring **2264** illustrated in FIG. **40**A. According to the illustrated example, the torsion spring **2512** is a compressive, rubber spring with adjustable down-pressure. Specifically, in this example, the torsion spring **2512** is in the form of an external structure **2512***a* in which an internal structure **2512***b* is positioned. The external and internal structures **2512***a*, **2512***b* are generally rectangular and are concentrically aligned along a central axis. Furthermore, the internal structure **2512***b* is offset at an angle of about 90 degrees relative to the external structure **2512***a*. When the shaft **2506** rotates in a first direction (e.g., counterclockwise), the internal structure **2512***b* moves with the shaft **2506** such that corners of the internal structure **2512***b* tend to align with corners of the external structure **2512***a*. Simultaneously, the external structure **2512***a* applies a second, opposing force (e.g., clockwise) that counters the first direction and forces the internal structure **2512***b* and the shaft **2506** back towards the equilibrium point.

(227) In addition to applying an opposing force to the rotational force of the shaft **2506**, the torsion spring **2512** compresses to dampen the effects of the rotational force of the shaft **2506**. The compression provides a smoother change in movement for the blade arm **2260**, and increases the torsion spring **2512** resistance to fatigue.

(228) Another benefit of integrating the torsion spring **2512** in the blade arm **2260** is that the torsion spring is protected from environmental conditions, including dirt or mud, that can potentially interfere with the applied compressive force. Yet another benefit of the torsion spring **2512** is that it reduces the number of exposed components, which can be a hazard to human operators.

(229) FIGS. **44**C-**44**G illustrate an application of soil hardness sensing for controlling the down pressure on a pair of closing wheels **2551** journaled on a support arm **2553** having an upper end that pivots around a horizontal axis **2554**. A ground gauge wheel **2555** is journaled on a support arm **2556** having an upper end that pivots around the same horizontal axis **2554** as the support arm **2553**. The ground gauge wheel **2555** rolls along the surface of the soil with little variation in its vertical position relative to the soil surface, because of the wide and smooth surface area of the wheel **2555**. The closing wheels **2551**, on the other hand, penetrate into the soil, and thus change their vertical positions according to the hardness of the soil. The resulting pivoting movement of the support arm **2553**, relative to the more stable position of the support arm **2556**, is thus representative of the soil hardness. This relative pivoting movement of the support arm **2553** is measured by an angular measurement device **2560** coupled to the upper end of the support area **2553**.

(230) In the illustrative embodiment of FIGS. **44**C-**44**G, the angular measurement device **2560** is formed by the combination of (1) a cam **2561** attached to a stub shaft **2561***a* projecting laterally from the support arm **2553** and (2) an adjacent inductive proximity sensor **2562**. As the support arm **2553** pivots around the axis **2554**, the corresponding angular movement of the cam **2561** is detected by the sensor **2562**, which produces an electrical output signal that is proportional to the distance between the surface of the arm **2561** and the adjacent and of the sensor **2562**. That distance varies as the angular position of the cam **2561** changes with the pivoting movement of the support arm **2553**, and thus the output signal produced by the sensor **2562** is proportional to the angular position of the support arm **2853**, which in turn is generally proportional to the soil hardness. This signal can be used to regulate the down pressure exerted on the closing wheels **2551**, by the hydraulic actuator **2563**, to compensate for variations in the sensed soil hardness.

(231) FIG. **45** is a schematic diagram of a hydraulic control system for any or all of the hydraulic

actuators in the systems described above. The hydraulic cylinder **2600** is supplied with pressurized hydraulic fluid from a source **2601** via a first controllable two-position control valve **2602**, a restriction **2603** and a check valve **2604**. The pressurized hydraulic fluid supplied to the cylinder **2600** can be returned from the cylinder to a sump **2605** via a second controllable two-position control valve **2606**, a restriction **2607** and a check valve **2608**. Both the control valves **2602** and **2606** are normally closed, but can be opened by energizing respective actuators **2609** and **2610**, such as solenoids. Electrical signals for energizing the actuators **2609** and **2610** are supplied to the respective actuators via lines **2611** and **2612** from a controller **2613**, which in turn may be controlled by a central processor **2614**. The controller **2613** receives input signals from a plurality of sensors, which in the example of FIG. **45** includes a pressure transducer **2615** coupled to the hydraulic cylinder **2600** via line **2616**, and a ground hardness sensor **2617**. An accumulator **2618** is also coupled to the hydraulic cylinder **2600**, as described in detail above, and a relief valve **2619** connects the hydraulic cylinder **2600** to the sump **2605** in response to an increase in the pressure in the cylinder **2600** above a predetermined level.
(232) To reduce the energy required from the limited energy source(s) available from the tractor or other propulsion device used to transport the row units over an agricultural field, the control valves **2602** and **2606** are preferably controlled with a pulse width modulation (PWM) control system implemented in the controller **2613**. The PWM control system supplies short-duration (e.g., in the range of 50 milliseconds to 2 seconds with orifice sizes in the range of 0.020 to 0.2 inch) pulses to the actuators **2609** and **2610** of the respective control valves **2602** and **2606** to open the respective valves for short intervals corresponding to the widths of the PWM pulses. This significantly reduces the energy required to increase or decrease the pressure in the hydraulic cylinder **2600**. The pressure on the exit side of the control valve is determined by the widths of the individual pulses and the number of pulses supplied to the control valves **2602** and **2606**. Thus, the pressure applied to the hydraulic cylinder **2622** may be controlled by separately adjusting the two control valves **2602** and **2606** by changing the width and/or the frequency of the electrical pulses supplied to the respective actuators **2609** and **2610**, by the controller **2613**. This avoids the need for a constant supply current, which is a significant advantage when the only available power source is located on the tractor or other vehicle that propels the soil-engaging implement(s) across a field.
(233) The hydraulic control system of FIG. **45** may be used to control multiple hydraulic cylinders on a single row unit or a group of row units, or may be replicated for each individual hydraulic cylinder on a row unit having multiple hydraulic cylinders. For example, in the system described above having a ground hardness sensor located out in front of the clearing wheels, it is desirable to have each hydraulic cylinder on any given row unit separately controlled so that the down pressure on each tool can be adjusted according to the location of that tool in the direction of travel. Thus, when the ground hardness sensor detects a region where the soil is softer because it is wet, the down pressure on each tool is preferably adjusted to accommodate the softer soil only during the time interval when that particular tool is traversing the wet area, and this time interval is different for each tool when the tools are spaced from each other in the direction of travel. In the case of a group of row units having multiple hydraulic cylinders on each row unit, the same hydraulic control system may control a group of valves having common functions on all the row units in a group.
(234) FIG. **46**A is a schematic diagram of a modified hydraulic control system that uses a single three-position control valve **2620** in place of the two two-position control valves and the two check valves used in the system of FIG. **45**. The centered position of the valve **2620** is the closed position, which is the normal position of this valve. The valve **2620** has two actuators **2620***a* and **2620***b*, one of which moves the valve to a first open position that connects a source **2621** of pressurized hydraulic fluid to a hydraulic cylinder **2622** via restriction **2620***c*, and the other of which moves the valve to a second open position that connects the hydraulic cylinder **2622** to a sump **2623**. Electrical signals for energizing the actuators **2620***a* and **2620***b* are supplied to the respective

actuators via lines **2624** and **2625** from a controller **2626**, which in turn may be controlled by a central processor **2627**. The controller **2626** receives input signals from a pressure transducer **2628** coupled to the hydraulic cylinder **2622** via line **2629**, and from an auxiliary sensor **2630**, such as a ground hardness sensor. An accumulator **2631** is coupled to the hydraulic cylinder **2622**, and a relief valve **2632** connects the hydraulic cylinder **2622** to the sump **2623** in response to an increase in the pressure in the cylinder **2622** above a predetermined level.

(235) As depicted in FIG. **46**B, a PWM control system supplies short-duration pulses P to the actuators **2620***a* and **2620***b* of the control valve **2620** to move the valve to either of its two open positions for short intervals corresponding to the widths of the PWM pulses. This significantly reduces the energy required to increase or decrease the pressure in the hydraulic cylinder **2622**. In FIG. **46**B, pulses P**1**-P**3**, having a voltage level V**1**, are supplied to the actuator **2620***b* when it is desired to increase the hydraulic pressure supplied to the hydraulic cylinder **2622**. The first pulse P**1** has a width T**1** which is shorter than the width of pulses P**2** and P**3**, so that the pressure increase is smaller than the increase that would be produced if P**1** had the same width as pulses P**2** and P**3**. Pulses P**4**-P**6**, which have a voltage level V**2**, are supplied to the actuator **2620***a* when it is desired to decrease the hydraulic pressure supplied to the hydraulic cylinder **2622**. The first pulse P**4** has a width that is shorter than the width T**2** of pulses P**2** and P**3**, so that the pressure decrease is smaller than the decrease that would be produced if P**4** had the same width as pulses P**5** and P**6**. When no pulses are supplied to either of the two actuators **2620***a* and **2620***b*, as in the “no change” interval in FIG. **46**B, the hydraulic pressure remains substantially constant in the hydraulic cylinder **2622**.

(236) FIG. **46**C illustrates an electrical control system that has a separate electrical controller **2651**, **2652**, **2653** . . . **2654** on each of multiple row units R**1**, R**2**, R**3** . . . Rn drawn by a single tractor T. Thus, the hydraulic actuators on each row unit can be controlled independently of the actuators on the other row units. All the row unit controllers **2651**-**2654** are controlled by a master controller **2650**, which may be located on the tractor or the draw bar, or even on one of the row units. The master controller **2650** sends electrical signals to, and receives electrical signals from, each individual row unit in parallel, which provides significant advantages, especially when combined with the use of intermittent control signals such as the PWM signals discussed above. For example, the master controller can coordinate changes in pressure in the multiple row units sequentially, so that only a single row unit draws power from the source at any given time. In another example, each row unit can signal the master controller when power is needed by that row unit, and then the master controller can control the supplying of power to only those row units requiring adjustment, and during the time interval when each row unit requires power for making adjustment. This reduces the time required to cycle through the row units to which power is sequentially supplied. In yet another example, the individual row units can send the master controller signals indicating the magnitude of adjustment required, and the master controller can assign higher priorities to those row units requiring the largest adjustments, so that those row units receive power for making adjustments more quickly than row units assigned lower priorities. Or the higher priority row units can be provided with power during more cycles than row units having lower priorities.

(237) Turning now to FIG. **47**, a row-clearing unit **3010** is mounted in front of a planting row unit **3011**. A common elongated hollow towing frame **3012** (typically hitched to a tractor by a draw bar) is rigidly attached to the front frame **3013** of a four-bar linkage assembly **3014** that is part of the row unit **3011**.

(238) As the planting row unit **3011** is advanced by the tractor, a coulter wheel **3015** works the soil and then other portions of the row unit part the cleared soil to form a seed slot, deposit seed in the seed slot and fertilizer adjacent to the seed slot, and close the seed slot by distributing loosened soil into the seed slot with a closing wheel **3018**. A gauge wheel **3019** determines the planting depth for the seed and the height of introduction of fertilizer, etc. Bins **3016** and **3017** on the row unit carry the chemicals and seed which are directed into the soil. The planting row unit **3011** is urged downwardly against the soil by its own weight. If it is desired to have the ability to increase this

downward force, or to be able to adjust the force, a hydraulic or pneumatic cylinder and/or one or more springs may be added between the front frame **3013** and the linkage **3014** to urge the row unit downwardly with a controllable force. Such a hydraulic cylinder may also be used to lift the row unit off the ground for transport by a heavier, stronger, fixed-height frame that is also used to transport large quantities of fertilizer for application via multiple residue-clearing and tillage row units. This hydraulic or pneumatic cylinder may be controlled to adjust the downward force for different soil conditions such as is described in U.S. Pat. Nos. 5,709,271, 5,685,245 and 5,479,992.
(239) The row-clearing unit **3010** includes an attachment frame that includes a pair of rigid arms **3020** and **3021** adapted to be rigidly connected to the towing frame **3012**. In the illustrative embodiment, the arms **3020** and **3021** are bolted to opposite sides of the front frame **3013** of the row unit **3011**, which in turn is rigidly attached to the towing frame **3012**. An alternative is to attach the row-clearing unit **3010** directly to the towing frame **3012**. At the bottom of the row-clearing unit **3010**, a pair of cooperating toothed clearing wheels **3022** and **3023** are positioned upstream of the coulter wheel **3015** of the planting row unit **3011**.
(240) The clearing wheels **4022**, **4023** are arranged for rotation about transverse axes and are driven by the underlying soil as the wheels are advanced over the soil. The illustrative wheels **4022**, **4023** are a type currently sold by the assignee of the present invention under the trademark TRASHWHEEL. The toothed wheels **4022**, **4023** cooperate to produce a scissors action that breaks up compacted soil and simultaneously clears residue out of the path of planting. The wheels **4021** and **4022** kick residue off to opposite sides, thus clearing a row for planting. To this end, the lower edges are tilted outwardly to assist in clearing the row to be planted. This arrangement is particularly well suited for strip tilling, where the strip cleared for planting is typically only about 4010 inches of the 4030-inch center-to-center spacing between planting rows.
(241) In FIGS. **47** and **48**, the clearing wheels **4022** and **4023** are shown in two different vertical positions. Specifically, the wheels **4022**, **4023** are in a lower position in FIG. **1**, where the elevation of the soil is decreasing, than in FIG. **48**, where the soil elevation is increasing.
(242) The row-clearing unit **10** is shown in more detail in FIGS. **49-55**. The two frame arms **4020**, **4021** are interconnected by an arched crossbar **4024** that includes a pair of journals **4025** and **4026** for receiving the leading ends of a pair of laterally spaced support arms **4030** and **4031**. The support arms **4030**, **4031** are thus pivotally suspended from the crossbar **4024** of the attachment frame, so that the trailing ends of the support arms **4030**, **4031** can be pivoted in an arc around a horizontal axis **4032** extending through the two journals **4025**, **4026**.
(243) The row-clearing wheels **4022** and **4023** are mounted on the trailing ends of the support arms **4030** and **4031**, which are bolted or welded together. As can be seen in FIGS. **50-52**, the wheels **4022**, **4023** can be raised and lowered by pivoting the support arms **4030**, **4031** around the horizontal axis **4032**. The pivoting movement of the support arms **4030**, **4031** is controlled by a hydraulic cylinder **4070** connected between the fixed crossbar **4024** and the trailing ends of the support arms **4030**, **4031**. FIGS. **50-52** show the support arms **4030**, **4031**, and thus the clearing wheels **4022**, **4023**, in progressively lower positions. The downward pressure applied to the support arms **4030**, **4031** to urge the clearing wheels **4022**, **4023** against the soil is also controlled by the hydraulic cylinder **4070**.
(244) The hydraulic cylinder **4070** is shown in more detail in FIGS. **53-55**. Pressurized hydraulic fluid from the tractor is supplied by a hose (not shown) to a port **4071** that leads into an annular cavity **4072** surrounding a rod **4073**, and then on into an accumulator **4079**. After the internal cavities connected to the port **4071** are filled with pressurized hydraulic fluid, the port is closed by a valve, as will be described in more detail below. The lower end of the annular cavity **4072** is formed by a shoulder **4074** on the rod **4073**, so that the hydraulic pressure exerted by the hydraulic fluid on the surface of the shoulder **4074** urges the rod **4073** downwardly (as viewed in FIGS. **53-55**), with a force determined by the pressure of the hydraulic fluid and the area of the exposed surface of the shoulder **4074**. The hydraulic fluid thus urges the rod **4073** in an advancing direction

(see FIG. **54**).

(245) When the rod **4073** is advanced outwardly from the cylinder **4070**, the rod pivots the support arms **4030**, **4031** downwardly, thereby lowering the clearing wheels **4022**, **4023**. Conversely, retracting movement of the rod **4073** pivots the support arms **4030**, **4031** upwardly, thereby raising the clearing wheels **4022**, **4023**.

(246) The accumulator **4079** includes a diaphragm that divides the interior of the accumulator into a hydraulic-fluid chamber **4079***a* and a gas-filled chamber **4079***b*, e.g., filled with pressurized nitrogen. FIG. **53** shows the rod **4073** in a position where the diaphragm is not deflected in either direction, indicating that the pressures exerted on opposite sides of the diaphragm are substantially equal. In FIG. **54**, the hydraulic force has advanced the rod **4073** to its most advanced position, which occurs when the resistance offered by the soil to downward movement of the clearing wheels **4022**, **4023** is reduced (e.g., by softer soil or a depression in the soil).

(247) As can be seen in FIG. **54**, advancing movement of the rod **4073** is limited by the "bottoming out" of a coil spring **4075** located between a flange **4076** attached to the inner end of the rod **4073** and a flange **4077** attached to the interior of the cylinder **4070**. As the rod **4073** is advanced, the coil spring **4075** is progressively compressed until it reaches its fully compressed condition illustrated in FIG. **54**, which prevents any further advancement of the rod **4073**. Advancing movement of the rod **4073** also expands the size of the annular cavity **4072** (see FIG. **54**), which causes the diaphragm **4078** in the accumulator **4079** to deflect to the position illustrated in FIG. **54** and reduce the amount of hydraulic fluid in the accumulator **4080**. When the rod **4073** is in this advanced position, the support arms **4030**, **4031** and the clearing wheels **4022**, **4023** are pivoted to their lowermost positions relative to the row unit **4011**.

(248) In FIG. **55**, the rod **4073** has been withdrawn to its most retracted position, which can occur when the clearing wheels **4022**, **4023** encounter a rock or other obstruction, for example. When the rod **4073** is in this retracted position, the support arms **4030**, **4031** and the clearing wheels **4022**, **4023** are pivoted to their uppermost positions relative to the row unit. As can be seen in FIG. **55**, retracting movement of the rod **4073** is limited by engagement of a shoulder **4080** on the rod **4073** with a ring **4081** on the trailing end of the cylinder **4070**. As the rod **4073** is retracted by forces exerted on the clearing wheels **4022**, **4023**, the coil spring **4075** is progressively expanded, as illustrated in FIG. **55**, but still applies a retracting bias to the rod **4073**.

(249) Retracting movement of the rod **4073** virtually eliminates the annular cavity **4072** (see FIG. **55**), which causes a portion of the fixed volume of hydraulic fluid in the cylinder **4070** to flow into the chamber **4079***a* of the accumulator **4079**, causing the diaphragm **4078** to deflect to the position illustrated in FIG. **55**. This deflection of the diaphragm **4078** into the chamber **4079***b* compresses the gas in that chamber. To enter the chamber **4079***a*, the hydraulic fluid must flow through a restriction **4080**, which limits the rate at which the hydraulic fluid flows into the accumulator. This controlled rate of flow of the hydraulic fluid has a damping effect on the rate at which the rod **4073** retracts or advances, thereby avoiding sudden large movements of the moving parts of the row-clearing unit.

(250) When the external obstruction causing the row cleaners to rise is removed from the clearing wheels, the combined effects of the pressurized gas in the accumulator **4079** on the diaphragm **4078** and the pressure of the hydraulic fluid move the rod **4073** to a more advanced position. This downward force on the clearing wheels **4022**, **4023** holds them against the soil and prevents uncontrolled bouncing of the wheels over irregular terrain, but is not so excessive as to leave a trench in the soil. The downward force applied to the clearing wheels **4022**, **4023** can be adjusted by changing the pressure of the hydraulic fluid supplied to the cylinder **4070**.

(251) FIG. **56** is a schematic of a hydraulic control system for supplying pressurized hydraulic fluid to the cylinders **4070** of multiple row units. A source **4100** of pressurized hydraulic fluid, typically located on a tractor, supplies hydraulic fluid under pressure to a pressure control valve **4101** via supply line **4102** and receives returned fluid through a return line **4103**. The pressure control valve

101 can be set by an electrical control signal S**1** on line **4104** from a controller **4112**, to deliver hydraulic fluid to an output line **4105** at a desired pressure. The output line **4105** is connected to a manifold **106** that in turn delivers the pressurized hydraulic fluid to individual feed lines **4107***a*, **4107***b* . . . **4107***n* connected to the ports **4071** of the respective hydraulic cylinders **4070** of the individual row units. The row units include respective pressure sensors **4108***a*, **4108***b* . . . **4108***n* that monitor the forces on the tools to which the respective hydraulic cylinders are coupled, and the sensors produce electrical output signals that are fed back to the controller **4112** for use in determining a desired setting for the pressure control valve **4101**.
(252) FIG. **57** is a schematic of a modified hydraulic control system that permits individual control of the supply of hydraulic fluid to the cylinder of each separate row unit. Portions of this system that are common to those of the system of FIG. **56** are identified by the same reference numbers. The difference in this system is that each of the individual feed lines **4107***a*, **4107***b* . . . **4107***n* leading to the row units is provided with a separate pressure control valve **4110***a*, **4110***b* . . . **4110***n*, respectively, that receives its own separate electrical control signal on one of a plurality of output lines **4011***a*, **4011***b* . . . **4111***c* from an electrical controller **4112**. This arrangement permits the supply of pressurized hydraulic fluid to each row unit to be controlled by the pressure control valve **110** for that row unit. The individual valves **4110***a*, **4110***b* . . . **4110***n* receive pressurized hydraulic fluid via the manifold **4116** and separate supply lines **4113***a*, **4113***b* . . . **4113***n*, and return hydraulic fluid to a sump on the tractor via a return manifold **4114** connected back to the return line **4103** of the hydraulic system **4100** of the tractor.
(253) One benefit of the control systems of FIGS. **56** and **57** is that as agricultural planters, seeders, fertilizer applicators, tillage equipment and the like become wider with more row units on each frame, often 36 30-inch rows or 54 20-inch rows on a single 90-foot wide toolbar, each row-clearing unit can be controlled independently of every other row-clearing unit. Thus, the down pressure for each row unit can be remotely adjustable from the cab of the tractor or other selected location. This permits very efficient operation of a wide planter or other agricultural machine in varying terrain without having to stop to make manual adjustment to a large number of row units, resulting in a reduction in the number of acres planted in a given time period. One of the most important factors in obtaining a maximum crop yield is timely planting. By permitting remote down force adjustment of each row-clearing unit (or group of units), including the ability to quickly release all down force and let the row cleaner quickly rise, e.g., when approaching a wet spot in the field, one can significantly increase the planter productivity or acres planted per day, thereby improving yields and reducing costs of production.
(254) On wide planters or other equipment, at times 90 feet wide or more and planting at 6 mph or more forward speed, one row-clearing unit must often rise or fall quickly to clear a rock or plant into an abrupt soil depression. Any resistance to quick movement results in either gouging of the soil or an uncleared portion of the field and reduced yield. With each row unit having its own separate control, the clearing wheels and the rod of the hydraulic cylinder can move quickly and with a nearly constant down force.
(255) Although the illustrative embodiments described above utilize clearing wheels as the agricultural tools, it should be understood that the invention is also applicable to row units that utilize other agricultural tools, such as fertilizer openers or rollers for firming loose soil.
(256) In order to dynamically control the hydraulic pressure applied to the soil-engaging tools in response to varying soil conditions, each pressure sensor is preferably connected between the ram of each hydraulic actuator **4019** and the support member for the tool controlled by that ram. One such system is illustrated in FIG. **58**, in which a tractor hydraulic system **4100** supplies pressurized hydraulic fluid to multiple row units **4401***a*, **4401***b* . . . **4401***n*. In the illustrative system, each row unit includes three hydraulic cylinders **4402**, **4403** and **4404**, one for each of three tool support members **4405**, **4406** and **4407**, and the hydraulic fluid is supplied to each hydraulic cylinder through a separate pressure control valve **4408**, **4409** or **4410** via a supply manifold **4102** and a

return manifold **4103**. A separate pressure sensor **4411**, **4412** or **4413** (e.g., a load cell or strain gauge) is connected between the ram of each of the cylinders **4402**, **4403** and **4404** and its associated tool support member **4405**, **4406** or **4407**, respectively. The electrical output signals from all the pressure sensors **4411-4413** are sent to a controller **4420**, which generates a separate control signal for each of the pressure control valves **4408**, **4409** and **4410**.
(257) In FIG. **58**, the components of each row unit have been identified by the same reference numerals used for those same components in the other row units, with the addition of the same distinguishing suffixes used for the row units. For example, in row unit **4401***a*, the three hydraulic cylinders have been designated **4402***a*, **4403***a* and **4404***a*. Only three row units **4401***a*, **401***b* . . . **401***n* are shown in FIG. **58**, but it will be understood that any number of row units may be used, and it is common practice to have a tractor pull many more than three row units, all of which are coupled to the hydraulic system of the single tractor.
(258) The controller **4420** continuously monitors the electrical output signals from the pressure sensors **4411-4413** and uses those signals to produce a separate control signal for each of the valves **4408-4410**. These signals control the pressure control valves **4408-4410** to maintain desired hydraulic pressures in the respective hydraulic cylinders **4402-4404** of all the row units. Consequently, if different row units encounter different soil conditions, those conditions are sensed by the respective pressure sensors **4115** and the output signals produced by those sensors cause different hydraulic pressures to be supplied to the different row units, thereby compensating for the particular soil conditions encountered by the different row units. For example, if some or all of the row units **4401** move from a region of relatively soft soil into a region of relatively hard soil, the output signals from the pressure sensors **4411-4413** on those row units will increase. These increases are detected by the controller **4420**, which then automatically adjusts the control signals supplied to the corresponding valves to increase the hydraulic pressure supplied to the hydraulic cylinders associated with those valves.
(259) The system of FIG. **58** is capable of providing independent control of the down pressure on different tools, such as the clearing wheels and the closing wheels, on the same row unit. The controller **4420** receives a separate input signal from the pressure sensor associated with each separate cylinder, and produces a separate control signal for each separate pressure control valve. Thus, the hydraulic pressure supplied to each separate hydraulic cylinder may be separately controlled, independently of all the other cylinders, whether on the same row unit or different row units.
(260) The controller **4420** may be programmed to use different algorithms to determine how the hydraulic pressure supplied to any given cylinder is adjusted in response to changes in the signals from the pressure sensor for that cylinder. For example, the controller can simply convert the signal from a given pressure sensor into a proportional signal having a linear relationship with the sensor output signal, to produce a control signal that falls within a suitable range for controlling the corresponding pressure control valve (e.g., within a range of 0-10V). Alternatively, the conversion algorithm can apply a scaling factor or gain to the signal from the sensor as part of the conversion. Filters may also be employed in the conversion process, e.g., to ignore sensor signals above a first threshold value and/or below a second threshold value.
(261) The sensor output signals may also be averaged over a prescribed time period. For example, the signal from each pressure sensor may be sampled at predetermined intervals and averaged over a prescribed time period, so that the control signal supplied to the pressure control valve associated with that sensor does not change abruptly in response to only a brief, temporary change in soil conditions. Certain parameters, such as scaling factors, can be made manually selectable to enable an operator selection to customize the behavior of one or more row units to suit personal preferences. Different “mappings” may also be provided to enable an operator to select predetermined sets of variables correlated to different conditions.
(262) FIGS. **59** and **60** illustrate a load cell **4500** for sensing the pressure on a pair of clearing

wheels **4022** and **4023**. The load cell **4500** couples the rod of the hydraulic cylinder **4070** to the two arms **4030** and **4031** that carry the clearing wheels **4022** and **4023**, so that the load cell is subjected to the same forces as the clearing wheels. Specifically, the load cell **4500** extends through an annulus **4501** attached to the end of the cylinder rod, and the opposite ends of the load cell extend through closely fitting apertures in the arms **4030** and **4031** and are secured thereto by a pair of C clips **4502** and **4503**. As the forces exerted on the load cell change, the electrical output signal produced by the load cell on its output line **4504** changes in proportion to changes in the exerted forces.

(263) The control system described above may utilize position sensors, pressure transducers, load sensors, biased mechanical switches, etc. to detect varying field conditions, and sends signals to a programmable logic controller. The controller in turn analyzes and processes those signals into a corrected usable signal, to be output to a number of integral hydraulic, pneumatic, or electric actuators that control parameters such as the down force on different parts of each row unit. The information collected in the process is preferably also used for a remote interactive display and controller, or for the development of soil condition maps, for use in future field planning, and maintenance.

(264) As the science of agronomy expands, several factors that boost the yield potential of various row crops have been identified. Many of these factors can be controlled and physically manipulated by means of mechanical operations on soil and its accompanying residue and/or additional in-field obstacles such as rocks, waterways, etc. The need to have real-time control over all implement systems is of critical importance as row crop operations move to large platform tools, with single operators.

(265) Additionally, the mapping of in-field obstacles has strong potential to supplement planning for field development and maintenance, such as the removal of obstacles in the field (e.g., rocks, fence posts, etc.), determining appropriate crop rotation, identifying trouble spots for soil erosion, identifying areas that may benefit from tiling, determining appropriate tillage practices, and determining application rates for fertilizers and pesticides.

(266) Row unit down force can be used to control both the depth of a seeding unit or other agricultural implement, and the compaction of soil from a depth-gauging member such as the gauge wheels on a row crop planter. Two important elements of this process are the ability to ensure that the ground-engaging element (e.g., the vee opener blade on a planter row unit) consistently runs at a uniform depth, and that in the process of achieving depth, the gauging element(s) does not excessively compact the ground. Compacted ground is known to inhibit the germination and emergence of row crop seeds, as well as the lateral root growth of a row crop seedling.

(267) Row cleaner down force can be used to control the height and load of a floating row cleaners, which are devices that stretch and deliver row crop residue around the path of a seeding implement, or other depth gauging member to ensure that the depth gauging member runs upon a consistent surface. Running on a consistent surface allows for more uniform depth of the ground-engaging member. In the case of a seeding machine, this promotes consistent depth of seed, which is known to boost yield potential.

(268) A controllable down force can be used to regulate both the depth of a ground-engaging element of a cutting disc, and compaction caused by an adjacent gauge wheel. As an example, consistent depth of fertilizer is known to those skilled in the art to promote ideal nutrient uptake in a row crop plant. Consistent depth can also allow for uniform soil coverage of fertilizer by a furrow-closing device. Uniform coverage can reduce fertilizer loss from surface runoff, and/or loss due to volatilization of nitrogen, and off gassing.

(269) Closing wheel down force can be used to regulate the depth on a furrow-closing device. Consistent, properly calibrated down pressure and depth on a furrow closing device on a seeding unit, or other ground engaging tool, can ensure soil coverage over the furrow without causing

excess compaction, or blow-out. This is of particular importance in the placement of row crop seeds. The seed ideally requires the furrow closer to press soil tight to the seed to promote germination, while allowing the surface to remain loose, so that the seedling can emerge with little resistance due to compaction, or crusting.

(270) A depth gauging element actuator is any device that allows for remote adjustment of the depth-gauging element of a row crop tool. Gauging depth is a critical element of almost all row crop tools (seeding units, tillage tools, fertilizer coulters, etc.) In the case of a seeding unit, gauge wheel settings are of primary importance. Uniform depth of the seed is well known to significantly improve yield potential. A real world example: If the gauge wheels on a seeding unit build up with mud, it is important to adjust the stops on the gauge wheels to correct for the added increase in radius on the gauge wheels, and maintain vee-opener blade depth.

(271) In one embodiment, a planting row unit is attachable to a towing frame for movement in a forward direction on a field having soil of varying hardness conditions. The planting row unit includes an opener device forward of the towing frame for preparing the soil for receiving at least one of the fertilizer and the seeds. The opener device includes a soil-hardness sensor for detecting changes in soil-hardness conditions and an opener blade for maintaining, in response to the changes, a substantially constant soil-penetration depth Z in the soil independent of the varying hardness conditions. A modular actuator is mounted to the opener device for applying pressure to the opener blade.

(272) The nature of systems of large numbers of sensors and actuators on agricultural implements can be confusing and cumbersome if the performance of all individual units, and their auxiliary components, cannot be quickly reviewed, and subsequently adjusted in a timely manner. Row crop production is extremely time and soil-condition sensitive, and certain operations benefit tremendously from the easing of real-time operator input control, particularly in the case of systems installed on ultra-wide toolbars (over 60 ft.). In many of these systems, one operator must monitor and make adjustments to 50 or more units. Those units may have 4 or 5 auxiliary systems that also require monitoring and adjustment. The necessity to have a comprehensive high-speed controller and monitor to assist in regulating all actuator activity in a particular system is evident when a single operator must monitor and adjust hundreds of components in real-time. Smaller operators can also realize a significant advantage if methods are properly employed.

(273) A system for integrated control over all onboard actuators on an agricultural implement is described here. Typical of a row crop tool are two primary elements, a ground-engaging component, and a depth-gauging component. There may be more than one ground-engaging component, or depth-gauging component, depending on the tool. The positions of the lowest elements of the individual components are necessarily unequal. The lowest element of the ground-engaging component/s is identified by the extent to which the engaged media (e.g., soil, crop residue) is being physically manipulated. The lowest element of the gauging component regulates the extent to which the ground-engaging components manipulate the engaged media. Regulating the depth on a ground-engaging component is of primary interest.

(274) For measurement and regulation of depth, the chief sensing element of this system is a position sensor. This sensor may be linear or angular in nature and, depending on the method, may be either an absolute or a relative displacement sensor. This sensor may also be a laser rangefinder, or ultra-sonic in nature. This measurement is the primary input to an onboard programmable controller. The physical device generating this primary input may be used on an auxiliary or add-on component, such as a leading furrow opener having both a ground-engaging member and a depth-gauging member fitted with a position sensor situated to measure the relative distance between the ground-engaging member support, and the depth-gauging member support. The device may also be located on the ground-engaging member and depth-gauging member of the primary tool, such as the vee-opener blades on a seeding unit. Supplementary sensors may be installed both as primary sensing units, as well as performance correction devices, on the primary tool and on auxiliary tools.

For example, on a seeding device, position sensors may be installed on a leading furrow opener, on a residue-managing device, on the seeding row unit, and on the furrow closer. In many cases, due to cost constraints, operators may choose only one or two position sensors as their primary signals, with the additional sensor(s) only positively contributing to error correction over the entire device. Ideally, all four inputs are utilized for analyzing a row unit, and auxiliary tool position, and outputting a signal to all actuators that re-position the tool, or auxiliary components, to allow for maximum performance from the tool and its auxiliary components.

(275) For correction and determination of performance of row crop tool actuators, the chief sensing element is an integrated pressure transducer. Supplemental performance measurements may include load sensors (which are pre-installed on many ground-engaging tools) or biased proximity switches. These sensors may be used to correct errors that occur in the processing of the position sensor signal, and to verify that the actuators are performing properly. For example, many seeding units are equipped with “load pins” on the upper stops of the units' gauge wheels. Such load pins can generate signals that correlate directly to the signals generated by the position sensors.

(276) Integration of mechanical and electrical devices is possible with outdoor-rated, compact programmable logic controllers. The multi-channel controller in this system receives the input signal of the position sensor of the primary ground-engaging tool, and any additional auxiliary signals, and then processes those signals to generate a base signal that is output to the actuators. This signal may be processed using a number of mathematical methods to output a signal best suited for proper response from a particular actuator. After the signal is processed, it is checked and corrected using the signals from pressure transducers, load sensors or biased proximity switches. For example, in a seeding unit that is equipped with an actuated furrow opener, an actuated residue manager, a row unit down force actuator, and an actuated closing wheel, the primary signal is received from the furrow-opener position sensor. This signal is supplied to a controller that averages or otherwise mathematically manipulates the signal to produce a clean, consistent signal to each component's actuator. This signal typically differs for each actuator, and different computations are typically required for each output signal.

(277) Once the signals of all the sensors have been processed and corrected, and the actuators have been activated, it is preferred to be able to visually inspect the performance of each individual row unit and its auxiliary components. Also, due to the nature of agricultural field work, it is beneficial to be able to control all elements of the system from a remote location such as a tractor cab. To this end, the system may employ a vehicle bus to direct information to an in-cab monitor from the individual row controllers, where the information can be processed and viewed in a variety of different configurations. This information may also be delivered wirelessly to a remote location to alert an operator (e.g., via text messaging or e-mail) when errors occur with an actuator or any of its associated sensors. Some operators will choose to employ all available actuators and all available sensors on all rows, and will want to have direct control row-by-row, in sections, or across the entire toolbar, depending on the operation and the disposition of the operator.

(278) The preferred user interface is an interactive in-cab display having several features that allow the operator to quickly review all systems and adjust the appropriate actuator(s) accordingly. The display may provide row-by-row viewing of the functionality of individual tools and auxiliary components, or the functionality may be viewed over integrated sections, or by averages of units over a particular section. The interface also alerts the operator when any of the various actuators and/or sensors are malfunctioning, and signals which rows or sections need to be checked for repair, or calibration.

(279) There are a large number of mathematical methods by which individual controllers process and output signals. Due to the nature of the engaged media, the controller must sample the position of a particular tool, or component, and create a meaningful signal to be transmitted to the actuator. When in the field, row crop tools often encounter some relatively periodic oscillations due to ridges formed from a variety of pre-plant tools (tillage, fertilizer application, etc.). Additionally the

position sensor will register large spikes as a result of encountering massive in-field obstacles (e.g., rocks, concrete, fence posts, etc.). Depending on location, the number of large spikes may be very frequent. The controllers must be able to register a wide variety of oscillations. In general, as ground hardness increases, the actuator must increase down force to push with more force against the hard ground. However, a massive, hard object like a rock requires a different approach. When encountering a massive object, increasing pressure on the actuators will greatly increase general wear on the row crop tool, potentially causing irreparable damage. Thus, when encountering massive objects, the controller preferably recognizes the immovable object and, whenever possible, reduces pressure on the row unit to avoid excessive wear on the tool.

(280) The reading of the signals from the position sensors provides an additional side benefit. As the data stream feeds into the controller, a forward velocity signal and a GPS coordinate signal may simultaneously be gathered from the local CAN. This data collectively can form a soil condition map of the field, identifying large stones or other obstacles that the operator can later efficiently remove by referring to the map. Additionally, when planning for tillage in a particular field, the operator may use the soil condition map to help identify areas that require more or less tillage.

(281) Rocks, clods, soil type, soil hardness, moisture level and other environmental factors can affect the aperiodic oscillations of any ground-engaging tool sensor signals. The system identifies oscillations unique to a particular condition, or obstacle, using wave pattern recognition software. This data stream is synchronized with the GPS signal, and is used to develop a graphical representation of the field, providing a interactive map with GPS coordinate locations of soil compaction, excessive moisture, in-field obstacles such as rocks, or fence posts that the user may want to remove, or identify other conditions that, if treated, may boost soil fertility.

(282) This system may employ the input from any number of cameras, either section-by-section, or row-by-row. There are a variety of small, robust, weatherproof camera systems available on the market. The implementation of visual surveillance is for two primary purposes: visual verification of in-field obstacles for use with soil condition maps, and remote row unit inspection in the case of error signals. When reviewing soil condition maps generated by the system, it is helpful to visually inspect the obstacle, or other condition that is identified by the system. Upon encountering a unique signal of interest, the controller activates a camera remotely to snap a still shot of the obstacle or condition of interest, or if the camera is generating video content, that data stream is time-stamped to easily synchronize with the video. The user may then select an obstacle identified by the system as a signal of interest, and visually inspect the ground, to more easily determine if it is profitable to remove an obstacle or otherwise treat the soil.

(283) As toolbars grow in size, the distance from the ground-engaging tool to the eyes of the operator may be too great for detailed inspection. Further, with the common use of multiple-hose routings for the delivery of products, and with the integration of high-capacity commodity tanks or hoppers into toolbars, it may be impossible for the operator to see some rows from the operator's vantage point. If a sensor in the system sends an error signal, the error may or may not be adversely affecting performance. The cost of stopping an ultra-wide planter, even for a few minutes, during the optimal planting window can be significant. If an implement is sending an error message, but upon visual inspection seems to be functioning adequately, it may prove to be more profitable to keep the implement moving. In some configurations, having the ability to visually inspect areas on an implement that has sensors detecting errors can allow the operator to determine if the problem is critical and needs to be addressed, or if it can wait until the implement consumables are depleted and is stopped for reloading, or is otherwise down for maintenance.

(284) An additional function of the in-cab display is to assist in controlling the depth-gauging member of the row crop tool. The ability to remotely control depth may be of use to operators who are working in fields with widely varying conditions. The ability to slightly raise or lower the ground-engaging element of the tool can be critical in some applications. Additionally, in wet conditions mud build-up on a depth-gauging member may cause erratic and uneven placement of a

particular commodity (e.g., seed, fertilizer), which adversely affects yield potential.
(285) The system may include a photogate, sonogate, rangefinder or other sensor that directly determines the height of mud buildup on a gauge wheel. This may also be accomplished by using a sensor capable of determining the angular velocity of a wheel. As the radius on the wheel increases due to mud buildup, the angular velocity changes proportionally, and so may be used to adjust the depth setting to account for the additional radius of the gauge wheel. In either case, sensors determine the average displacement between the opener and the gauge wheel. If a change in relative displacement occurs, the system recognizes that change, and sends a signal to the gauge wheel actuator to make the appropriate adjustment, and maintain a set displacement.
(286) FIG. **61** illustrates a complete system of tools that includes (1) a soil-hardness-sensing unit that includes a cutting disc **5001**, a gauge wheel **5001***a*, a cutting disc position sensor **5002**, a cutting disc actuator **5003**, a cutting disc pressure transducer **5004**, a cutting disc load sensor/proximity switch **5005**; (2) a controllably actuated row cleaner **5006** that includes a pair of cleaning wheels **5006***a* and **5006***b*, a row cleaner position sensor **5007**, a row cleaner actuator **5008**, a row cleaner pressure transducer **5009**, a row cleaner load sensor/proximity switch **5010**; (3) a remotely actuated row unit that includes an actuator cradle **5011**, a row unit position sensor **5012**, a row unit actuator **5013**, a row unit pressure transducer **5014**, a row unit load sensor/proximity switch **5015**; (4) a furrow-opening disc D and an adjacent gauge wheel G; (5) a furrow closing unit **5016** that includes at least one closing wheel **5016***a*, a furrow closer position sensor **5017**, a furrow closer actuator **5018**, a furrow closer pressure transducer **5019**, a furrow closer load sensor/proximity switch **5020** and a trailing gauge wheel **5021**; and (6) a row unit programmable controller **5022**.
(287) In FIG. **61**, the cutting disc actuator **5003** receives a signal from the position sensor **5002**. This sensor's signal is the initial signal to be processed, corrected and then output to the various actuators **5003**, **5008**, **5013** and **5018**. Depending on the needs of the operator, some tools may be added or removed, but all have the same general configuration: sense position, adjust actuator, and verify or correct signal with load sensor or proximity switch.
(288) FIG. **62** illustrates an exemplary algorithm for use in the system of FIG. **61**. In this diagram, the various sensor signals are supplied to and processed by the row controller **5022**. The signals from the position sensors, the load sensors, and the pressure transducers of all the components are fed simultaneously into the row unit controller **5022**. This may include all the signals from all available sensors, or may utilize a smaller number of inputs if the demands of the operation do not require more advanced control over a particular operation. After all sensor signals are received, the controller **5022** generates output signals that produce any desired changes in the position and/or pressure of all the system actuators. Additionally, if available, the signals from the position sensors may be adjusted by employing the inputs from the pressure transducers, or the load sensors associated with the actuators. In this example, every row is controlled individually by means of an output signal on a vehicle bus **5024** from the in-cab controller/monitor **5025**. Here, “Row N” **5023** is the nth row of a large platform seeding machine. Each of the N row units has an onboard controller **5022** coupled to the vehicle bus **5024** and a battery **5031**. All components may be monitored, and controlled from the in-cab interface.
(289) FIG. **63** is an example of an algorithm similar to the algorithm of FIG. **62**, but in this case the row cleaner unit has been removed. Despite the lack of a row cleaner, a properly placed position sensor can still generate a usable signal. However, the more inputs, the more potential physical malfunctions may occur. In some instances, fewer inputs may lead to a slightly more trouble-free signal generation.
(290) FIG. **64** is another example of a simplified algorithm. In this example only the cutting disc, and the row unit are outfitted with sensors, and actuators. This system requires much less computational power, and once again reduces the chance of potential problems that may arise from large numbers of sensors in a single row unit.

(291) FIG. **65** illustrates a system that provides sectional control over row unit actuators. In this example, the signals of m row units in each of n sections are fed into a single controller on a master row unit X for that section. All the other row units in each section are slave units controlled by the controller **5040**—in the master row unit. The signals received by the controller **5040** on a master unit are combined to generate a separate output signal for each of the slave units' actuators. Each section then has its own output that may be monitored and controlled from the in-cab interface. This sectional control is another technique to reduce the overall cost of such a system. In many instances, field conditions over the width of a small number of rows change very little. In this case, the operator can still realize significant advantages utilizing sectional control.
(292) FIG. **66**A shows an in-cab interface when the implement is stationary, and FIG. **66**B shows an exemplary display when the implement is moving across a field. In this particular example, the implement has five sections of row units. The display for each section includes three columns, one for each of the three different actuators included in each row unit. In this example, the actuators are identified as "C" for a coulter, "G" for clearing wheels, and "R" for the row unit, and the bars in the respective columns represent the average performance of all the actuators of each of the three types in the row units in the identified section. The display for each column is a vertical column of small horizontal bars. In FIG. **66**A, none of the bars is illuminated because the implement is stationary. In FIG. **66**B, the bars are depicted as illuminated uniformly but, as described in detail below, one of the bars in each column will be illuminated more brightly and with a color different from the other bars in that column, with the vertical position and color of that bar graphically indicating the average performance level of the corresponding tools in the row units in that particular section.
(293) At the top of each column, a displayed number represents the current average performance of the corresponding is in the row units in that particular section, where 100% performance represents sensor signals that cause the controller to produce an output signal that does not require any changes in the respective actuators for that type of tool in the row units in that particular section. For example, in Section 1, the 98% at the top of column "C" means that the average value of the outputs of the actuators for the coulters in the three row units in Section 1 has been within 98% the respective target values for those actuators during the time interval used to compute the average value. The time interval used to compute the average values is typically a sliding window that is 2 to 5 minutes long, during about 120 to 300 sensor readings are taken for each actuator.
(294) FIG. **66**C depicts an exemplary screenshot **6612** of a modified display on a video display **6610** in a monitor system **6600** for an agricultural machine such as an agricultural seed planter (e.g., a planting unit **10**, a fertilizer/opener unit, a strip-till cleaner unit, a full-width tillage unit, or any other agricultural machine for which a judgment about how much depth penetration of soil is needed or desired). The monitor system **6600** includes a controller, such as the controller **112**, **2613**, **2626**, **4112**, **4420**, or the main controller **915**, central processor **2614**, **2627** or master controller **2650**, or any other controller or processor described herein. The controller used to control the displays shown in FIGS. **66**A-**66**E is a controller specially programmed with machine-readable instructions embodied in software and/or firmware to perform the row monitoring aspects described in connection with FIGS. **66**A-**66**E.
(295) As described above, the row planting unit **10** includes multiple row units, such as **16** in number. Each of the row units has a soil-engaging tool **2202**, such as a coulter (e.g., a fertilizer coulter) or V-opener or furrow-opening disk or coulter **11**, **711**, **800**, **2112**, **3015** (sometimes called CFX™ herein), a row cleaner **2122**, **2222** (sometimes called GFX™ herein), and/or a closing wheel **2114**, **2214** (sometimes called TFX™ herein). Each of the row units also includes one or more actuators (typically multiple actuators), such as any combination of a hydraulic actuator **2120**, **2220** that actuates the row unit, and one or more modular actuators **2420** which cause the soil-engaging tools **2202**, **2104**, **3015**, **2122**, **2114** to be urged toward earth (e.g., the soil) according to an actuator signal received from the controller. If there are multiple soil-engaging tools in any given row unit, then the row unit preferably has one actuator for each soil-engaging tool. Thus, if

there are four soil-engaging tools on a row unit, then there are four separate actuators, one for each of the four soil-engaging tools. A “soil-engaging tool” is a tool (or implement) that is configured to engage soil or earth under control of a control system.

(296) In some aspects, the planting row unit itself includes one or more tools or implements, such as any combination of a coulter, a gauge wheel, a hardness sensor disk or wheel, and the like. Each “tool” is associated with at least one actuator that controls the one or more tools mechanically coupled to that actuator. To avoid confusion, the row unit itself (whether it is a planter type, a fertilizer type, a strip-till cleaner, a full-width tillage type, etc.) can be considered a tool or implement, such as when it has a gauge wheel or a coulter or the like attached to it. However, in other aspects, each tool can be independently actuated by its own respective actuator, and the graphical user interfaces shown and described herein enable the operator to separately monitor at least one measurable parameter for each such tool on the row unit. Thus, when describing a row unit herein as having or including a soil-engaging tool, it is more accurate to say that each row unit has one or more soil-engaging tools “associated with” the row unit.

(297) Each of the row units includes one or more sensors, such as the position or ground-hardness sensors, pressure sensors, load cells or strain gauges described above. Each sensor measures a parameter related to or indicative of the force or pressure exerted on the mechanism associated with one of the actuators or the position of that mechanism. Each sensor provides an electrical signal indicative of the measured parameter to the controller. The measured parameter can be a force or pressure, or a position related to a distance traveled by the soil-engaging tool, such as a depth of soil penetration by the soil-engaging tool. For example, when the sensor is a position sensor, the measured parameter can be a position related to a distance into the soil penetrated by the soil-engaging tool, e.g., the position can include an angular displacement or distance (e.g., height relative to earth) between the soil-engaging tool, on one hand, and ground or a reference structure on the row planting unit **10**, on the other hand. When the sensor is a pressure sensor, the parameter can be a force or a pressure. Force and pressure are related quantities, so these terms are used interchangeably herein. Again, there is preferably one sensor for each soil-engaging tool of the row unit. Thus, if there are four soil-engaging tools on a row unit, then there are four separate sensors, one for each of the four soil-engaging tools. Note that there can be more than one sensor that measures different parameters relating to the same soil-engaging tool. In aspects of the present disclosure, a minimum of one sensor is provided for each soil-engaging tool in each row, though any number of sensors can monitor multiple parameters relating to the soil-engaging tool, such as soil hardness of the soil engaged by the tool, soil moisture, downforce on the tool, load on the tool, vertical position of the tool relative to the surface of the soil, angular position of the tool relative to a fixed reference structure, pressure on the tool, geographic location or position of the tool (e.g., GPS coordinates), and the like.

(298) The video display **6610** is coupled to the controller, which executes machine-readable instructions stored on one or more non-transitory storage media. The machine-readable instructions can be implemented as firmware or software or both and stored on the one or more non-transitory storage media. The controller causes the video display **6610** to display graphical elements thereon, and a conventional touch-sensitive interface (not shown) can be coupled to or integral with the video display **6610** to receive human inputs corresponding to selections of selectable elements displayed on the video display **6610**. In the example shown in FIG. **66**C, the video display **6610** displays in real time as the row units are moved along the earth, row monitor graphical representations **6620**, **6630**, **6640** that indicate deviations of measured values from target values for different actuators on each of the 16 row units. The planting row unit preferably maintains a consistent soil depth penetration across the field being planted so that the seeds are planted a consistent depth into the soil, e.g., 3 inches, depending on the crop being planted. Thus, the measured values can be ultimately related to actual soil penetration depths as measured by the sensor(s), and the target values are related to a desired soil penetration depth as a function of the

crop being planted. For example, the measured value can correspond to Z.sub.ACT, described above in connection with FIGS. **40**A and **40**B, and the target value can correspond to Z.sub.THEOR, described above in connection with FIGS. **40**A and **40**B.

(299) In the exemplary screen shot in FIG. **66**C, there are sixteen row units grouped into three sections, labeled Section 1, Section 2, and Section 3, respectively, though any other textual or graphical label can be used to indicate the different sections. The first Section 1 includes six row units, the second Section 2 includes four row units, and the third Section 3 includes six row units. The number of row units in each of the sections is merely exemplary, and any number of sections can be predefined or defined by the operator of the row planting unit **10**, where the number of sections does not exceed the number of row units. Similarly, any number of row units can be predefined or defined by the operator of the row planting unit **10**, where the number of row units in a section does not exceed the total number of row units in the row planting unit **10**. No one row unit can be defined to be a member of more than one section.

(300) The row monitor graphic representations **6620**, **6630** and **6640** represent actuators on each of the respective row units. In this example, the row monitor graphical representation **6620** shows measured parameter deviations for an actuator acting on the row unit frame in each of the sixteen row units. The row monitor graphical representation **6630** shows measured parameter deviations of a fertilizer coulter implement for each of the sixteen rows. The row monitor graphical representation **6640** shows measured parameter deviations of a row cleaner implement for each of the sixteen rows. The screen shot **6612** includes a button **6626**, which can be actuated through the touch-sensitive interface to show additional tools or implements, such as a cleaning wheel implement. As explained above, each row unit includes a hydraulic actuator **2120**, **2220** that actuates the planting row unit **10** as a whole, and the deviation of the measured parameter from the target parameter is shown for each of the row units in the topmost graphical representation **6620**.

(301) The screenshot **6612** also includes a target line **6622** that indicates the desired value of a measured parameter on the row monitor graphical representation **6620**. In this example, the measured parameter deviation (i.e., an indication of whether and how much the measured parameter deviates from the target parameter) is displayed as an illuminated horizontal bar (though any other graphical representation can be used) in real time as the sixteen row units are moved along the earth. Each of the sixteen row units is shown as one of sixteen vertical columns **6624-1** through **6624-16**, each of which graphically resemble a measurement meter for each of three different actuators in the three windows **520**, **6630** and **6640**.

(302) The target line **6622** bisects each of the vertical meters **6624-1** through **6624-16** such that a deviation above the target line **6622** means that too much force or pressure is being applied by the corresponding actuator, and a deviation below the target line **6622** means that too little force or pressure is being applied by that actuator. Alternatively, a deviation above the target line **6622** can mean that too little force or pressure is being applied by the corresponding actuator, and a deviation below the target line **6622** can mean that too much force or pressure is being applied by that actuator. The target value for each soil-engaging tool can be predetermined and stored in the one or more non-transitory storage media. Such target values are well known to or readily ascertainable by those of ordinary skill in the art to which the present disclosure pertains, and can be dependent upon the type of crop being planted by the row planting unit **10**.

(303) In the “Planter Down Force Monitor” window **6620** in the display shown in FIG. **66**C, the measured parameter deviation for each of the sixteen rows is shown in a color that represents the extent of the deviations between the measured value and the target value for each planter row unit **10**. For example, the color green can be used to indicate that the measured value is within an acceptable range above or below the target value, e.g., a percentage deviation of +/−10% to +/−20% from the target value; the color yellow can be used to indicate that the measured value exceeds but does not maximally exceed the acceptable range, e.g., a percentage deviation of +/−20% to +/−40% from the target value; and the color orange can be used to indicate that the

measured value maximally exceeds the acceptable range, e.g., a percentage deviation of +/−40% to +/−80% from the target value. When the measured value exceeds the target value by more than +/−80%, the color red can be used to indicate a tool malfunction.

(304) The operator can touch any of the measurement meters corresponding to the row units to select that row unit or tool for a more detailed display in windows **6650**, **6660** and **6670** on the right-hand side of the display screen. In the example shown in FIG. **66**C, the operator has selected the fertilizer coulter in the ninth row by touching the meter **6632** in the graphical representation **6630**. Thus, the controller causes the window **6650** to display a graphical portrayal of the soil engaging tool(s) on the ninth row unit. In this example, two soil-engaging tools are shown in the graphical portrayal **6650**, a row cleaner implement (GFX™) and a fertilizer coulter implement (CFX™). Again, fewer or more tools or implements can be displayed by the monitor system, such as a closing wheel implement (TFX™). The displayed soil-engaging tools are shown in colors corresponding to the colors of the latest measured values for the respective tools for the ninth row unit in the meter windows **6620**, **6630** and **6640**. For example, here, the fertilizer coulter is shown in red, indicating a tool failure or malfunction, and the row cleaner and the row unit down force actuator are shown in green, indicating operation within an acceptable range. A legend **6628**, which is not displayed on the video display **6610**, is shown in FIG. **66**C to aid the reader in correlating the black-and-white symbol patterns with the displayed color.

(305) The display window **6660** displays the latest numerical values measured for each of the tools or implements for the selected row or for the row unit (RFX™) (in this example, the ninth row). In this example, the representations are shown as values in psi (pounds per square inch) and corresponding values in pds (pounds, at the bottom of the implement where it engages the soil) for four tools. Here, a closing wheel tool is not shown on the screenshot **6612**, but the operator can use the button **6626** to scroll down to see a row monitor graphical representation for the closing wheel (referred to as “Tfx” in FIG. **66**C). One of tne of the row monitor graphical representations **6620**, **6630**, **6640** may disappear from view to make room for the new row monitor graphical representation. The values n**1**-n**4** in the row monitor window **6660** represent the values in psi measured by the sensors associated with each of the four tools in the ninth row, and the values n**6**-n**9** represent the values in pounds corresponding to the measurements by the sensors associated with each of the four tools in the selected row (here, the ninth row). These values n**1**-n**4** and n**6**-n**9** change in real time as the implements are moved along the earth by the row planting unit **10**. Here, the different tools are as follows: Cfx refers to a fertilizer coulter or opener tool, which is monitored in sixteen different rows in the row monitor graphical representation **6630**. Rfx refers to a planter row unit, which is monitored in sixteen different rows in the row monitor graphical representation **6640**. Gfx refers to a row cleaner tool, which is monitored in sixteen different rows in the row monitor graphical representation **6620**. Tfx refers to a closing wheel tool, whose row monitor graphical representation is not shown in this screenshot **6610**.

(306) The screenshot **6612** includes a button **6670** that indicates a row number (here, **9**), which corresponds to the row unit selected by the operator as described above. As the row units are being moved along the earth, the operator can select, via the touch-sensitive interface, the button **6670** to change the row unit.

(307) FIG. **66**D illustrates an example screenshot **6614** that is displayed in response to the operator's selecting the button **6670** shown in FIG. **66**C. A number keypad **6672** is shown, and the operator can enter a new row unit number using the keypad **6672**, and then press the OK button **6674** to cause a different row unit (e.g., the first row unit) to be displayed as the graphical portrayal **6650** and the measured parameters for the soil-engaging tools for the newly selected row unit to be displayed in the row monitor window **6660**. Alternately, instead of selecting the button **6670**, the operator can sequentially cycle to the next row by selecting button **6682** or to the previous row by selecting button **6684**. The keypad **6672** allows the operator to jump quickly to any desired row number, and this feature enhances the user experience as the number of row units increases. For

example, if the operator is currently monitoring row unit number **2**, and desires to start monitoring row unit number **16**, the keypad **6672** allows the operator to quickly begin monitoring row unit number **16** without having to press a button multiple times. Or, the operator can simply touch, via the touch-sensitive interface relative to the video display **6610**, one of the vertical columns **6624-1** through **6624-16** for any of the soil-engaging tools to begin monitoring parameters being monitored by that row unit in the row monitor window **6660**. By presenting the operator with multiple ways of easily selecting any tool in any row, the operator can quickly monitor those parameters without having to slow down or stop the row planting unit **10** or focus prolonged attention on the video display **6610**, which would otherwise lead to a loss of efficiency, unnecessary distraction, or even an accident. For example, if the operator is monitoring row unit **2** as the row planting unit **10** is moving along the earth, and suddenly the column for the row cleaner tool in row number **15** indicates a red color indicating a potential tool malfunction, the operator can quickly either touch the column (**6624-15**) for the graphical representation **6640** for the row cleaner tool to immediately begin monitoring in real time the parameter values being measured by the one or more sensors associated with the row cleaner tool in that row.

(308) FIG. **66**E illustrates an example row diagnostic screen **6616** displayed on the video display **6610**. This screenshot **6616** includes a graphical representation **6690** of the row planting unit **10** for the selected row (number **9** in this example). The row diagnostic screen **6616** also displays four tool parameter monitor windows **6686-1** through **6686-4** and the keypad **6672**. Each of the tool parameter monitor windows **6686-1** through **6686-4** includes an up arrow **6692***u* and a down arrow **6692***d*, which allows the operator, via the touch-sensitive interface, to scroll through various measured or calculated parameters associated with the respective tool. For example, the tool parameter monitor window **6686-1** corresponds to a fertilizer coulter tool (called Cfx in FIG. **66**E), and displays a load parameter in pounds and a ride quality index (RQI) in percent. The load can be measured by one or more of the sensors associated with the tool, and the RQI can be calculated from the measured load. The up and down arrows **6692***u*, **6692***d* allow the operator to scroll through additional parameters, shown below the screen **6672** in block **6688**. Block **6688** is not actually displayed on the screen **6616** until the operator scrolls through to them. Rather, for ease of illustration, the block **6688** is shown below the screen **6616** and portrays additional parameters that can be monitored by the operator in the row diagnostic screen **6616**. For example, the pressure on the tool in psi can be monitored, the noise in the tractor cabin in dB can be monitored, the power utilized by that row unit or by that tool can be monitored in amps or watts, and the potential monetary damage caused by a particular tool malfunction, for example, can be calculated and displayed as a dollar amount. The monetary damage can be calculated as a function of the number of time units a tool has malfunctioned, for example, and a predetermined amount of revenue derivable by time unit and stored in the one or more storage media accessed by the row monitor controller.

(309) Three other tools are also shown on the row diagnostic screen **6616**. Multiple measured or calculated parameters associated with the row cleaner tool in row unit number nine is shown or can be accessed by selecting, via the touch-sensitive interface, the up or down arrows **6692***u*, **6692***d* in the tool parameter monitor window **6686-2**, multiple measured or calculated parameters associated with the planter tool in row unit number nine is shown or can be accessed by selecting the up or down arrows **6692***u*, **6692***d* in the tool parameter monitor window **6686-3**, and multiple measured or calculated parameters associated with the closing wheel in row unit number nine is shown or can be accessed by selecting the up or down arrows **6692***u*, **6692***d* in the tool parameter monitor window **6686-4**. Additional tools in row unit number **9** can be accessed by selecting, via the touch-sensitive interface, the left or right arrows **6692**L, **6692**R on the row diagnostic screen **6616**. Alternately, the left and right arrows **6692**L, **6692**R can be used to move sequentially between adjacent row unit numbers. For example, when there are four tools in each row unit, then all four tool parameter monitor windows **6682-1** through **6682-4** can be shown on one screen **6616**,

allowing the left and right buttons **6692**L, **6692**R to be used to cycle through the next or previous row unit. Alternately, the operator can use the keypad **6672** on the row diagnostic screen **6616** to jump to any row unit number or cycle to an adjacent row unit.
(310) As depicted in FIG. **70**, the algorithm described above in connection with FIG. **40**B may be modified to produce the values (Z.sub.ACT−Z.sub.THEOR) and/or (Z.sub.THEOR−Z.sub.ACT) at steps **5270**F and **5270**G for display at step **5279***i*, to provide a visual display of the difference between the current actual depth Z.sub.ACT and the theoretical depth Z.sub.THEOR.
(311) FIG. **67** is an example of possible input signals from a sensor associated with a tool of or associated with a row unit. Some periodic oscillations are typical of a real world environment. Ridges are formed in the field from any number of soil handling operations, and would be apparent from the signal received from the position sensors. These small oscillations are easily removed, and transformed into a smooth, usable signal by averaging over some time period, and using that averaging as a smoothing operation. In some cases the implementation of a low pass filter, or other noise cancelling process can be implemented to further smooth the signal output to the actuator. It is important that any tool smoothly, and consistently follow ground contours. Such an operation requires a smooth consistent signal from the row controller. In FIG. **67**, $\psi(t)$ is an example of a real-time signal (e.g., in volts, amps, capacitance, or resistance) being received from the position sensor. $\Phi(t)$ is a smoothed signal to be used a base signal for output to the various actuators.
(312) As has been mentioned previously, massive or immovable objects can be encountered in the field. It is important to detect significant spikes and to remove them from the signal. To that end, one method of sensing a spike is running a differentiation process on the input signal, $\psi(t)$, and determining the slope of a function over a time period. If there is a rapid change in slope over a relatively small period of time, it can be assumed that the unit has contacted a massive object. In response, the controller can stop taking measurements from the row unit. After detecting the spike, the controller reverts to a recently generated average signal and hold. After a short time, the controller once again begins sampling the signals from the various row sensors. Eliminating these spikes from the input signal greatly reduces the potential for excess down force on a tool encountering a massive object, which can otherwise greatly reduce the life of a tool.
(313) Another method of eliminating spikes is to average over some time period and check a phase-shifted multiple of the original signal. As an example, a “cutoff” point may be 1 or 1.5 standard deviations at any given time. The phase shift allows the controller to use a recent signal to eliminate any significant spikes.
(314) FIG. **68** is an exemplary touch-screen display depicting a control panel for use by an operator to select the type of tool to be monitored on the display.
(315) FIG. **69** is an example of an exemplary interactive map screen. Here, signals of interest are pictorially represented, such as by a most-likely pattern match, on the monitor (e.g., rock, waterway, terrace.). They can be outlined or highlighted in red to be readily identified as a potentially troublesome obstacle. Chart **5026** illustrates a possible pictorial representation of tire tracks from a grain cart, combine or tractor tire, or may also represent a pivot track from an irrigation rig. Chart **5027** illustrates an impassable obstacle, like a roadway, or other solid immovable obstacle. Chart **5028** illustrates a massive infield obstacle such as a rock, fencepost or other in-field object. Chart **5029** represents excessive moisture, or waterway in the path of a particular tool. Chart **5030** is an example of a local anomaly, such as a sand boil, or a rock pile. Chart **5131** is an area of light residue. An area of light residue is of interest, because it may represent an area of poor crop performance, or an area prone to erosion. Chart **5032** represents a terrace, or other zone where the implement may or may not be returning usable consistent signals. Chart **5033** represents contours of variation both in soil density and in moisture content. Such areas are frequently referred to as management zones. These areas are interactive, and can be closely analyzed. Selecting the contour in a particular spot can give some local information about soil type, rock pressure, and moisture levels. To help illustrate, FIG. **69** includes a key showing various in-

field conditions graphically. Beside each graphic representation is a possible associated signature signal of a particular in-field obstacle or condition. Signals from position sensors, load sensors and pressure transducers all have signature signals that reflect the engaged media. This system identifies the signature signal of interest, and produces a graphical representation of the condition on the map.

(316) Aspects of the present disclosure relate to an agricultural implement row unit controller (computer), which is integrated row-by-row, or by section-by-section, for automated control over corresponding actuators of a primary ground engaging tool, and its auxiliary components or attachments, or a group of attachments or tools, for example, any combination of a vee-opener type planter row unit, a fertilizer coulter, a row cleaner, and a closing wheel.

(317) A signal processor operates on input signals from one or more row unit-mounted sensors, and sends the generated output signal to one or more row units, and their auxiliary tools actuators, such as, for example, signals received from position sensors on one or more tools, signals received from pressure transducers on one or more tools, signals received from load sensors of one or more tools, a signal sent to a vee-opener type planter row unit down force actuator, a signal sent to a row cleaner actuator, a signal sent to a fertilizer coulter actuator, a signal sent to a closing wheel actuator.

(318) Aspects of the present disclosure also relate to methods of signal processing that recognizes signature waveforms unique to a particular field condition—a “signal of interest.” Input signals are simultaneously integrated and differentiated to identify local maxima, and minima, and their associated areas over an experimentally determined time period. Discrete-time optimal control operations (e.g., a Monte Carlo algorithm) can provide additional corrections for signal recognition. This signal includes information from a position sensor, a laser rangefinder or other sensor designed to measure relative displacement of a ground engaging device, and its depth gauging member, or a combination of such devices. This method also identifies errors due to sensor malfunction by noting that the data stream is absent, or outside of specification, and in some cases may be used to identify mechanical failures of a particular tool. Signature waveforms unique to a particular condition can be used in combination with the forward speed of the tractor, and a GPS signal to create a map that identifies field conditions, and presents the operator a data stream that can correlate to a map with graphical representations of a particular conditions.

(319) A signal of interest can be, for example, a spike from a massive in-field obstacle identified by a slope approaching infinity over a time period proportional to the product of an averaged in-field obstacle length, and an averaged implement velocity; or a signal of interest can be the signature area, over a predetermined time period, of a semi-regular, semi-repeating signal unique to a particular soils characteristics, such as dry bulk density, wet bulk density, porosity, volumetric water content/saturation, particle size distribution, intergranular contact forces, and shear stress.

(320) Another method of signal correction employs the input signals of existing implement (tool) sensors, and other supplementary sensors to verify that the primary signal generator is functioning properly, and provides additional corrected signals that can be superposed into the base signal to ensure output signals properly affect a given actuator. For example, the signal from a load pin installed on the stops of a gauge wheel on a vee-opener type planter row unit, or the signal of a pressure transducer installed on a hydraulic actuator can be monitored. These signals correct a primary input signal from a position sensor or other displacement sensor, mounted on an opening coulter, which is leading a planter row unit.)

(321) Another aspect includes a system of cameras, mounted on or near a row unit, or section of row units, and oriented so that a particular row unit, or section of row units can be visually inspected remotely. This system has the ability to snap still photographs to be analyzed either in real-time, or for reference later to assist in the development of a field maintenance plan.

(322) A graphical user interface (GUI)/computer collects row controller information via a vehicle bus, and simultaneously displays input and output information of an agricultural implements row

units sensors and unit controllers, and the sensors of the row units auxiliary components. This display shows information on any number of row unit actuators either row-by-row or by section averages, such as shown in FIGS. **66**A-**66**E. The operator can select a particular tool or tool set, using a simple graphical representation of the tool, or a text description of a tool to monitor a particular tools performance, and make judgments on whether to address errors returned by a local row controller, or if it is more profitable to keep the implement moving (see FIG. **66**E), and address the error after planter consumables have been depleted and the implement is stopped. This interface is customizable to allow the user to prioritize toolsets by their individual criteria of importance. This interface also allows for on-the-go changes to the signal processing of the individual row controllers. The GUI may also display a photograph of an erring unit by employing the feed of cameras mounted either row-by-row, or by section, granting the user the ability to visually inspect, and make judgment calls on the importance of addressing a particular error, or if it is more profitable to continue the operation despite the error. For example, any combination of the following can be displayed: the simultaneous display of the overall performance, power consumption, system pressure, errors, and profit loss based on the signals received from the sensors of a row crop planters: actuated fertilizer coulters, actuated row cleaners, actuated row unit down force, gauge wheel depth regulators, actuated closing wheels, and also the customizable display of additional supplemental, or preexisting sensors.

(323) A user alert system recognizes errors streaming in from the vehicle bus and alerts the operator remotely. This alert system uses existing mobile platforms to send error information to any number of e-mail addresses, or text enabled wireless devices such as tablets, or mobile phones. This allows both operators and farm managers to be aware of onboard malfunctions as they occur. This system also works in tandem with the camera system to issue a command to a particular camera to generate a visual record of the error.

(324) A system of mapping, created from an incoming data stream from the primary monitors computer, which presents field condition maps, graphically represented on a GUI either in-cab, or on a remote computer. This map exploits the information collected from the pattern-recognition algorithm to make semi-realistic, graphical representations of field conditions. These representations are selectable and the user can zoom-in on a particular area to allow for a better understanding of the level of profit loss that may be associated with a particular field condition. The map would allow to zoom out to view and entire field, or set of adjacent fields, or zoom in for detailed analysis, such as the identification, and graphical representation of rocks, waterways, terraces, sand boils, residue levels, tire tracks, grain cart tracks, or any other condition that may require a change to a particular operation, or may require field maintenance.

(325) A system for sensing, using either a photogate, a sonogate, a laser rangefinder or other such device, to directly detect the change in radius on a gauge wheel as it builds with mud and residue, or sheds mud and residue. This signal is processed to be sent to an actuator that regulates the depth stops on a farm implements depth gauging element. As an alternative, a sensor that detects angular frequency may be used for example, in the case of a gauge wheel, as the angular velocity decreases, it is proportional to an increase in radius, and hence mud or debris on the wheel. This signal can then be used to determine the proper setting on the stops of the gauge wheel. Additionally, variations in optimum depth for a agricultural implement may change as the implement moves through the field, this system allows for on-the-go variations in planting depth to optimize seed placement for a particular set of field conditions.

(326) An actuator that regulates the relative displacement between the lowest members of a ground-engaging tool, and that tools depth-gauging member. This actuator would use receive signals from the sensors to ensure a gauging member of its associated tool has the ideal displacement from the ground-engaging member. This actuator may be hydraulic, or electric in nature, and is robust enough to accommodate the instantaneous forces associated with a particular agricultural implement.

(327) It will be evident to those skilled in the art that the invention is not limited to the details of the foregoing illustrated embodiment and that the present invention may be embodied in other specific forms without departing from the spirit or essential attributes thereof. The present embodiment is therefore to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims rather than by the foregoing description, and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein.

Claims

1. A hydraulic control system configured to control an up force and a down force relative to an agricultural implement, comprising: a hydraulic cylinder housing a double-acting ram; a first energy storage device and a second energy storage device coupled to the double-acting ram via a first controllable valve to control supply of pressurized fluid to the hydraulic cylinder; a fluid sump coupled to the hydraulic cylinder to control return of pressurized fluid to the fluid sump; an electrical controller operatively coupled to the first controllable valve to cause selective opening and closing of the first controllable valve and to thereby cause at different times selective application of the up force and the down force relative to the agricultural implement in response to or at least partially based on at least a GPS coordinate signal received from a GPS system.
2. The control system of claim 1, wherein the GPS coordinate signal is indicative of a speed of the agricultural machine.
3. The control system of claim 2, wherein the electronic controller is configured to cause the down force to be adjusted based on a soil-hardness signal indicative of a hardness of soil that the agricultural implement is traversing.
4. The control system of claim 2, wherein the electronic controller is configured to cause at different times selective application of the up force relative to the agricultural implement.
5. The control system of claim 1, wherein the electronic controller is configured to cause the down force to be adjusted based on a soil-hardness signal indicative of a hardness of soil that the agricultural implement is traversing.
6. The control system of claim 5, wherein the electronic controller is configured to receive sensor signals from the agricultural implement and/or a ground-engaging tool to develop a graphical representation of a field.
7. The control system of claim 1, wherein the electronic controller is configured to cause at different times selective application of the up force relative to the agricultural implement.
8. The control system of claim 1, wherein the electronic controller is configured to form a soil condition map from at least the GPS coordinate signal.
9. The control system of claim 1, wherein the electronic controller is configured to receive sensor signals from the agricultural implement and/or a ground-engaging tool to develop a graphical representation of a field.
10. The control system of claim 9, wherein the electronic controller is further configured to provide an interactive map with GPS coordinate locations of conditions associated with the field.
11. The control system of claim 10, in combination with a display configured to display the interactive map, the display optionally including a touchscreen and depicting a control panel relative to the touchscreen.
12. The control system of claim 11, wherein the conditions include any one or more of soil compaction, moisture, in-field obstacles, or a condition related to soil fertility.
13. The control system of claim 1, wherein the GPS coordinate signal is indicative of a position of the agricultural implement.
14. The control system of claim 1, in combination with a plurality of row units of or coupled to the

agricultural machine.
15. An agricultural machine comprising the control system of claim 1.